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THE ROLE OF HERBIVOROUS FISH IN THE RECONSTRUCTION OF FOOD ICHTHYOFAUNA AND THE BIOLOGICAL RECLAMATION OF WATER BODIES

by D. S. Aliyev, Institute of Zoology, Academy of Sciences Turkmen SSR, Ashkhabad. Manuscript received 29 September 1975.

One of the significant scientific research projects of recent years in the field of fishery biological science, aimed at substantially raising the fish productivity of inland water bodies and the profitability and efficiency of pond fish culture in our country, has undoubtedly been the solution of the multifaceted problem involved in the economic utilization of Far Eastern herbivorous food fishes. The results of the investigations of the Amur Ichthyological Expedition of Moscow State University in 1945-1949, working under the direction of G. V. Nikol'skiy, served at the immediate stimulus to the organization of research work on this problem. It is no exaggeration to say that all subsequent work connected with the economic utilization of herbivorous fishes has been essentially a continuation of the work begun by this expedition. It should also be noted that solution of the herbivorous fish problem became possible as a result of the efforts of the large team of researchers and production workers performing their quite complex and laborious work under the aegis and guidance of the Ichthyological Commission of the Ministry of the Fish Industry USSR and the Scientific Council for Problems in Hydrobiology, Ichthyology and Utilization of the Biological Resources of Water Bodies of the Academy of Sciences USSR.

Nationwide production volume of herbivorous types of commercial pond fish has been rising recently from year to year. At least a quarter of a million centners of the pond-grown fish in 1973 consisted of new specimens of pond fish culture. Moreover, this portion of pond-grown fish was produced exclusively as a result of more efficient use by the fish of the natural food supply and pond fertilizer, with no expenditure of scarce mixed feeds. The wide-scale adoption of herbivorous fish in fish culture in inland water bodies already makes it possible to produce a great many valuable table fish in some of them now. Considering that our country has at its disposal a vast network of water bodies in which herbivorous fish can be successfully used, we can, in the long run, count on obtaining many hundred thousand centners of commercial fish from these fish. The use of herbivorous fish for the biological reclamation of water bodies of varying economic purpose is now expanding more and more.

Enough time has passed since the first favorable results in the artificial propagation and acclimatization of herbivorous fish, as well as their incorporation into the food ichthyofauna of water bodies and into pond pisciculture in Turkmenia, Krasnodarskiy Kray, the Ukraine and other regions of the country (Aliyev, 1961, 1965; Verigin, 1963; Vovk and Prikhod'ko, 1963; Bizyayev and Motenkov, 1964; Vinogradov and Yerokhina, 1972; et al.), and we now have sufficiently extensive factual data to judge their role in raising fish productivity and in the biological reclamation of water bodies.

Drawing on the example of the water bodies of Turkmenia in the Amu-Dar'ya River system, where a new composition of fish fauna has arisen and come into being by virtue of highly productive stocks formed here of white and black amur [Ctenopharyngodon idella (Val.) and Mylopharyngodon piceus (Rich.)], silver carp and bighead [Hypophthalmichthys molitrix (Val.) and Aristichthys nobilis Rich.], as well as white Amur bream [Parabramis pekinensis (Bas.)], we can see most clearly, as nowhere else, the extremely favorable role of the newcomers in the fauna and flora and in the fishery utilization of the water bodies. This holds true in equal measure for the use of herbivorous fishes to prevent the biological disruptions that arise in the economic utilization of water bodies and water courses.

Significance of Herbivorous Fish in Raising Fish Productivity of Water Bodies

The water bodies of Central Asia, including Turkmenia, have always been marked by rather low fish productivity due to their meager bioproductivity, as noted by many investigators (Nikol'skiy et al., 1933; Nikol'skiy, 1940; Stepanova, 1953; et al.). The fish productivity of most of the water bodies during the period preceding the acclimatization of herbivorous fishes was, with rare exception, found to be 5-10 kg per hectare (for example, Lake Balkhash 5.0-11.0, the Murgab and Tedzhen reservoirs in Turkmenia 5.0-17.0, the reservoirs of Uzbekistan 5.0-14.0 kg per hectare). It is interesting to note that raising the fish productivity of Central Asian water bodies to 25-30 kg per hectare was, until recently, regarded as the maximum of their possible fish productivity, reaching which involved implementation of the recommendations of scientific research studies (Tikhiy, 1957).

Such low fish productivity was due to the mountainous character of the runoff of Central Asian rivers, carrying primarily snow and ice water which is low in biogenous and organic matter. Even without this, in a significant percentage of the water bodies of Central Asia which had undergone rank overgrowth with aquatic vegetation, the small quantity of nutrient salts that the water contained was not properly utilized for productive purposes, being consumed by aquatic plants. This was due to the fact that the aquatic plants here, in view of the practical absence of any immediate consumers among the fauna of the water bodies, played no decisive role in the food supply of the commercial fishes and other aquatic organisms. On the contrary, macrophytes en masse, as they decompose in the water, as a rule create unfavorable living conditions for aquatic organisms, thus causing the relatively low biological (economic) productivity of the water bodies. What we have said applies in equal measure to cases where nutrients go to stimulate the development of lower aquatic plants -- phytoplankton. All this, in final analysis, resulted in great losses of matter and energy and, given the low food supply for local food ichthyofauna, occasioned the low fish productivity of our water bodies.

Fishery biological investigations of the past few years have shown that a radical increase in the fish productivity of Central Asian water bodies can be achieved, even under conditions where the water contains quite negligible food resources, if the composition of the food ichthyofauna and the food supply are appropriately restructured.

In keeping with the most successful realization of these goals were the introduction of herbivorous fish into the food ichthyofauna composition of the water bodies, and the enrichment of the food supply of local fish fauna with herbivorous detrivorous organisms from among the invertebrates. In keeping with the goals of a radical restructuring of the composition of food ichthyofauna to the maximum extent was the introduction of herbivorous food fishes of the Far Eastern complex into the composition of the local fish fauna of the water bodies (a macrophytophage -- the white amur, and a phytoplankton-eater -- the silver carp, as well as a phyto- and zooplankton-eater -- the bighead).

The large volume of scientific-research and experimental-production work on herbivorous fishes has permitted their adoption in fishery practice. This became possible due to the fact that questions relating to the artificial culture and creation of self-reproducing stocks of herbivorous fishes in the basins of a number of rivers in the USSR south were successfully solved.

As for the Central Asian water bodies, the creation of self-reproducing stocks of herbivorous fish in the Amu-Dar'ya River basin -- the mightiest water artery of this region -- resulted in their extensive distribution throughout all the basin's water bodies and contributed to a substantial rise in their fish productivity and an increase in the fish catch as well in the inland water bodies of the Turkmen SSR (Table 1).

The data of Table 1 show that the sharp increase in the fish catch in the republic's water bodies was accounted for almost exclusively by the take of the herbivorous fish that had been acclimatized here. An especially marked increase in the take of herbivorous fish species has occurred since 1970 and has been due to the lifting of the previously imposed ban on catching them.

Table 1

FISH CATCHES IN INLAND WATERS OF TURKMENIA, in centners

1) Вид	1967	1968	1969	1970	1971	1972	1973	1974
2) Сом	1011	682	699	775	746	570	749,0	715,4
3) Сазан	2271	1987	1621	2220	2435	2817	2726,8	3370,0
4) Усач	216	408	622	1030	1285	819	808,3	1268,3
5) Жерех	167	298	248	280	291	253	342,1	675,1
6) Храмуля	588	696	629	500	727	290	81,0	65,0
7) Белый амур	37	64	19	670	297	145	282,5	230,0
8) Толстолобики	114	67	64	470	1970	3571	5180,2	4957,9
9) Лещ	—	330	269	450	708	487	363,0	528,0
10) Вобла (плотва)	482	275	34	100	111	282	1136,0	1219,0
11) Судак	—	—	—	—	5,6	46	97,0	191,0
12) Щука	50	77	39	20	7	10	9,8	—
13) Шемая	—	—	—	—	—	—	326,6	336,0
14) Чехонь	—	—	—	—	—	—	—	50,0
15) Всего	4936	4884	4244	6515	8582,6	9292	12102,3	13605,7

Key:

1. Species
2. Sheatfish
3. Carp
4. Barbel
5. Asp
6. Khramulya
7. White amur
8. Silver carp
9. Bream
10. Roach
11. Pike perch
12. Pike
13. Shemaia
14. Chekhon
15. Total

The favorable consequences of bringing in herbivorous fishes are particularly indicated by the experience of fishery operations on a number of water bodies in Turkmenia. Extremely indicative in this respect is the fishery operations experience of one of the largest water bodies in the republic -- the Khauzkhan Reservoir on the Kara-Kum Canal, which now yields almost half the fish caught here. This reservoir has now become one of the most highly productive fishing grounds in the republic as a result of the acclimatization of herbivorous fishes (Table 2).

With the introduction of herbivorous fish into fish industry turnover, there has been a sharp rise in the fish productivity of this reservoir (Table 3). The fish productivity of the Khauzkhan Reservoir now already exceeds 60 kg per hectare, and in respect of this index the reservoir cannot be topped even by other, most highly productive natural fishing grounds of the country. The proportion of herbivorous fish species in the total fish catch in this reservoir is now at least 75-80%. Such a ratio of herbivorous and local species of food fishes in the catches undoubtedly comes close to the optimum and is aimed at fuller utilization of the energy resources of water bodies for the production of fish protein output.

Table 2

FISH CATCH IN KHAUZKHAN RESERVOIR, in centners

1) Вид	1967	1968	1969	1970	1971	1972	1973	1974
2) Сом	219	199	272	202	211,8	290	153	204
3) Сазан	761	849	584	635	486,6	695	1312	1840
4) Жерех	—	120	146	75	39	6	6	—
5) Усач	22	10	—	—	1,5	4	2	—
6) Храмуля	22	30	16	39	10,3	25	—	8
7) Белый амур	—	2	14	366	273,7	78	144	124
8) Толстолобики	—	8	50	413	1645,8	3359	4841	4707
9) Судак	—	—	—	—	5,6	46	95	87
10) Всего	1024	1218	1082	1730	2674,3	4503	6553,0	6970

Key:

1. Species
2. Sheatfish
3. Carp
4. Asp
5. Barbel
6. Khramulya
7. White amur
8. Silver carp
9. Pike perch
10. Total

The introduction of herbivorous fishes into the composition of food ichthyofauna and the increase in the share which they represent of the total fish productivity of water bodies has not caused any reduction in the catches of local food fishes, particularly the carp.

This situation is well illustrated by comparing the fish productivity, broken down by individual groups of commercial fishes, of the Khauzkhan Reservoir following the acclimatization of herbivorous fishes with that of the Tashkepri Reservoir on the Murgab River during the period preceding their acclimatization (Table 4).

Table 3

DYNAMICS OF FISH PRODUCTIVITY OF KHAUZKHAN RESERVOIR

1) Год	2) Средняя площадь водохранилища, тыс. *га*	3) Улов рыбы, *ц*	4) Рыбопродуктивность, *кг/га*
1967	6,3	1024	16,2
1968	6,2	1218	19,4
1969	6,9	1082	18,0
1970	6,3	1730	27,3
1971	7,6	2674	35,0
1972	10,0	2510	45,0
1973	10,7	6553	61,2
1974	–	6970	–

Key:

1. Year
2. Average area of reservoir, in thousands of hectares
3. Fish catch, in centners
4. Fish productivity, in kg per hectare

Table 4

COMPARISON OF FISH PRODUCTIVITY OF KHAUZKHAN RESERVOIR (1973-1974) AND TASHKEPRI RESERVOIR (1953-1956) FOR INDIVIDUAL GROUPS OF FOOD FISHES

1) Рыба	5) Рыбопродуктивность, *кг/га*	
	6) Хаузханское водохранилище	7) Ташкепринское водохранилище
2) Растительноядные (толстолобики, белый амур)	45,0–46,6	–
3) Сазан	12,2–17,2	11,1–17,4
4) Прочие	2,4–2,8	0,2–1,4

Key:

1. Fish
2. Herbivorous fish (silver carp, white amur)
3. Wild carp
4. Others
5. Fish productivity, in kg per hectare
6. Khauzkhan Reservoir
7. Tashkepri Reservoir

The data of Table 4 show that the fish productivity of the Khauzkhan Reservoir for local food fish species, including the most valuable of them -- the carp, did not in any way decline as a result of the introduction of herbivorous fish into the composition of the ichthyofauna and fluctuates in a range of 12-17 kg per hectare. Such fish productivity for local food fish species is at the level of the most highly productive Central Asian water bodies (Stepanova, 1953; Tikhiy, 1957; Aliyev, 1958). One must not fail to mention also that in the Khauzkhan Reservoir there has been an increase in the proportion of the larger-size and heavier categories of carp in the catches as compared with the catch of this fish in the Murgab reservoirs in 1953-1955. Our research has shown that in the Khauzkhan Reservoir 42.2% of the carp catches is accounted for by fish 50-64 cm or more in size (an average of 54.7 cm) and weighing 2-4.5 kg or more (an average of 3.2 kg). Here 57.8% of the carp catches now consist of fish 31-50 cm in size (an average of 39.4 cm) and weighing 0.5-2.0 kg (an average of 1.2 kg). In the Khauzkhan Reservoir carp less than 31 cm in size are not caught at all. But in the Murgab reservoirs almost half of the food carp caught consisted of fish less than 27-28 cm long.

It should be noted that the potentials for further increasing the fish productivity and fish catch in the Khauzkhan Reservoir are not limited to the data adduced in Tables 3 and 4. A study of the biological indices of the fishes being caught and the state of their food supply indicate that the catches here can be intensified still more and the fish productivity of the reservoir brought up to 100 kg per hectare or more. Just as in the Khauzkhan Reservoir, the potential for raising the fish productivity and increasing the fish catch undoubtedly exists in all the water bodies of the Amu-Dar'ya Basin and other water bodies connected with it. It is the duty of the practical fishery organizations to realize these potentials, which would permit a significant increase in the number of fish caught in our inland fresh- and brackish-water bodies.

It is now becoming increasingly obvious, and we are fully justified in saying, that no other scientific and practical fishery measure carried out previously in our inland water bodies or any complex thereof has given such an economic return in raising the fish productivity of water bodies as has the implementation of measures to introduce herbivorous fish into the fishery practice of inland water bodies. Mention must also be made here of the fact that under the conditions in the irrigated oases in the Amu-Dar'ya River basin and in contiguous territories, herbivorous fish are making it possible, and in most cases have already made it possible, to solve the very important problem of preventing the overgrowth of various water bodies and water courses, including irrigation and collector and drainage canals.

The mass-scale stocking of numerous water bodies in the Amu-Dar'ya basin with herbivorous fishes which is now being observed is made possible exclusively, as our investigations have shown, by their spawning in the

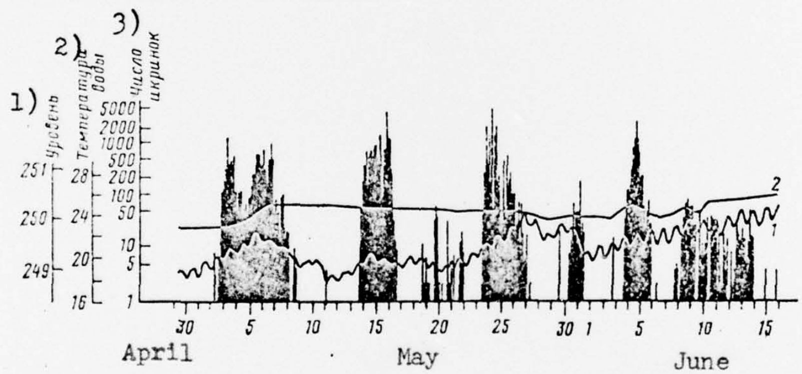
Kara-Kum Canal. Reproduction of these fishes is not noted even under the conditions of the Amu-Dar'ya River itself.

The spawning of herbivorous fishes in the Kara-Kum Canal is one of the few cases of their successful naturalization in the water bodies of the world outside their natural areal. However, the spawning of herbivorous fishes in the Kara-Kum Canal is so far the only known case of their natural reproduction under conditions of a man-made artificial water course. Herein lies the special meaning and practical significance of studying all aspects of the question relating to the reproduction biology of herbivorous fishes in the Kara-Kum Canal. The ultimate purpose of this research obviously is, from the example of the Kara-Kum Canal, to develop a water course model that will permit solution of the problem of the guided creation of self-reproducing stocks of herbivorous fishes in other water systems of the country where canals are being built, too. The long-term solution of this problem would permit considerable lessening of the acuteness of the problem of providing the needs of herbivorous fish stocking material for different sectors of the national economy. This research is also important for solving the problem of assuring the spawning of herbivorous fishes in the future as well, under the new conditions of the hydrological regime on the Kara-Kum Canal due to further construction on it and the building of the Kyzylayak hydroengineering complex on the Amu-Dar'ya. There are grave fears now that the spawning of herbivorous fishes will become impossible under the new conditions of the hydrological regime on the river and canal.

Cessation of herbivorous fish spawning under the new conditions of the hydrological regime on the Kara-Kum Canal will have an extremely adverse effect on the fish productivity of the water bodies of the Amu-Dar'ya basin and may lead again to overgrowth of the canal, entailing dangerous consequences for its further construction and operation.

The Kara-Kum Canal imeni V. I. Lenin, construction of which was begun in 1954, now extends altogether over 900 km and is one of the country's largest irrigation projects. It originates on the Amu-Dar'ya 40 km south of Kerki and, cutting northwest across the 400-kilometer sandy Kara-Kum desert through the Murgab and Tedzhen oases, runs along the Kopet-Dag plain towards the Caspian Sea. With maximum water intake from the Amu-Dar'ya River, amounting now to about 400 cubic meters of water per second, in the canal as it moves westward, the water is taken for irrigation, and in the terminal part of the canal the water discharge totals a few dozen cubic meters per second.

A number of channel and inlet reservoirs have been built on the canal. Of decisive significance for creating spawning conditions and assuring the yield of juvenile herbivorous fishes in the Kara-Kum Canal is the head Kelif Reservoir, which serves mainly for accumulation of the river's sediment runoff. The canal's gravity-regulated flow from the Amu-Dar'ya River is achieved by a system of intake headworks which provide a discharge of water which is more or less stable during the year. Such a water intake system eliminates any appreciable effect from spring-summer flood phenomena in the river on the hydrological regime of the canal. The canal's water level for this reason is not subject to significant fluctuations in the spring-summer period. However, the significance of the presence of an intake headwork on the Amu-Dar'ya for the life of the ichthyofauna of the canal and its water bodies is great. For the greater part of the year (the autumn-winter period) the water level in the canal and river is usually the same. During this time the fish encounter no obstacles in the path of their movements either from the river to the canal or back. The picture is different during the spring-summer rise in the water level of the river due to flooding. During this period a backwater of as much as two meters in comparison with the water level of the canal is created upstream from the structures. This circumstance results in significant water-flow rates under the gates of the structures. Calculations show that, with regulation of the canal runoff from the Amu-Dar'ya during the period from April through August, water-flow rates in a range of 6-7 m per second are created under the gates of the headworks. There is no doubt that such a rapid stream cannot be negotiated by the fish and it becomes an obstacle in the path of the spring-summer prespawning migrations of fish from the canal to the river. None of the other structures built in the canal proper are any obstacle in the upstream fish migration route during any season of the year.



Dynamics of downstream migration of roe of Far Eastern pelagophilous food fishes (white and black amur, silver carp and bighead) in Kara-Kum Canal in 1969:

1) water temperature; 2) water level.

Key:

3. Number of eggs

The length of the canal in the section from the Amu-Dar'ya till it issues into the Kelif Reservoir is about 80 km, its width 70-100 m. In this section the canal runs in a dredge-excavated bed with relatively steep banks. The canal has only one binnacle in this section -- the Bassaga-Kerki. Water discharges in the canal during our observation period fluctuated from 160 to 390 cu m per sec at water-flow rates averaging 0.9 m per sec (maximum flow rates did not exceed 1.2 m per sec). The canal in this section carries a large amount of suspended matter.

We describe the hydrological and other conditions of this section of the canal in such detail solely because it is here, in the 13-kilometer section in the region of the afterbay of the headworks, that the spawning grounds of herbivorous fishes are located. All species of the acclimatized pelagophilous food fishes are spawned in this section of the canal (white and black amur, silver carp and bighead). Observations have shown that the springtime rise in the water temperature to 15-17° causes the sexually mature fish to migrate en masse upstream in the canal, and when en route they reach the headworks, they crowd together in its afterbay. Here under the conditions just described, the spawning of the acclimatized pelagophilous fish takes place.

Having studied in detail for the past seven or eight years the reproduction biology of Far Eastern pelagophilous food fishes acclimatized in the Kara-Kum Canal (white and black amur, silver carp and bighead), we now have fairly extensive data on this question. Some idea of the peculiarities of the spawning of these fishes in the Kara-Kum Canal is afforded by the information given in the figure, which shows the dynamics of the downstream migration of roe in the spawning grounds of all four species of pelagophilous fishes in the canal during 1969 (see Figure).

However, on the basis of only the materials now available it is impossible to draw conclusive inferences regarding the effect of the factors in the external environment that make possible the natural reproduction of herbivorous fishes in the Kara-Kum Canal. Nor, as far as is known, is there as yet any positive solution of this question as far as the native rivers of the herbivorous fishes are concerned (the Yangtze and Amur). We encounter the same situation when it is a matter of the new regions where they are acclimatized -- the Tone-Gawa River (Japan) and the Kuban' River (USSR).

Almost all authors who have conducted investigations on the Amur and Yangtze believe that the determinative factors in the conditions of the external environment that assure the maturation of sex products and stimulate the act of spawning in the brood stock of herbivorous fishes are the level regime of river flow resulting from the peculiarities of the region's monsoon climate (Kryzhanovskiy et al., 1951; Nikol'skiy, 1956; Vin Pen-lu and Liang Tze-Sin, 1964). Their typical spawning regions, for example in the Yangtze River, are the initial reaches of river flow in a plain where irregularities of the bed and the articulation of the bank line, as well as the confluence of streams, result in the creation of a considerable mixed-flow and flow-turbulence region. During the spawning season sharp rises of at least 1 m in the water level and, consequently, an increase in flow rates ranging from 1.0-1.8 m per sec are, in the opinion of the aforementioned authors, factors that stimulate fish spawning. No spawning occurs if the water line in the spawning grounds is low or when the water level drops from some flood crest.

The dependence of spawning activity on flow rates, which also determine a river's water level, can, some authors suggest, be used to predict the start and duration of the spawning of herbivorous fishes under the conditions in the Yangtze River (Vin Pen-lu and Liang Tze-Sin, 1964). In the opinion of these same authors, other factors (turbidity and temperature of the water) are not determinative. Water temperature determines only the start of spawning, and that only if the onset of spawning temperatures is accompanied by a certain level regime of the river. These same adaptive peculiarities in the reproduction biology of herbivorous fishes are, in the opinion of Japanese investigators, determinative in the spawning of herbivorous pelagophilous fishes under the conditions of their acclimatization in the Tone-Gawa River. Here, however, it was noted that in rare scattered periods the spawning of herbivorous fishes took place even when the water level of the river was low (Inaba et al., 1957).

The opinion that a river's level regime is of determinative significance in stimulating spawning by herbivorous fishes has been quite widely accepted among specialists. That is why we, too, previously believed that hydrological conditions in the Amu-Dar'ya River conformed more to the biological requirements for reproduction of herbivorous fishes than conditions in the Kara-Kum Canal. In general, given such an approach, naturalization of herbivorous fishes in the canal was out of the question, i.e., under conditions in an artificial water course with completely regulated discharge, which rules out the influence of the factor of flow conditions on fish spawning. In fact, however, the reproduction of herbivorous fishes has taken place in the Kara-Kum Canal rather than in the Amu-Dar'ya proper.

Nevertheless, what factors or complex of factors have to be present in the external environment in order to make possible the natural reproduction of herbivorous fishes under conditions of acclimatization? This question has always been coordinate with the whole problem of the economic exploitation of these fishes. It remains so still. We do not at present have sufficient data for a more or less satisfactory answer to this question. Therefore the views presented here are, of course, of a purely tentative character. But at the same time these views may be of interest in broadening our knowledge of the reproductive biology of herbivorous fishes.

The results of our investigations studying the reproductive biology of herbivorous fishes in the Kara-Kum Canal do not permit singling out any individual factor here conducing to the spawning of the newcomers. The complex of simultaneously operative factors, cited below, obviously decisively affected stimulation of their spawning.

The considerable length of the Kara-Kum Canal, calculated as many hundreds of kilometers, is of substantial significance. We should set apart especially a stretch of the canal in the section from the Amu-Dar'ya till it empties into the Kelif Reservoir, sufficient to make possible the downstream migration and development of roe (more than 80 km). There must be a certain stretch of a water course (river, canal), it seems to us, in order to prepare the reproductive system of spawners physiologically for spawning, which preparation is effected during prespawning migrations of fish to spawning grounds that entail adult fishes' overcoming the resistance of the water flow. The absence of spawning, for example in the region of the afterbay of the Khauzkhan Reservoir where adult fish also concentrate during the spawning period, indicates the determinative significance of this factor in the stimulation of spawning. In this reservoir, the length of the channel that fishes negotiate during their prespawning migrations amounts to no more than 1.5-2.0 km.

The discharge of water through the canal must be no less than 170-200 cu m per sec, the rate of flow 0.9-1.2 m per sec. These conditions are necessary not only for immediate stimulation of the act of spawning, but also to assure preparation of the adult fish, as has just been mentioned.

An important role is also played by the presence of a headwork in the canal barring the possibility of free passage for adult fish into the Amu-Dar'ya during the spawning period and conducing to their concentration in the region of the afterbay of the headwork. All this to some extent simulates conditions in the spawning grounds of rivers in the homeland of the herbivorous fishes. There are grounds to suppose that the absence of a headwork or the possibility of free passage for adult fish from the canal into the river during their prespawning migrations might rule out the likelihood of natural reproduction of herbivorous fishes in the Kara-Kum Canal.

The data adduced here are extremely inadequate and once more convince us that the scientific questions involved in study of the biology of the spawning of herbivorous fishes, which have very important economic aspects besides, are still far from solved not only in their native region but also in regions where they have been acclimatized. Comprehensive and thorough study of this phenomenon and the taking of practical measures aimed at making the natural spawning of herbivorous fishes possible in the Kara-Kum Canal in the future as well in conjunction with its further construction remain a most important task not only for scientific, but also for industrial fishery and water-management organizations.

Solving the whole complex of questions involved in creating self-reproducing stocks of herbivorous fishes in the country's other water systems, too, no doubt requires the collective efforts of many investigators working at different bodies of water, including rivers in the native region of herbivorous fishes. The role of organizer and coordinator of these investigations should, as heretofore, remain with the Scientific Council for Problems in Hydrobiology, Ichthyology and Utilization of the Biological Resources of Water Bodies of the Academy of Sciences USSR and the Ichthyological Commission of the Ministry of the Fish Industry USSR.

Significance of Herbivorous Fishes in the Biological Reclamation of Water Bodies and Water Courses

Putting herbivorous fishes to practical application in the national economy is not limited to their significance for the fish industry alone. These fish will give no less benefit when used to prevent the overgrowth of water bodies and water courses and the formation of "blooms" on the water. The possibility of making effective use of herbivorous fish along these lines is due to their capacity to live exclusively on higher aquatic plants (white amur) and algae (silver carp) in the water bodies. It must be emphasized that simultaneously with such an approach we have in mind making use of the vegetative output of water bodies as tremendous reserves of higher aquatic plants and phytoplankton in order to produce economically valuable biological output for man. Of course, such an approach to a solution of the problem is based on knowing the biological processes going on in water bodies and enables the phenomena of overgrowth and eutrophication of water bodies to be transformed from adverse to favorable phenomena, and this, apart from the economic advantages, takes on very serious implications for environmental protection.

The rightness of such an approach to natural phenomena is indicated by experience in successfully solving (on a very large scale, incidentally) the problem of preventing the overgrowth of water bodies and water courses with higher aquatic plants by using a very valuable commercial specimen -- the white amur. It has proved itself well in water use for fishery, irrigation and technical purposes. There is every reason to say that a similar effect will be obtained if silver carp are used to prevent the eutrophication of water bodies. The assertion that the basic component of phytoplankton in the formation of "blooms" on water, namely blue-green algae, in particular microcystis, is toxic to fish can hardly be taken seriously. In the Khauzkhan Reservoir during the mass development of microcystis in August-September, it serves as an important food resource for silver carp and bighead. Our investigations have shown that during this period this species of blue-green algae accounts for not less than 50-60% of the volume of the silver carp and bighead's alimentary bolus.

The role of the white amur in reclamation has emerged most clearly in preventing intensive overgrowth of the Kara-Kum Canal. Now at one time in an especially heavily overgrown section of the canal below the Kelif Reservoir, more than 10,000 linear kilometers of passageways had to be cut through during the growing season in order to remove the overgrowth of aquatic plants from the channel of the canal. Performance of this work took a great deal of resources and manpower. In fact, the efficiency of further construction and operation of the canal depended on solution of this problem. At present, prevention of canal overgrowth with aquatic plants is achieved exclusively by virtue of the self-reproducing stocks of white amur created here. This, in fact, now makes possible the unhampered passage of Amu-Dar'ya water for such significant distances despite the fact that hydrological and other conditions for its peopling with aquatic plants remain exceedingly favorable as before (Aliyev, 1972, 1973, 1974; Vlasov, 1975).

Great effect has been obtained in the republic from the employment of herbivorous fishes to prevent the overgrowth of irrigation canals. Since 1968, due to the wide use of this technique, the necessity of clearing irrigation canals of overgrowth, including very laborious clearance by hand, has been practically eliminated in the Tashauz and Chardzhou oases of the republic.

The same thing is happening now in the Murgab Oasis too. The work we conducted here jointly with the water-management organizations in 1971-1975 yielded very favorable results. As an example we can cite our experience with the employment of the biological method of reclamation in the interrayon main irrigation canal -- the Ak-Er. This canal, 8.5 km long in its main part, due to intensive overgrowth usually had one-time mechanized clearance every year, the cost of which amounted to 9,500-10,000 rubles. Later in the same year during the spring and summer months the vegetation was mowed by hand two or three times with the manpower of kolkhoz members. The cost of the manual labor to do this amounted to 1,600-1,700 man-days.

At present, for a number of years now, prevention of the overgrowth of this canal, including all its binnacles for more than 190 km, has been fully achieved by employment of the biological method of reclamation.

Similar effect from employment of the biological method was obtained in 1973-1975 in other main irrigation canals of the Kaushut-Bent water-allocation system of the Murgab River. These include the Alasha-Yab, Sukhty-Yab, Samsyk-Yab, Aman-Khan-Yak and other canals with all their binnacles, the total length of which is many hundreds of kilometers. Thus, at present, due to the wide employment of the biological method the necessity of clearing irrigation canals of overgrowth has been practically obviated in territories of the main oases of the republic with a total length of 22,700 km. Small irrigating ditches of the brigade network constitute the only exception.

In a number of cases the farms themselves show initiative in employing fish to prevent the overgrowth of the irrigating ditches on the farms. "Tedzhen" (Tedzhen Rayon, Ashkhabad Oblast), the largest cotton-growing sovkhoz of the republic is doing systematic work along this line, profiting from consultation with us. The sovkhoz thereby saves about 40,000 rubles a year, which in previous years were spent to carry out mechanized and manual clearance work on the total of 200 km of irrigation canals in operation. Preventing the overgrowth of the irrigation canals and other water bodies in the territories of the oblasts of the Uzbek SSR adjoining Turkmenia in the lower reaches of the Amu-Dar'ya River is also achieved by the "work" of herbivorous fishes. The herbivorous fish find their way into these canals and water bodies from the river by reason of their spawning in the Kara-Kum Canal.

Thus, on the basis of the adduced data we can judge the scale of the economic return in the event of universal employment of this method of reclaiming the country's irrigation canals with a total length of more than 400,000 km.

Maintenance of the canals of the collector and drainage network in relatively normal operating condition also involves great outlays of manpower and resources due to its tendency to become overgrown and deformed. The expenditures of the Turkmen Ministry of Water Management for these purposes are now over eight million rubles annually for collectors in the republic with a total length of 14,000 km. Nationwide, where the total length of this network is over 200,000 km, the outlays amount to hundreds of millions of rubles every year.

The deterioration of the operating indicators of most canals of the interfarm and on-farm collector and drainage network results not only from their susceptibility to intensive overgrowth, but also, as is known, from the deformation of their banks and from siltation. Therefore, preventing the overgrowth of collectors and drains alone does not eliminate the necessity of subsequently regularly clearing them of the detritus formed in consequence of the deformation of the canal bed. On the other hand, total destruction of the vegetation in the canals of the collector and drainage network entails acceleration of the processes of canal erosion and siltation. Such a situation occurred as a result of the mass-scale employment of the herbicides diuron and atrazine in a campaign conducted by the All-Union Scientific Research Institute of Chemical Plant Protectants in 1967-1973 to control the overgrowth of the collector and drainage network in a number of rayons of Turkmenia.

Maximum effect in the reclamation of collectors and drains is achieved by simultaneous solution of the overgrowth and siltation problem. Preventing the deformation and siltation of the beds of the canals of the collector and drainage network is best achieved by using the bank-reinforcing capability of the root system of riparian aquatic vegetation. The root system of plants with its thick, strong and flexible framework reinforces the soil of the banks, diminishing the fluidity of the ground and contributing to its erosion-resistance. In the canals of the collector and drainage network of the country's irrigated regions, the common reed, with its root system strongly developed and penetrating deep into the soil, can be successfully used for this purpose. The root system of plants, thickly reinforcing the soil of the banks and making possible the free drainage of ground water, at the same time prevents soil particles from being carried away into the canal bed. This assures the normal functioning of collectors and drains and prevents their deformation and siltation.

However, the positive role of the root system of vegetation in preventing the deformation of canal beds is achieved only when the water-conducting zone of the beds of drains and collectors is free of overgrowth, in consequence of which no need arises to clear them frequently with earth-moving machinery, especially excavators, or to suppress its development through the use of toxic chemicals. In both these cases the thickly-reinforced plant root system destroys the soil structure of the canal banks and for this reason, naturally, its protective role cannot be manifested.

The use of the root system of riparian vegetation, in particular the reed, as a biological bank reinforcement to prevent the deformation of the beds of collectors and drains can be successful only when combined with the simultaneous use of the white amur to prevent them from subsequently becoming overgrown.

The most effective employment of the biological method of reclaiming the beds of collector and drain networks is achieved with appropriate preliminary engineering preparation. Preliminary preparation of an overgrown and silted-up collector and drain for employment of the biological method consists in deepening the canal along its center and, without fail, constructing on both sides of the cut a narrow strip of bank overgrown with reeds. With such preparation, almost all categories of collector become suitable for habitation by the white amur which will keep under control the development of the aquatic vegetation therein, while the reed rood system left intact on a narrow strip of bank is capable of reliably preventing the deformation and siltation of the canals (Aliyev, 1974). Preliminary engineering preparation of collectors for employment of the biological reclamation method is most successfully executed with the use of type UPM-1 hydraulic dredges and even ordinary draglines.

Use of the biological method in collectors thus prepared reliably prevents the possibility of their becoming overgrown and silted up, and eliminates for years the necessity of clearance work on them. This is attested by experience with employment of the method in question on many collectors in Tashauz, Chardzhou and Mary oblasts of the Turkmen SSR, which have no longer needed clearance work either for overgrowth or siltation from the time this method was adopted (beginning in 1968-1969). Experience with the practical use of this method has shown the possibility of effectively solving with biological resources a complex engineering problem, namely the problem of preventing the deformation of collector beds.

One of the important advantages of using fish to prevent the overgrowth of canals is also the fact that at the same time great opportunities are opened up for converting the vast network of canals of hydroreclamation systems and the water bodies formed therein into highly productive fishing grounds.

We shall not discuss here the question of using herbivorous fishes to reclaim water bodies and water courses with other economic purposes, although very worthwhile positive results have been achieved in a number of these. These results no doubt include the great benefit to the national economy that the country obtained from using herbivorous fishes to prevent the overgrowth of the cooling ponds of thermoelectric plants (Shimanskiy and Verigin, 1968).

Stocking water bodies with herbivorous fishes also has very important medical and sanitary aspects for the control of blood-sucking insects (Aliyev and Bessmertnaya, 1968). Overgrown and marshy sections of water bodies, as is known, serve as breeding sites for many blood-sucking insects (mosquitoes, biting midges, horseflies), which are vectors of a number of infectious and invasive diseases of man and domestic animals. The mass-scale appearance of the malaria mosquito [Anopheles pulcherrimus] in the capital of the republic and its environs in 1966-1969 resulted from the intensive overgrowth of two Ashkhabad reservoirs -- the Kurtlinskoye and the Sportivnoye. At that time, more than 80% of the mosquitoes harassing humans and domestic livestock was accounted for by this species, whose existence was due solely to the fact that there were thickets of submerged vegetation in the reservoirs. The treatment with toxic chemicals that the sanitary authorities gave the environs of the reservoirs at the haunts of the mosquitoes did not have the necessary effect. The work, conducted at these water bodies in recent years on the use of herbivorous fishes to prevent their becoming overgrown, simultaneously permitted a radical solution of this problem. The white amur released here in 1970 cleared them of aquatic vegetation in the same year. As the white amur destroyed the submerged aquatic vegetation, which here occupied more than 60% of the water area of the reservoirs, the mosquitoes were deprived of the biotope used for oviposition and the development of larvae. As a result of the measures that were taken, no mosquitoes people these water bodies to this day. A general improvement has taken place in the sanitary and epidemiological situation of the water bodies, which, incidentally, are recreation spots for the urban population.

In connection with the use of the white amur for reclamation, I should like to dwell on one more aspect. Does not the destruction of higher aquatic vegetation by the white amur adversely affect the fauna and flora and the ecosystem of the water bodies? Of course, if the water body is intended especially for raising higher aquatic vegetation, the white amur unquestionably yields no benefit here, and this fish must not be released here, of course: Even so, in individual cases there is a possibility of using this fish, for example to prevent weeds from peopling rice check plots. In all other cases there is, of course, no need to fear adverse consequences for the economic use of water bodies because of the white amur's preventing them from becoming intensively overgrown.

Destruction of higher aquatic vegetation by the white amur will hardly lead to a diminution of the self-cleansing capabilities of water bodies. In this case, the phytomass of higher aquatic vegetation will be replaced by the phytomass of algae, which can take part in the self-cleansing processes with no less effectiveness.

Nor do the views that the destruction of higher aquatic vegetation by the white amur will, by impoverishing the phytophilous biocoenosis, lead to impoverishment of the food supply for commercial fishes in the water bodies (Vinogradov and Zolotova, 1974), stand up under criticism. To the contrary, we must assume that the reconstructed trophic levels of the water bodies have become more advantage as a consequence of such intervention. For example, in the Khauzkhan Reservoir the biomass of zoobenthos has more than doubled in comparison with the preceding period. This is understandable. Whereas considerable areas of the bottom of this water body were earlier polluted by hydrogen-sulfide fermentation as a result of the death of a huge mass of higher aquatic plants every year, now that there is no vegetation these areas are becoming fit for stocking with invertebrates as food for fishes. This fact has affected the fish productivity of the Khauzkhan Reservoir and other water bodies of the Amu-Dar'ya/Kara-Kum Canal system.

In connection with the use of the white amur in these two small Ashkhabad reservoirs to prevent their becoming intensively overgrown, we cannot help mentioning an article in the hydrobiological journal by Sh. I. Kogan (1974) who claims that a zoogenous succession allegedly springs up here in consequence and leads to replacement of their usual aquatic flora with water crowfoot. We must say that there are absolutely no grounds for such an assertion by the author. Water crowfoot is an ordinary plant in the shallow water bodies of the Murgab and Tedzhen river valley and the Kopet-Dag plain. This plant has never formed any significant accumulations in water bodies (Nikitin, 1957). In the two Ashkhabad reservoirs mentioned above, water crowfoot formed small beds in the shallow water even before the white amur was released into these reservoirs. Approximately the same situation remains at present, with this difference only, that although this plant appears in the shallows in the early spring, it disappears entirely in the summer, autumn and wintertime. The small overgrowth of crowfoot that appears in the shallow-water strip near the shore of the reservoirs in the springtime, to the contrary, is of important significance here as spawning substrate for the carp and other phytophilous fishes. From what has been said it becomes clear that it is baseless to speak of any adverse consequences from the introduction of the white amur into these reservoirs. The untenability of Sh. I. Kogan's other thesis, namely, denying the role of the white amur in preventing the overgrowth of the Kara-Kum Canal and ascribing this role to the high turbidity and great depth occurring here, has been conclusively shown in an article by Lenin prizeholder N. P. Vlasov, former chief of the Hydromechanization SMU [Construction and Installation Administration] of Karakumgidstroy [Kara-Kum Hydraulic Engineering] Trust.

Problems for Further Research

The practical results of the work on the acclimatization of herbivorous fishes and their adoption in fish industry practice have shown the highly important role of these fishes in reconstructing and creating productive ecosystems in inland water bodies. Investigations along this line must no doubt constitute the basis for work in the sphere of fishery biological science in the near term. This is all the more important because of the possibility of effectively employing herbivorous fishes to lower the pollution level and prevent the biological pollution of water bodies under conditions of the multipurpose utilization of water resources. The ever-increasing level of organic and biogenous pollution of water bodies by industrial, domestic and agricultural effluents and the consequent deterioration in natural-water quality and in the sanitary state of water bodies necessitate the conduct of appropriate research aiming at preventing the adverse effects of these factors on the ecosystem of water bodies.

The acuteness of the question is increasing especially in the Central Asian region, including Turkmenia, due to the volume, increasing from year to year, of chemical fertilizers used in agricultural production. Calculations show that the quantity of fertilizers to be applied to fields during the remaining two and a half decades of the present century will amost triple in comparison with the present-day level. At the same time, almost a fourth of the fertilizers applied to fields ultimately wash away into water bodies, causing them to become polluted and the quality of natural water to deteriorate. Provided that appropriate investigations of an exclusively interdisciplinary character are organized and conducted, realistic preconditions exist for solving the question of making use of the productive effect (from the standpoint of fisheries) of the chemical fertilizers washed away into water bodies, with simultaneous improvement of water quality and the sanitary state of water bodies.

At the present time, the principal obstacle restricting the scale of application of herbivorous fishes in different sectors of the national economy, as is known, is the unsolved state of the question of creating self-reproducing stocks thereof locally. Solution of this question would be helped by the performance of more thoroughgoing research on the biology of the natural reproduction of herbivorous fishes under conditions in the Kara-Kum Canal, which is the unique case of their natural reproduction under conditions in an artificial water course.

In this connection, the conduct of investigations to devise normative requirements for the planning and construction of the hydroengineering systems being built on different water arteries of the country, so as to recreate in them conditions making possible the natural multiplication of herbivorous pelagophilous fishes, takes on very important practical significance. We have in mind investigations of such a level as to permit the planning and construction of canals with prescribed parameters calculated to provide for the natural multiplication of herbivorous fishes. The quickest possible solution of this problem assumes special urgency due to the redistribution of the runoff of many of our rivers and the construction of a number of major canals, under way now and targeted for accomplishment in the near future.

Positive solution of this problem would permit effective solution of the question of creating in reservoirs and other water bodies the necessary numbers of herbivorous fishes (in particular, the silver carp) targeted for use in biological reclamation of these water bodies. To a certain degree, it would relieve the pressure of creating such numbers of herbivorous fish in reservoirs through artificial fish breeding and construction of nurseries. Finally, the creation of self-reproducing stocks of herbivorous fish in the country's most important water systems, especially in the southern regions, is at the same time unquestionably aimed at more rational utilization of the biological resources of a considerable portion of our inland water bodies in order to obtain valuable fish output.

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