STATE OF BREAM POPULATIONS IN RECONSTRUCTED WATER BODIES OF MOLDOVA

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Abstract. Bream, *Abramis brama* L., is a key species in fish communities of Moldovian Rivers and a main component of bottom food chains of river and lake ecosystems. With the reconstruction of water bodies, mainly for hydroelectric power stations needs, the ecological conditions changed substantially, which results in modifications in population state of biota. The negative effects of water bodies' reconstruction upon population status of bream in several Moldovian Rivers and reservoirs were studied. These effects manifest in detrimental changes in bream growth, age composition and reproductive success. The conclusion is made that the economical gain after the regulation of large and middle-size rivers is opposed by the negative impact upon fish community as a whole, as well as upon the ecology of individual species as applied to the indicator species *Abramis brama*.

Keywords: bream, *Abramis brama*, population structure, growth rate, reproduction, reservoir forming, reconstructed water bodies

INTRODUCTION

Bream, *Abramis brama* L., is a widely spread commercial fish species in water basins of Europe from the east of the Pyrenees to the north of the Alps, in rivers and lakes of the basins of North Sea, White Sea, Baltic Sea, Aegean Sea, Black Sea, Sea of Azov, Caspian Sea and Aral Sea [2, 26]. In Moldova the bream occurs everywhere in rivers, reservoirs and in other water bodies of Dniester and Danube River basins. Its commercial importance in these water basins was mentioned as early as in 1877-1918 [1, 5, 24, 49]. However, catches of bream in various river sectors were different. For example, in the upper sectors and in the middle part of the Dniester riverbed, prior to its damming, the ratio of bream in catches was low [28, 29]. While in the lower sector and in the Dniester estuary this species was dominant in catches and constituted from 14.5 to 38.9% of catches [9, 46]. In Danube River bream also was common all through the river [10], but its commercial importance was the highest in Danube Delta and in Prut River (a tributary), where its proportion in catches reached 11% [31].

Bream is an important component of aquatic biotic communities in the Republic of Moldova and is a key species in the bottom trophic chains of rivers and lakes. According to some authors [8, 9, 12, 16, 50], there are two forms of bream in the Dniester River: resident and semi-anadromous ones. Prior to damming the riverbeds was inhabited mainly by the resident form, while the area of semi-anadromous form was limited to the river mouth and Dniester estuary. After the construction of Dubasari and Dniester dams and the drainage of spawning grounds, the abundance of the resident form of bream decreased drastically, while the abundance of the semi-anadromous form increased [6]. The resident bream have rapidly adapted to new ecological conditions of the reservoirs (Dubasari, Cuchurgan, Dniester Reservoirs) and its population occupied the leading place in fisheries [11, 13, 16, 39, 40, 43, 47]. However, with the increasing of anthropogenic stress upon the aquatic ecosystems the bream population suffered negative changes that finally led to the reduction of their productivity and abundance [4, 12, 25, 34, 42, 53].

The aim of the present study is to show the negative impact of river course regulation and of water use upon the state of fish populations as applied to bream populations.

MATERIAL AND METHODS

The ichthyological material for the present study was collected in the basins of Dniester (Middle and Lower Dniester, Dubasari, Cuchurgan, and Ghidighich Reservoirs) and Prut Rivers (Lower Prut and Costeshti-Stinca Reservoir) (Fig. 1).

Characteristics of the studied water bodies and brief history of their formation and transformation

The Dniester River. The source of the Dniester River is in Carpathians, the length of its riverbed up to the Black Sea constitute 1352 km. Considering climatic, geographic and hydrological peculiarities, the Dniester was subdivided into three parts: upper, middle and lower [46].

The hydrological conditions of the Dniester were characterized by sprig-summer floods depending on snow melting in Carpathians and on torrential rains. During large floods the water level of the river might raise up to 10-12 m and the water discharge attained 8400 m^3/s [15].

According to Yaroshenko [46], the temperature conditions of the Dniester water depended on the period of snow melting in the Carpathians. Usually, the maximum water temperature was registered in June-July (up to 25°C) but in some cases it might decrease to 18-19° even in the lower reaches.

Built in 1954, the dam of Dubasari Hydroelectric Power Plant has separated the upper and middle part of the river from the lower reaches. This led to the disturbance of ecological conditions of fish reproduction. Due to peak smoothing of spring and summer floods and disturbance of the level regime of the river, combined with bank diking, a vast floodplain of the Lower Dniester was drained [6]. The river damming led to modification of the physical and chemical conditions of the ecosystem. For example, the temperature maximum shifted from June-July to July-August and the volumes of solid discharge in the lower reaches decreased by 2-5 times, resulting in water transparency increase by twice [12]. The negative anthropogenic impact upon Dniester ecosystem was also rendered by water pollution with industrial and domestic effluents and pesticides, water use by irrigation systems, as well as mass excavation of sand and gravel from the riverbed [6, 41, 48].

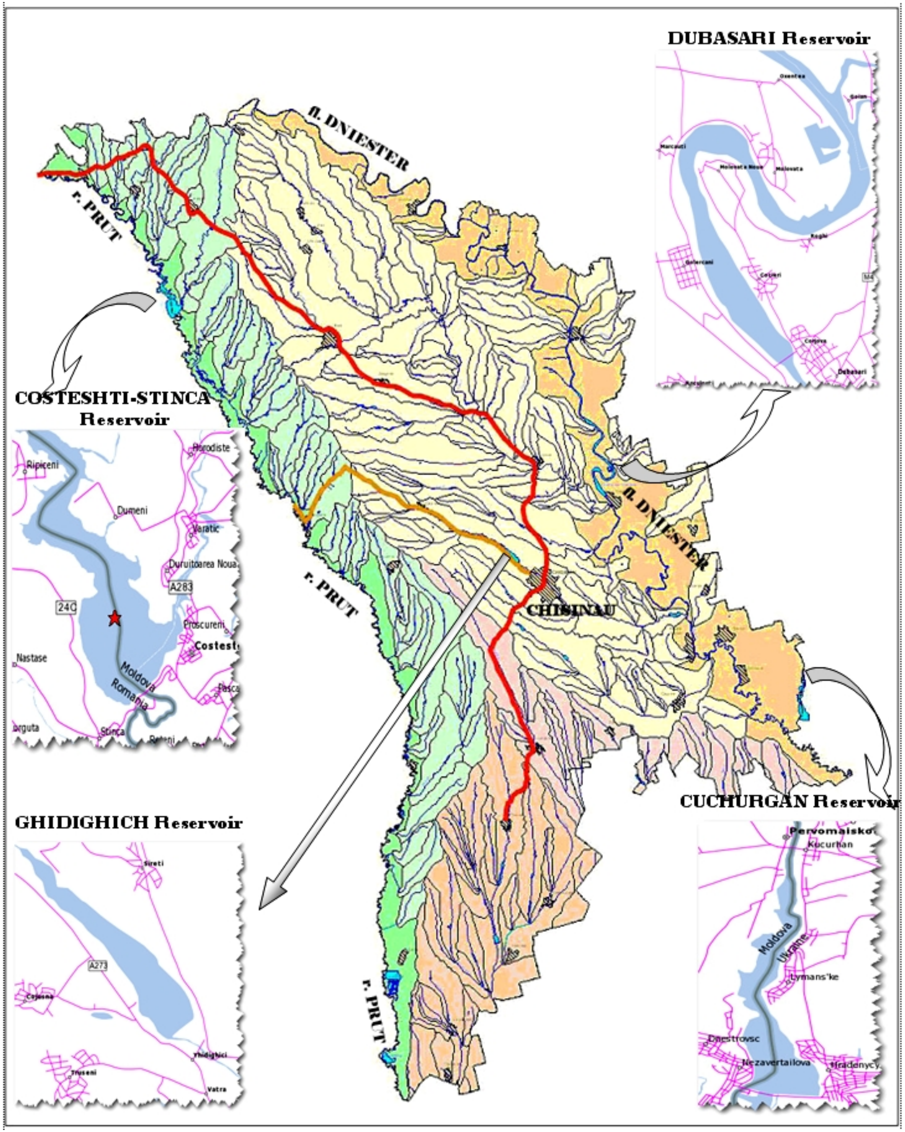

Figure 1. Map of the studied water bodies.

In 1981, the dam of Dniester Hydroelectric Power Plant crossed the Dniester in the lower part of the upper course of the river and has separated it from the middle part. This damming of the river changed radically the dynamics of intra-annual discharge, the course of natural floods, the physical and chemical conditions and already resulted in dangerous consequences for its ecosystems [12, 32, 35, 54]. The maximum water discharge is registered usually in March at the temperatures not complying with the conditions of fish reproduction. During the spawning period the volume of water flushing decreases drastically and undergoes significant fluctuations. As a result, the spawning grounds are not being filled with water or, if filled, are subsequently desiccated and cause mass destruction of juvenile fish and eggs. In the middle sector of the Dniester, during the spawning period, the multi-annual average water temperature decreased by 5-6^{0}C. The mass overgrowing of the riverbed with macrophytes deteriorates the oxygen supply and leads to secondary water pollution with organic matter. The quantity of suspended matter in river water decreased by dozens of times and the water transparency significantly increased.

Dubasari Reservoir was built on the lower part of the middle sector of Dniester in 1954. Its length was of 125 km, average width – 0.55 km, average depth – 7.5 m (maximum depth 19.5 m), area – 6800 ha. According to [11], Dubasari Reservoir was a typical flowing-through riverbed water basin with multiple (18 times per year) rate of water displacement. The flowage conditions of the reservoir contributed to permanent vertical translocation of water masses, with positive results on its thermal and hydrochemical conditions. However, its progressing pollution with industrial and domestic effluents has been recorded. Aquatic plants grew mainly in the reservoir bays and were almost completely absent in its riverbed sector.

At present, the riverbed part of Dubasari Reservoir is fully silted and is turned into a shallow water body of paludous type, densely overgrown with submersed macrophytes and algae [33]. The physical and chemical properties of water changed accordingly. In the spring-summer period cold water comes from the middle part of the Dniester and intensifies the process of macrophyte decomposing, the secondary pollution of water and leads to the threat of dissolved oxygen concentration decreasing to critical values. In addition, with the flushes of spring-time waters from Dniester Reservoir, more mineralized water with prevalence of sulfate ions reaches Dubasari Reservoir, while in the industrial-household effluents the prevalence of mineral and organic components of detergents is recorded [54].

Cuchurgan Reservoir – cooler of the Moldova Power Plant was built in 1964 by damming of Cuchurgan Estuary, which is a surviving remainder of a large Pra-Dniester Estuary [46]. Depending on water abundance of the particular years its water area expanded on over 1500-3200 ha and depth – from 1.7 to 3.2 m [44, 45]. The physical and chemical properties of its water were close to those of the lower part of the Dniester. Cuchurgan estuary was a spawning-feeding ground for phytophilous fishes of the Dniester. The dam construction of 4200 m long with a power station provoked the increase of water level in the reservoir, the average depth of 3.5 m (maximum depth 5 m) and the water surface of 2730 ha. Thus, the natural estuary was transformed into an artificial filling water body with circulating water supply for the power plant. Considerable changes in the thermal conditions were recorded during the period of reservoir existence. Due to the capacity increasing of Moldova Power Plant (in 1967-70), the average annual water temperature in the lower part of the reservoir already exceeded the natural temperature by 3.7°C. After the Moldova Power Plant has attained the designed output (1981-85), the water temperature in the lower part surpassed the natural temperature by 6.1°C, in the middle part – by 4.0°C [53]. The thermofication of the cooling water reservoir of the Moldova Power Plant led to certain modifications of abiotic factors (dissolved gases, biogenous elements, organic matter, ionic composition and water mineralization), as well as to the decrease in the primary production in the ecosystem [22, 53].

Due to the industrial capacity decrease of the Moldova Power Plant, the temperature conditions of the Reservoir during the last 10-12 years almost did not differ from the natural ones and the level of its mineral pollution significantly decreased. However, the ecological situation is still deteriorating. In comparison with 1981-85, the water mineralization increased twice and more and water hardness surpassed 18 mg/l [54]. The disturbance of hydrological conditions of the water body resulted in its extensive overgrowing with macrophytes and in secondary organic pollution with products of their decomposition.

Ghidighich Reservoir was created in 1962 on the Byk River, a tributary of the Dniester, in 12 km above Chişinău city. Its water area constituted 900 ha, length – 8.5 km, width – from 0.25 to 1.8 km and the mean depth – 5 m [17]. Unlike other small reservoirs of Moldova it was situated far from the zones of intense agriculture and industries and was used as recreation site of the population and for sport fishing. The levels of anthropogenic eutrophication and of water basin silting were relatively low during many years and its hydrological, physico-chemical and hydrobiological state were within the norm. However, recently the state of its ecosystem has been deteriorated due to the damming of the upper part of Byk River, increased discharge of organic-mineral pollution and mass invasion of pond fish juveniles.

The Prut River. Due to the borderline situation of the river its physical-geographic traits are rather poor studied [1, 2, 15, 23, 27]. The Prut River is one of major tributaries to the Danube. It originates on the north-eastern slope of the Chernigov Ridge of the Carpathians. The main sources of its water supply are the melt waters and atmospheric precipitation. Taking into consideration the hydrological, climatic and orographic traits of Prut basin, it was subdivided into three parts: upper, middle, and lower.

At present, due to the damming, the floodplain of the Prut over the largest part of the left bank is drained and turned into agricultural lands. The sharp fluctuations of the discharge from Costeshti-Stinca Reservoir to the tail-water provoke the spawning of fishes on spawning grounds remaining in the river floodplain and separated from it by dikes. Then these grounds dry up or are separated from the river and mass destruction of fish juveniles occurs due to oxygen deficiency and extermination by ichthyophagous birds. Almost all middle-sized and large tributaries of Prut are regulated by series of small reservoirs and ponds deeply polluted by waste waters.

Costeshti-Stinca Reservoir was built at the middle part of the Prut and became operational in 1978 as a water body of seasonal regulation. Its water area was 5900 ha, length 70 km, average width 0.8 km (maximum 3.6 km), and depth 27.6 m (maximum) and 11.5 m (average). The water temperature attained 28°C. The level of the reservoir changed noticeably during the year depending on the inflow of melt waters and rain water. The average water discharge through the dam was 190 m^3/s, at floods – 180-230 m^3/s (maximum up to 2800 m^3/s). The flow velocities were varying from 0.04-0.09 to 0.3-0.9 m/s. The bottom of the water body was mainly silty-sandy.

During the last 10 years the ecological conditions in the reservoir have significantly deteriorated. Abrupt fluctuations of the water level in the spawning period lead to the exposure of substrata and mass destruction of eggs and juveniles on spawning grounds.

Description of the biological material.

The material presented in the paper concerns the bream from Dniester basin (Middle and Lower Dniester, Dubasari, Cuchurgan and Ghidighich

Reservoirs) and Prut basin (Lower Prut and Costeshti-Stinca Reservoir). Fish was collected during six expeditions conducted in 2008-2009 by the personnel of Laboratory of Ichthyology and Aquaculture, Institute of Zoology, Academy of Sciences of Moldova. Control catches were obtained using stake nets (mesh size of 14-70mm) and two minnow seines (length 10 and 40m). Besides, for comparative analysis some historical materials collected during the last 100 years [2, 3, 12, 15, 21, 24, 31, 42, 46, 49, 53; annual reports of Institute of Zoology, Academy of Sciences of Moldova, and of State Ecological Inspectorate of Moldova] were involved. During the study period, 642 bream were collected (137 ind. from Dniester River, 110 ind. from Dubasari Reservoir, 63 ind. from Cuchurgan Reservoir, 75 ind. from Ghidighich Reservoir, 109 ind. from Prut River, 148 ind. from Costeshti-Stinca Reservoir). Fish were aged by counting annual rings on scales and cross-sections of pectoral fin rays [14]. Seasonal growth was estimated by observation data as well as by back-calculations from scales. Instantaneous rates of total mortality were estimated from the analysis of logarithmic catch curves. Fecundity was determined by weighing method.

The comparison of size-at-age data between populations was accomplished by means of growth performance index [30] which is calculated as follows:

$$\phi = \ln k + 2 \cdot \ln L_{\infty},$$

where k and L_{∞} are the parameters of von Bertalanffi's growth function (VBGF). Approximation of empirical data by the VBGF was performed using the least-squares procedure modified for non-linear functions (embedded in Statistica 6.0).

RESULTS

The analysis of dynamics of bream commercial catches in Moldovian water bodies showed that dam construction, draining of floodplain spawning grounds and other negative changes in habitats of Dniester basin led to diminishing of bream residential form, whereas the abundance of semi-anadromous form in the Dniester mouth and lagoon increased in the first decades after reconstruction [3, 21]. In 10-15 years after filling up of Dubasari, Cuchurgan, Costeshti-Stinca and some smaller reservoirs, bream abundance increased due to food resources growth and spawning grounds expanding (Fig. 2). Thus, annual catches of Dubasari bream reached 29.9 tons in 1974; maximal catches in Cuchurgan basin-cooler were observed in 1975 (8 tons); in Costeshti-Stinca Reservoir annual catches were 48-49 tons at 5-6 years after its filling up.

Afterward, silting, vegetation overgrowing and intoxication of the reservoirs have initiated the process of ecosystems degradation. In front of the dams and upstream the reservoirs (especially in water bodies with low water turnover) a lot of silt has been accumulated (for example, in front of Dubasari dam the thickness of silt layer is more than 10 m); the biomass of benthos has reduced; coastal shoals have been overgrown; the survival of bream larvae has diminished due to competition for food with juveniles of coarse fish species (bleak, dace, roach, white bream and others) that prosper in degrading ecosystems. As result, bream abundance and commercial catches have declined (Fig. 2), while its mortality has increased (Fig. 3).

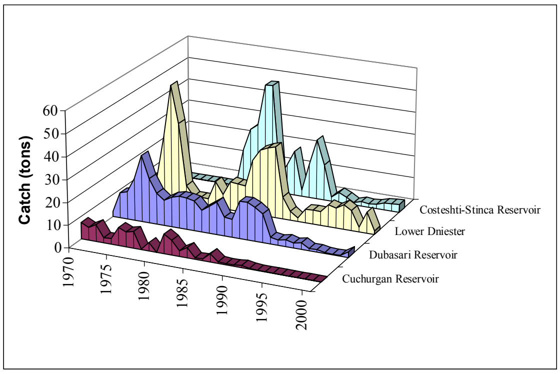

Figure 2. The dynamics of bream commercial catches in some Moldovian water bodies.

Apart from these reasons, bream populations depletion is caused also by negative changes in population structure under the influence of adverse environmental conditions, habitat and mass producers of catch. The number of age classes in spawning stock has shrunk due to delayed maturation, on the one hand, and life span decreasing, on the other. As the result of these processes, the abundance of bream in Dubasari reduced more than ten times in 1990-2000 (starting from the peak in 1970s), and in the last years catches did not reach 1 ton per year. In Cuchurgan basin-cooler, bream population is at its minimum values and since 1990s the fishing is ceased due to the reservoir overgrowing and steady increasing of toxicity. In Costeshti-Stinca Reservoir, which is the newest and most favorable water body among all, the catches of bream in the last 10 years significantly decreased as well (Fig. 2).

The bream population of Vatra (Ghidighich Reservoir) on the Byk River was created in 1961-1965 through stocking by artificially reared bream larvae from Dniester. At present, the population state is satisfactory; at the same time inter-population polymorphism is observed: there are two ecological forms of bream – one form consumes small zebra mussel and has very high growth rate, while the other form is a typical benthophagous with lower growth rate [7].

The structure of bream populations in unstable water bodies such as reservoirs is characterized by some essential peculiarities. At the beginning of reservoirs forming, when bream abundance was increasing and negative anthropogenic impact was rather low, the number of age groups increased by comparing with initial river populations (Fig. 4). For example, in Dubasari and Costesti reservoirs, 10-15 years after their construction, the relative number of immature individuals in the population accounted for more than 75%, while the number of age groups has increased to 10-11. With worsening of water basins ecological situation, deterioration of reproductive conditions, and under significant pressure of fishing, the age range diminished. For example in Dubasari reservoir in 2006-2008 years only 8 age groups were revealed, and in Costesti-Stanca – 9 age groups. At the same time in both reservoirs, the relative number of individuals of bream of the ages between 1 to 3 years was extremely low. In Cuchurgan reservoir at present the number of age groups reduced to 5 (mainly due to the reproductive part of the population). In Ghidighici reservoir the number of age groups in the population of bream for this period has not changed, although there was a tendency to reduce reproduction of its juveniles. Particularly drastic changes were registered for bream populations in the Lower Dniester (Fig. 4). In a whole, the diminishing of age classes number destabilizes the process of reproduction.

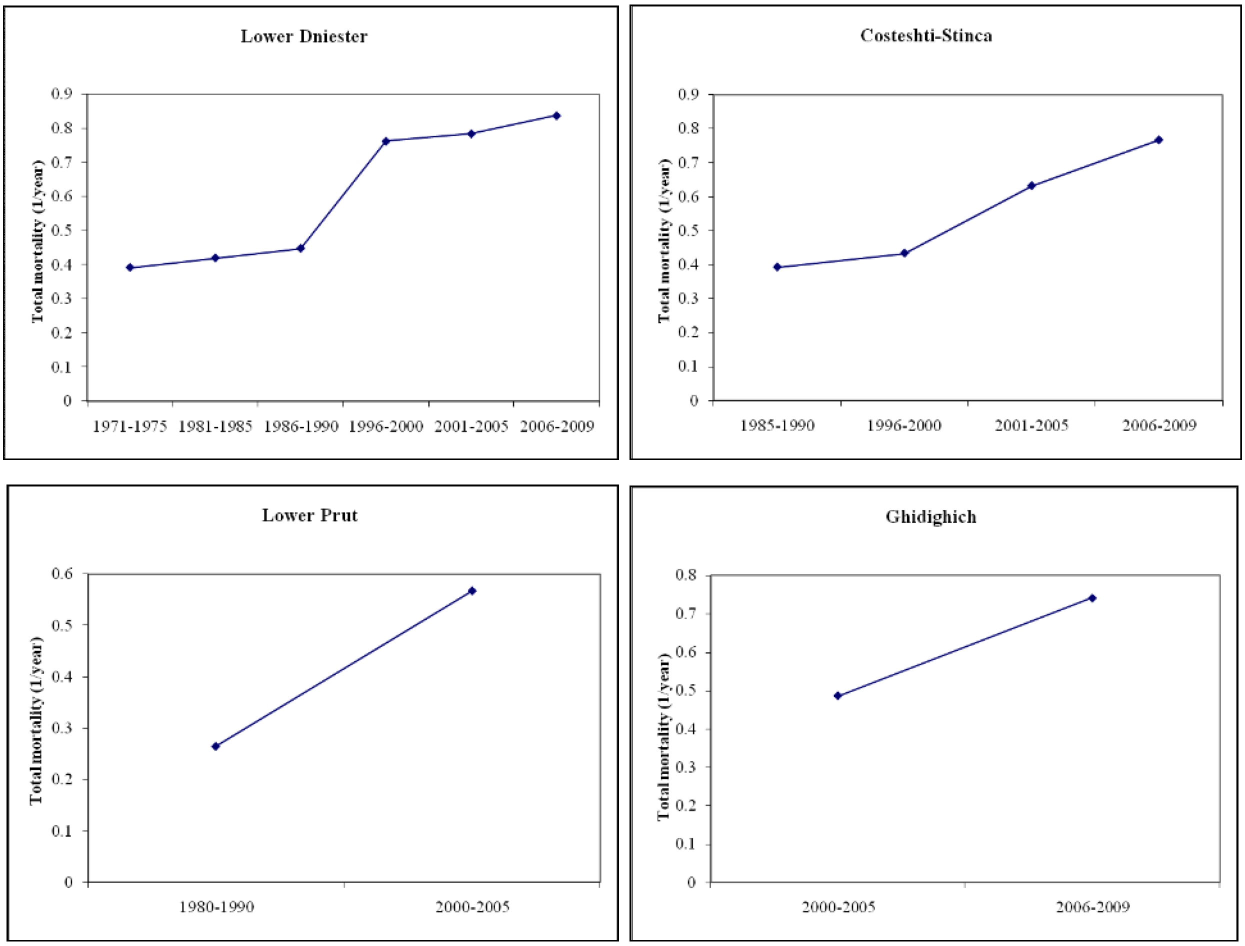

Figure 3. The dynamics of bream total mortality rate in some Moldovian water bodies.

On average, bream growth rate in Moldovian water bodies is rather high (Fig. 5) due to high water temperature and long vegetative period. The registered variations of growth rate in different water bodies are related to different level of food resources and diversity of biotopes. The highest growth rate was registered in the Lower Dniester and Vatra Reservoir (mollusk-consuming ecological form) (Fig. 5 & Table 1).

For the long-term period of observations bream growth rate has been changing. At the first stages of reservoirs functioning it has been increasing by comparing with initial river bream; as the environmental conditions in the reservoirs became worse as the result of their silting and toxication (thermofication in the case of Cuchurgan reservoir-cooler), it has decreased (Fig. 6).

DISCUSSION

In the last 50 years Moldovian scientists have been researching bream reproduction both in rivers and in reconstructed water bodies. Different processes were studied such as gametogenesis, oocytes resorption, fecundity, dynamics of gonado-somatic indexes [3, 12, 18, 19, 36-38, 51, 52].

During the period of these surveys, the average age of maturation in specific water bodies was changing mostly in relation with temperature and trophic conditions fluctuations (Table 2). As follows from Table 2, recently the age of maturation of bream from Dniester River and Dubasari Reservoir is increasing, which may be explained by the inflow of cold water from Dniester Reservoir. In the Lower Dniester River and the reservoir Costesti-Stanca a trend of maturation period of bream lengthening also have been registered, which is caused mainly to reduced food resources. In contrast, in Cuciurgan reservoir at present (on the background of reducing hyperthermia) the puberty time of bream is reduced.

The degree of oocytes resorption may serve as an indicator of abnormalities in gametogenesis process for populations from reconstructed water bodies. Before the creation of such water basins, the bream spawned two portions of eggs. Later, when unregulated discharge of cold water from upper water bodies became a common practice, the conditions of eggs maturation changed: in the lower river courses the second portion of eggs was subjected to total resorption. The disturbance of reproduction conditions within the reservoirs affected the first portion of oocytes as well and led to the fertility decrease in general.

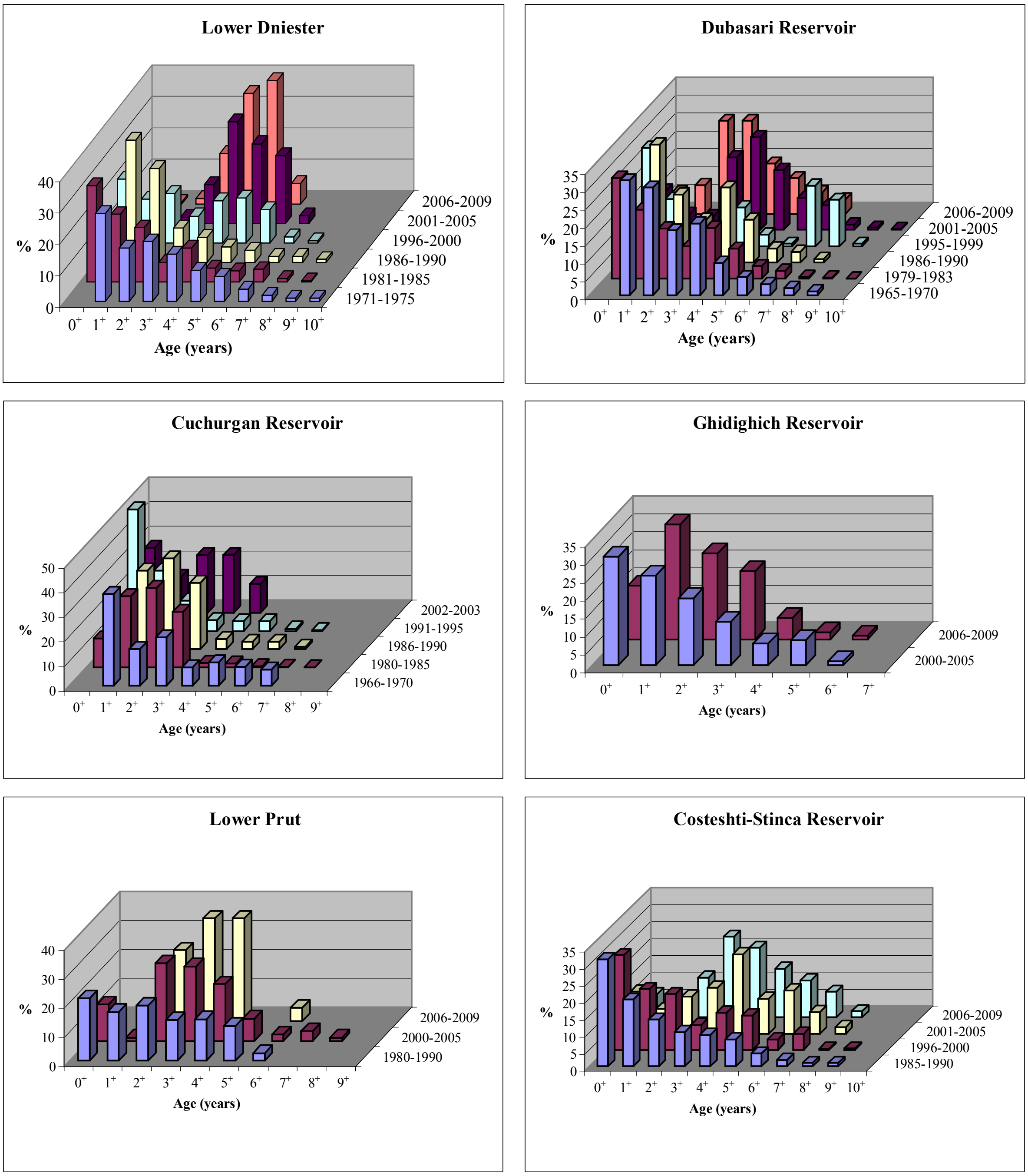

Figure 4. The dynamics of age composition in different bream populations.

Special studies of thermofication and dethermofication effects were conducted in Cuchurgan Reservoir where the temperature at the beginning increased by 6°C and then decreased. The study confirmed the lability of resorption process and its adaptive regulation: in the beginning females produced two portions of eggs, then only one portion, and now they produce two portions again [19, 20, 38].

Monitoring studies carried out in Moldovian water bodies in the last 50 years revealed the negative effect of river systems reconstruction upon fish community as a whole, as well as upon the ecology of certain species.

With the reconstruction of water basins, bream demonstrated high ecological plasticity and a wide range of structural and functional adaptations to the changing environment. As examples of such plasticity some adaptations may be pointed out: changes of growth rate, both in size and weight, of populations from Dubasari, Cuchurgan, Ghidighich and Costeshti-Stinca Reservoirs; appearance of two ecological forms of bream – mollusk-eating and zoobenthos-eating – in small Ghidighich Reservoir that differ by their growth rate.

At the early stages of the reservoirs functioning, increased food resource resulted in bream having higher growth rate and reproduction success. Later, with the constant progress of the reservoirs pollution and siltation, growth and reproduction of bream populations decreased. Other factors, influencing the state of populations, are unfavorable thermal conditions, especially in the period of gonads maturation and spawning. In the process, age ranges of spawning populations are shrinking which, along with extent resorption of sexual cells, lead to the instability of the whole reproductive process.

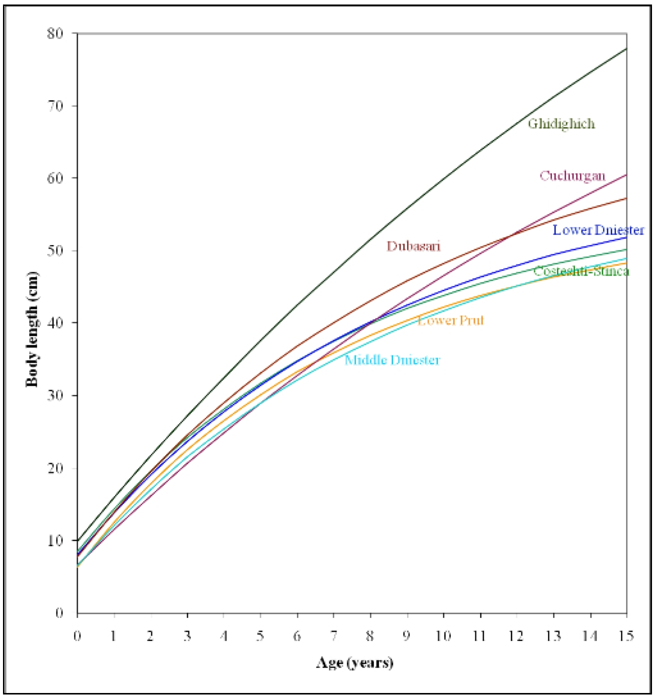

Figure 5. Theoretical (VBGF) curves of bream growth in size.

Table 1. Quantitative description of bream growth in size for several Moldovian water bodies (ϕ – growth performance index).

Water body	VBGF	ϕ
Middle Dniester	$L_t = 58.423\ (1 - e^{-0.113\ (t + 1.052)})$	5.958
Lower Prut	$L_t = 54.572\ (1 - e^{-0.136\ (t + 0.910)})$	6.005
Costeshti-Stinca Reservoir	$L_t = 57.014\ (1 - e^{-0.131\ (t + 1.226)})$	6.052
Lower Dniester	$L_t = 61.197\ (1 - e^{-0.116\ (t + 1.206)})$	6.076
Dubasari Reservoir	$L_t = 70.590\ (1 - e^{-0.104\ (t + 1.122)})$	6.246
Cuchurgan Reservoir	$L_t = 112.929\ (1 - e^{-0.047\ (t + 1.282)})$	6.399
Ghidighich Reservoir	$L_t = 153.095\ (1 - e^{-0.043\ (t + 1.561)})$	6.915

The age of maturation in both male and female bream fluctuates as well, according to irregularities of trophic resources and perturbation of natural seasonal changing of water temperature (as a result of cold water outflows).

The populations of bream from Middle Dniester, Dubasari and Cuchurgan Reservoirs demonstrate the species reaction to unusual changes of thermal regime. Cold waters outflow through Dubasari and Dniester dams lengthens the period of maturing of those individuals that inhabit the lower parts of the water bodies and increase the resorption of developing oocytes. All these processes have a detrimental effect upon population reproduction. The warming of Cuchurgan basin-cooler (more than 6^{o}C in some sectors by comparing with the natural temperature) disturbed the gametogenesis process (caused the resorption of the second portion of eggs). When the capacity of Moldova Power Station decreased and the water warming ceased, the resorption diminished either and female bream returned to two-portion spawning.

High ecological plasticity of bream allows to consider this fish species as a highly informative indicator species for estimating the state of freshwater ecosystems, both natural (rivers and lakes) and artificial (reservoirs and basins-coolers).

It can be noted that in reconstructed water bodies, created mainly for hydroelectric power stations needs, the ecosystems degradation begins after a certain period of time. Among the reasons that cause such degradations the following can be mentioned: slowdown of the water runoff; changes of water temperature (warming or cooling); increasing of water toxicity (including the effects of natural self-purification weakening). The timing of these “crisis” beginning in such human-made water bodies depends on various causes – water volume capacity, reservoir topography, water turnover, rate of toxicants accumulation, composition of toxicants etc.

Thus, economical benefits after the flow regulation of large and middle-size rivers is opposed by ecological losses – biodiversity reduction, natural self-purification deterioration, degradation of initial river ecosystems and of populations of some hydrobiont species.

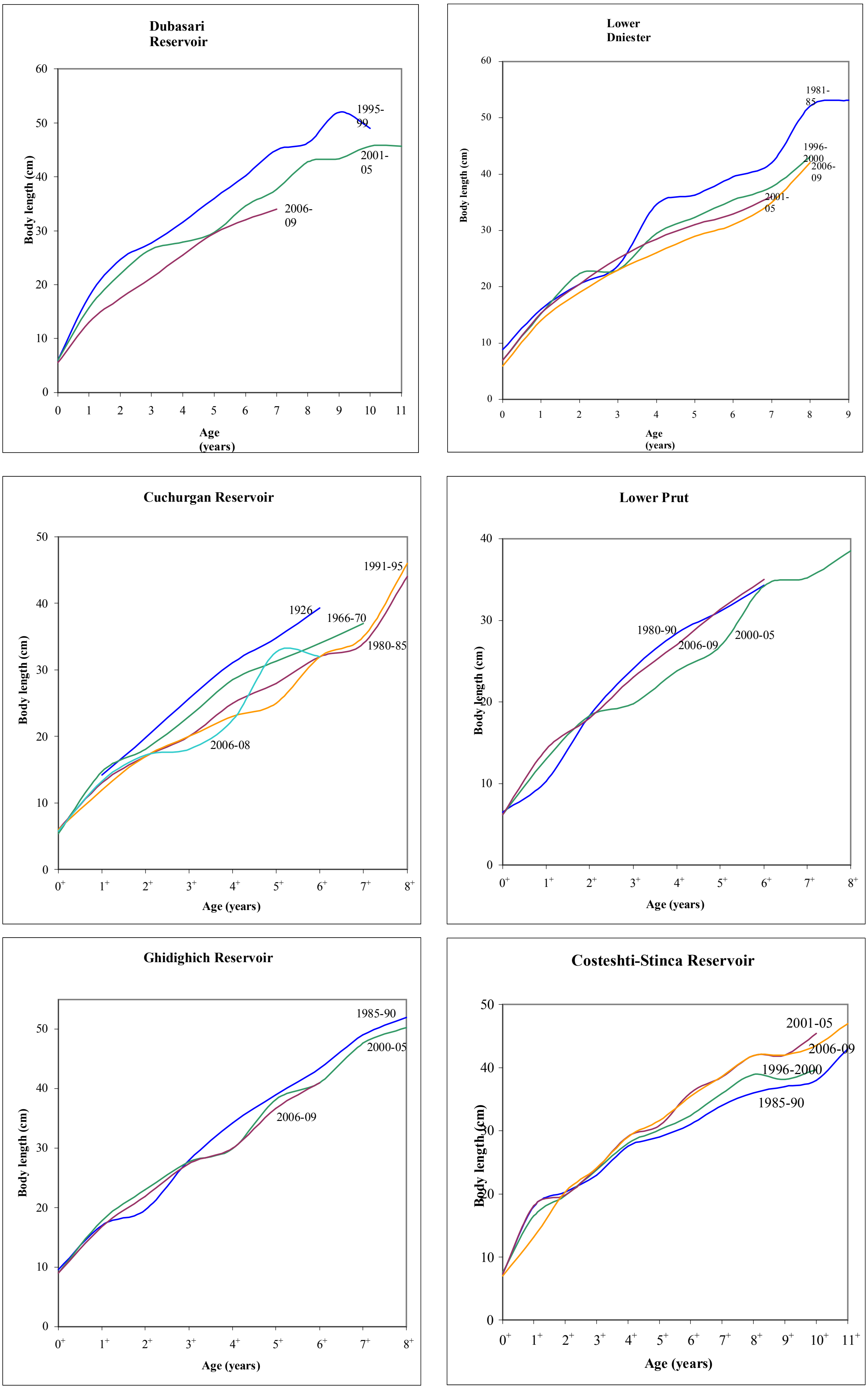

Figure 6. Bream growth in size in different water bodies.

Table 2. Mean age of maturation in bream females (above the line) and males (below the line) from Moldovian water bodies in different phases of their existence.

Middle Dniester	Beginning of 1950's. Prior to run-off regulation	First years of run-off regulation by the Dubasari Dam	-	1980's	Present time
	4 / 3	4 / 3	-	5 / 4	5-6 / 4-5
Dubasari Reservoir	-	First 10 years after filling up	1960-70's	-	Present time
	-	4 / 3	4-5 / 3-4	-	5 / 4
Lower Dniester	Prior to run-off regulation	First 10 years of run-off regulation	-	1980's	Present time
	4 / 3	3-4 / 2-3	-	4 / 3	4-5 / 3-4
Cuchurgan Reservoir	Cuchurgan Estuary before reconstruction	First 10 years of regulation	1970-75's, water temperature raised by 3°C	End of 1980's, water temperature raised by 6°C	Present time, water temperature decreasing
	3-4 / 2-3	4-5 / 2-3	2-4 / 2-3	5-6 / 4-5	4-5 / 3-4
Costeshti-Stinca Reservoir	Prior to Prut River run-off regulation	-	-	1980's	Present time
	4 / 3	-	-	4 / 3	5 / 4

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