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Hydrological conditions of reproduction of semi-migratory fish of the Lower Volga under climate change and water flow regulation (case study: Bream)

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ABSTRACT

Relevance. Being the most important spawning ground for valuable fish species, the Lower Volga plays a significant role in the Fishing Industry of Russia. However, anthropogenic factors combined with the climate change lead to degradation of the habitat and natural spawning conditions posing a threat to conservation of biodiversity and long-term sustainability of populations of semi-migratory fish. The purpose of the study is to evaluate the role of climatic and anthropogenic effect on the reproduction of semi-migratory fish of the Volga-Caspian fishery region. **The research methods** consist in the assessment and analysis of the long-term data from routine observations at hydrological gauge stations (GS) of the Lower Volga from 1936 to 2022, the main trends in water runoff changes, as well as parameters characterizing spawning conditions. **Results.** The characteristics of water runoff and other parameters determining the spawning conditions of semi-migratory fish species in natural conditions and during regulated runoff have been evaluated (case study 'Bream'). Some measures to restore the fisheries in the area have been proposed.

KEYWORDS: the Lower Volga, semi-migratory fish, water flow regulation, Volgograd reservoir, climate change, duration of the spawning period (DSP), floodplain spawning grounds, bream fingerlings, catch reduction.

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INTRODUCTION

The Lower Volga is the most important component of the ecosystem of the Volga-Caspian basin. The Volga-Akhtuba floodplain and the Volga Delta have always been a spawning ground for semi-migratory fish species (bream, roach, carp, walleye, etc.). However, in recent decades, the hydrological conditions of the area have been affected simultaneously by two factors – climate change and water flow regulation, their combined influence threatening sustainability of populations of semi-migratory fish of the Lower Volga [1].

Regulating the Volga River, which began in the middle of the 20th century with the construction of a cascade of reservoirs, radically changed the natural hydrological regime of the river: floods, which previously inundated spawning floodplains of semi-migratory fish, have greatly decreased [1-3]. Blocking the Volga riverbed with the dam of Volzhskaya Hydroelectric Power Plant (HPP) was one of the reasons for the critical decline in the number of sturgeons, their migration routes barred [3-8].

The phase of reduced runoff in the second quarter (which lasted until 1977) was caused by climatic changes [1, 9].

MATERIALS AND RESEARCH METHODS

The Volga Delta was chosen as the object of research, namely the area near the Verkhnee Lebyazhye and Astrakhan GS (Fig. 1, Table 1).

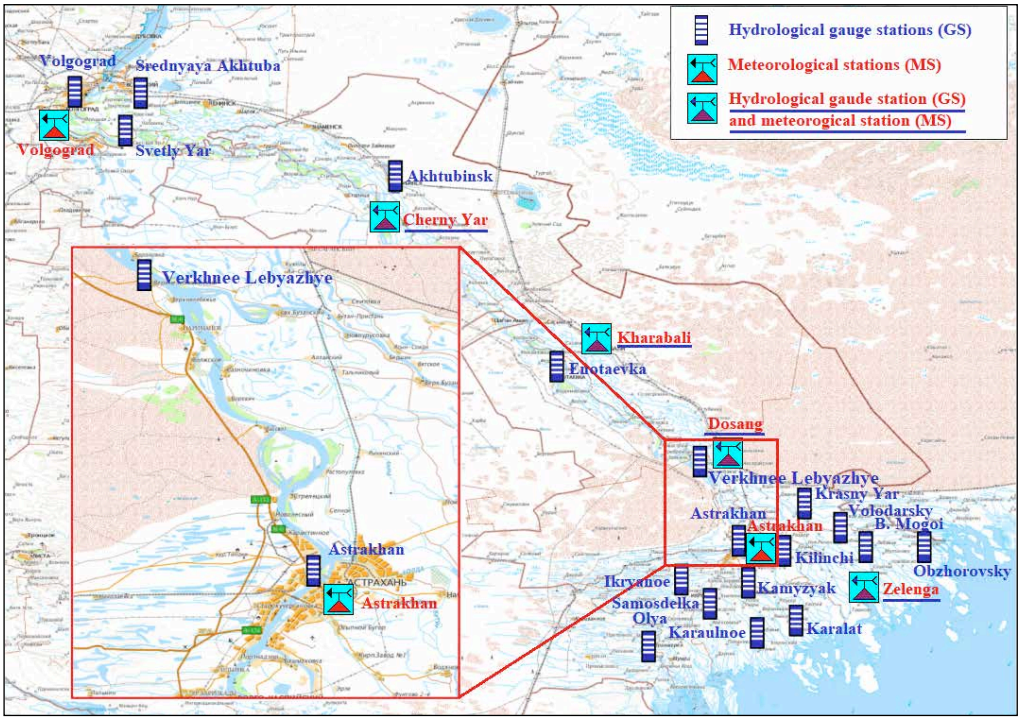


Figure 1. Research area.

Table 1. The list of the acting hydrological gauge stations at the Lower Volga*

Watercourse	Hydrological gauge station	Period of acting		Department
		Start-up time	Closing time	
the Volga	Volzhskaya HPP downstream	10.09.1961	Open	PJSC RusHydro
the Volga	Volgograd	13.04.1877	Open	VCHEM
the Volga	Svetly Yar	04.01.1931	Open	VCHEM
the Arhtuba (horn)	Srednyaya Akhtuba	17.04.1930	Open	VCHEM
the Volga	Cherny Yar	14.04.1877	Open	ACHEM
the Volga, the Enotaevka (tributary)	Enotaevka	13.04.1877	Open	ACHEM
the Volga	Verkhnee Lebyazhye	29.03.1931	Open	ACHEM
the Volga	Astrakhan	15.11.1876	Open	ACHEM
the Arhtuba (horn)	Akhtubinsk	18.09.1951	Open	ACHEM
the Arhtuba (horn)	Dosang	30.03.1931	Open	ACHEM
the Arhtuba (horn), the Ashuluk (tributary)	Kharabali	01.05.1931	Open	ACHEM
the Bakhtemir (horn)	Olya	27.04.1940	Open	ACHEM
the Buzan (horn)	Krasny Yar	28.04.1932	Open	ACHEM
the Tchurka (tributary)	Volodarsky	01.01.1979	Open	ACHEM
the Sarbai (tributary)	B. Mogoi	21.05.1940	Open	ACHEM
the Obzhorovo (tributary)	Obzhorovsky	01.11.1948	Open	ACHEM
the Zelenga (tributary)	Zelenga	01.08.1930	Open	ACHEM
the Bolda (tributary)	Kilinchi	26.09.1954	Open	ACHEM
the Kamyzyak (horn)	Kamyzyak	01.04.1914	Open	ACHEM
the Tabola (tributary)	Karalat	15.04.1960	Open	ACHEM
the Nikitski Bank	Karaulnoe	09.08.1932	Open	ACHEM
**the Staraya Volga (tributary)	Samosdelka	15.01.1932	Open	ACHEM
the Khurdun (tributary)	Ikryanoe	14.01.1932	Open	ACHEM

Note: * – the information about GS is taken from the AIS GMVO website[1]; ** – The GS Staraya Volga – Samosdelka was closed during the periods of 1936-1938, 1940-1949, 1965-1994.

[1] Automated information system for state monitoring of water bodies (AIS GMVO). Access mode: https://gmvo.skniivh.ru/ (access date: April 1, 2025).

The monitoring network of the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet) on the Lower Volga includes three hydrological gauge stations located in the area of responsibility of the Volgograd Center for hydrometeorology and environmental monitoring (VCHEM), and 19 hydrological gauge stations of the Astrakhan CHEM (ACHEM). Constant monitoring of daily water levels and discharge volumes in the inlet of the Lower Volga, the lower reaches of the Volzhskaya HPP, is carried out by a division of PJSC RusHydro.

The observation programs of hydrological gauge stations vary, but daily urgent observations of the water level twice a day are mandatory. The water discharge entering the top of the Volga Delta along the main channel is measured at the Verkhnee Lebyazhye GS.

Data on water discharges and water levels from 1936 to 2022 obtained from the Hydrological Yearbooks and the AIS GMVO[1]. Some of the materials have been provided by the N.N.Zubov State Oceanographic institute, the Hydrology Laboratory of the Institute of Geography of the Russian Academy of Sciences. The data gaps are restored according to the dependence Q = f(H).

To determine water temperature, data on the average decadal water temperature at the Verkhnee Lebyazhye GS for 1956, 1958, 1959, 1961-1965, and 1967-1988 are taken from Hydrological Yearbooks. Over the same years, the data of the Astrakhan meteorological station air temperature averaged over decades are taken from the VNIIGMI-MCD website[2]. A graph showing the relationship between air and water temperatures from 1936 to 2022 has been constructed.

Duration of the spawning period (DSP) is defined as the number of days during which the height of the water layer on the floodplain is at least 20 cm, and its temperature exceeds the minimum threshold required for the start of spawning of many semi-migratory fish species (more than 8°C for bream) [10].

The bream is chosen as a model object of research as the most well-studied semi-migratory fish species of great importance in the fisheries of the Lower Volga. Information on the number of bream fingerlings in the western part of the Northern Caspian Sea has been found in [11].

Data on the areas of flooding of the Volga Delta spawning grounds corresponding to certain water levels measured at the Astrakhan GS have been taken from [1, 12, 13].

[2] The All -Russian Research Institute of Hydrometeorological Information – World Data Center. Access mode: http://meteo.ru / (access date: April 1,2025).

RESULTS AND DISCUSSION

Fish catches

Catch assessment is essential to preserve ecosystem integrity, ensure the long-term sustainability of the fishing industry, and predict future fish stocks. Figure 2 shows a graph of changes in catches of generative freshwater fish of the Volga-Caspian region for the period of 1930-2022. Generative freshwater fish species are a collection of semi-migratory (80 per cent of the total) and riverine (20 per cent of the total) fish species. The data are taken from [1, 3].

In Fig. 2 one can see that from the 1930s to the 2000s, there was a fourfold decrease in catches, this problem being also handled in [8, 14-17].

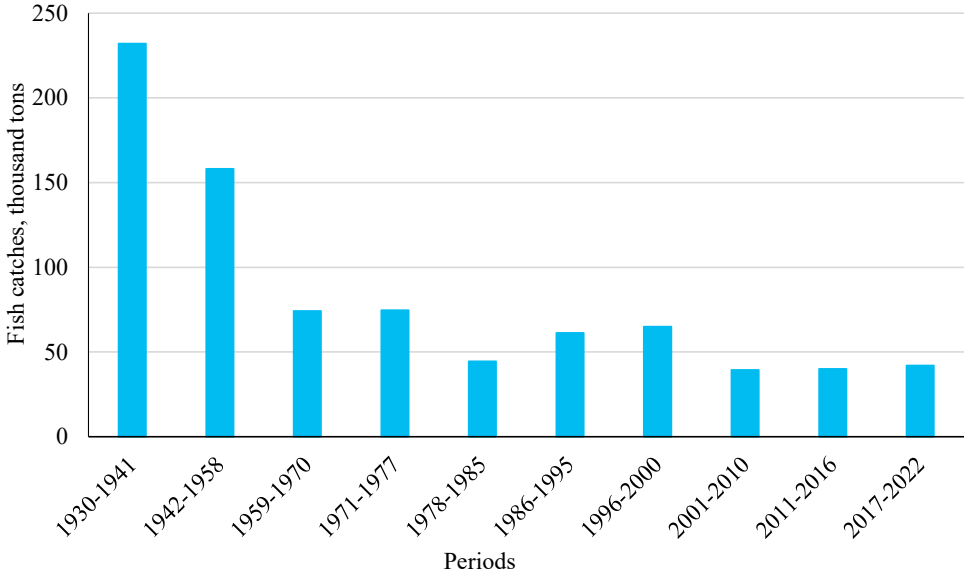


Figure 2. Catches of generative freshwater fish of the Volga-Caspian region [1, 2].

The significant reduction in catches from 230,000 tons to 70,000 tons in the 1950s and the 1960s was due, on the one hand, to the prohibition of marine fishing, and, on the other, to the deteriorating reproduction conditions caused by Volga River water flow regulation. The continued decline in catches in the 1970s occurred against the background of the low water period, which, together with a decrease in Volga River runoff and a drop in the Caspian Sea level, led to significant deterioration in the ecological situation in the Volga-Caspian region. Catches increased slightly in the 1980s, but remained four times lower than before runoff regulation. In the late 1980s and the 1990s, the formation of commercial fish stocks was against the background of increased water avail-

ability and transgression of the Caspian Sea. In the early 2000s, catches decreased again, reaching the lowest point for the whole period – about 40,000 tons, after that they stabilized. From 2006 to 2012, reproduction and feeding of bream generations took place under conditions of unfavorable abiotic and biotic factors, such as low spring floods and reduced spawning areas [15].

Spring flood runoff

Figure 3 shows a graph of long-term changes in spring Volga discharge rates and a difference integral curve (DIC) at the Verkhnee Lebyazhye GS.

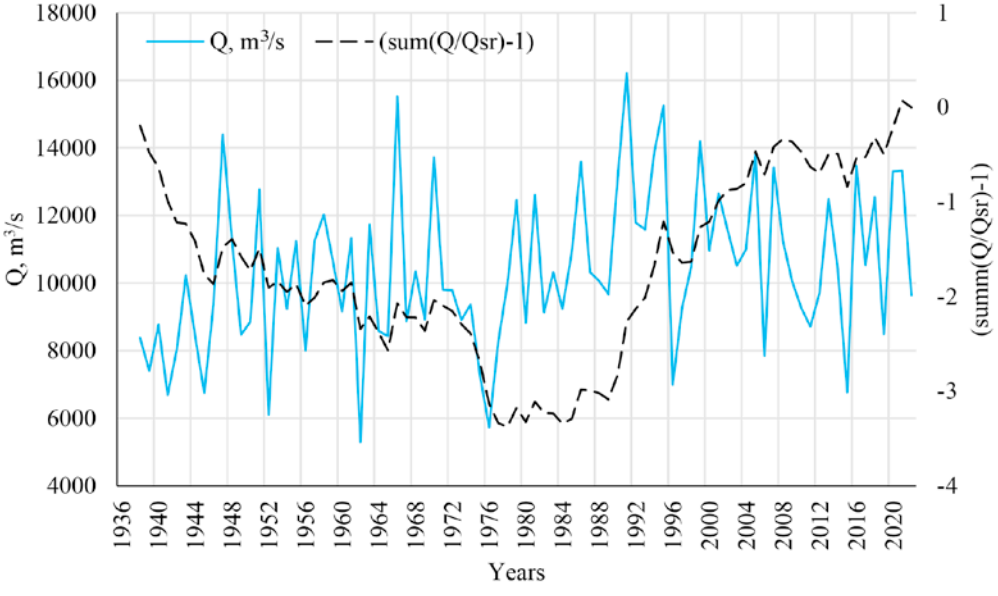


Figure 3. Spring (March-May) discharge rates on the Volga (Verkhnee Lebyazhye GS, 1936–2022) and the difference integral curve.

The series of discharge rates of the second quarter of year is divided into two phases: the low-water one until 1977, and the high-water one after 1978. In each phase, there are high water and low water periods: 1936-1945, 1971-1977 – of reduced water content; 1946-1970, 2005-2018 – of relatively stable water content; 1978-2004, 2019-2022 – of increased water content.

The changes in the average annual discharge rates on the Volga are similar to the ones in the average spring flood discharge rates since the share of spring flood runoff is 35-47 per cent of the annual one.

If spring flood runoff of the Volga tends to increase for more than a decade, why are the catches in this area decreasing [1]? To answer this question,

one should consider some other characteristics of the spring flood runoff in more detail.

Characteristics of the spring flood

When comparing the period of unregulated runoff (1936-1957) and the period of overregulated runoff (1961-2022), the following features can be identified. The timing of the flood shifted from mid-April to the last decade of April (from April 15 to April 21), with the flood being over three weeks earlier (on June 28 instead of July 20). The duration of the flood decreased by three weeks, from 86 to 62 days (Table 1, Fig. 4).

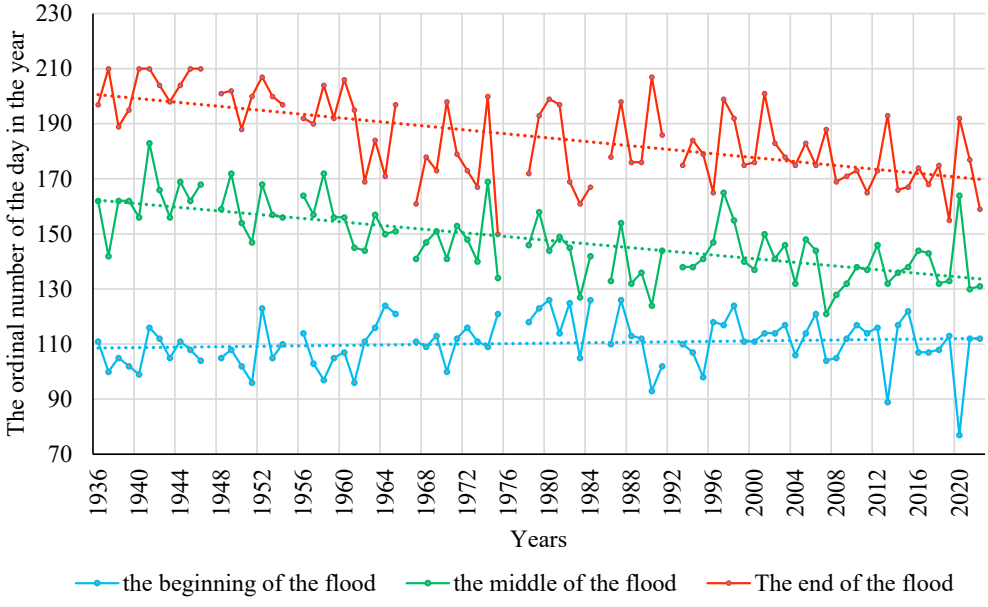


Figure 4. Dates of the beginning, middle and end of the Volga River flood (Astrakhan GS, 1936–2022).

The number of days with the flood rise phase decreased by 3.5 weeks, from 55 to 31 days. The duration of the flood recession changed slightly: before 1958 it was 39 days, and after that it was 36 days (Table 1, Fig. 5).

The rate of flood rise increased almost 1.64 times, from 5.8 to 9.5 cm per day. The rate of flood fall increased 1.3 times, from 5.6 to 7.3 cm/day (Table 2, Fig. 6).

The changes that have occurred negatively affect the warming and uniform runoff of water into the shallow riverbed network and reservoirs of the Volga Delta. The accelerated passage of high water creates competitive conditions for spawning fish belonging to different ecological groups.

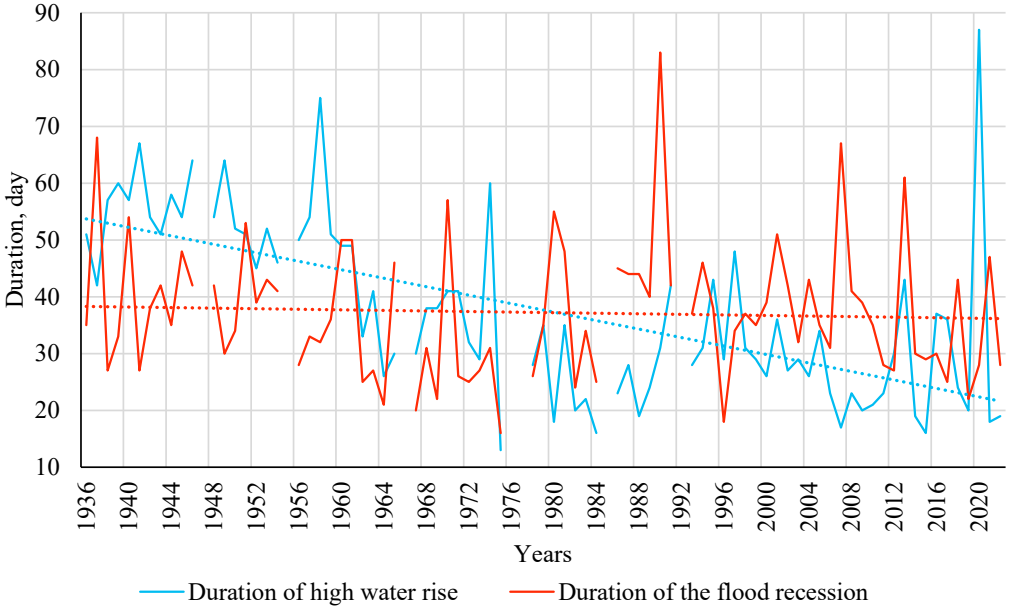


Figure 5. Duration of the rise and fall of the Volga River flood (Astrakhan GS, 1936–2022).

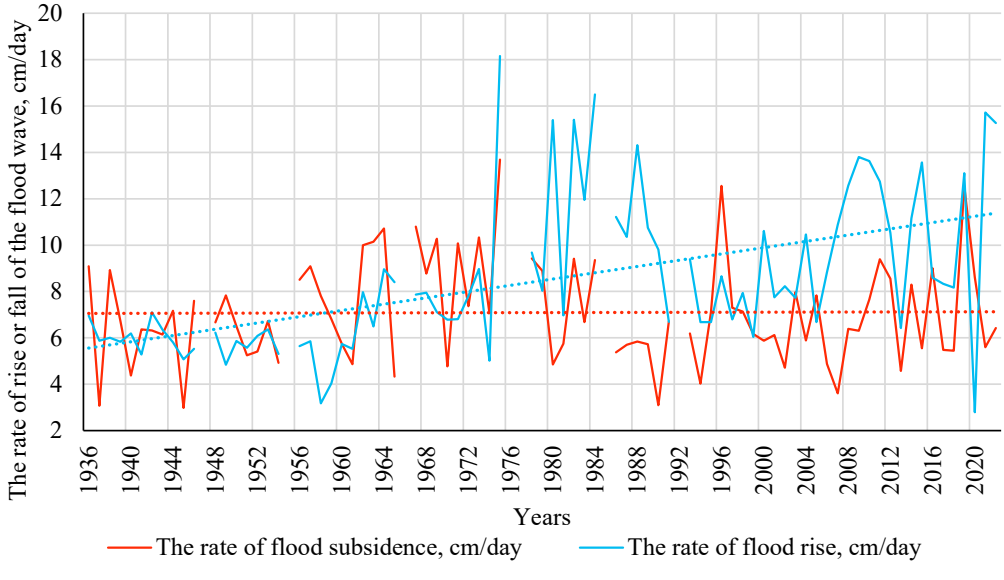


Figure 6. The rate of rise and fall of the Volga River flood (Astrakhan GS, 1936–2022).

Table 2. Characteristics of the Volga River spring flood (Astrakhan GS) during unregulated (1936–1957) and regulated (1961–2022) periods

Flood characteristics	Period	
	1936–1957 гг.	1961–2022 гг.
Flood beginning	April 15	April 21
Flood completion	July 20	June 28
Flood duration, days	86	62
Flood rise duration, days	55	31
Flood fall duration, days	39	36
Flood rise rates, cm per	5,8	9,5
Flood fall rates, cm per days	6,5	7,3

Duration of the spawning period (DSP)

The duration of flooding of the Volga-Akhtuba floodplain at the Volgograd and Verkhnee Lebyazhye GS was studied in [18]. Flood duration is considered to be the number of days during which the water level exceeds the mark of the floodplain in the area of GS. This indicator was compared for two periods: 1936-1957 and 1961-2017. It was revealed that, according to the Volgograd GS, flood duration of the regulated period decreased by 44.1 per cent compared with the unregulated period (from 37.4 to 20.9 days), and according to the Verkhnee Lebyazhye GS – by 18.5 per cent (from 49.7 to 40.5 days).

In the course of our study, we examined a similar indicator – flood duration, but we took into account the temperatures necessary for spawning of semi–migratory fish – the change in the duration of the spawning period (DSP) in the floodplains of various levels (poloi) of the Volga Delta at the Astrakhan GS (Fig. 7). According to [1, 12], floodplains (poloi) of the first (low) level are flooded at the water level from 351 to 451 cm above the "0" of the Astrakhan GS (or higher -24.29 m BS), the second (medium) – from 451 to 510 cm (or higher -23.29 m BS), and the third (high) – above 510 cm (or higher -22.70 m BS).

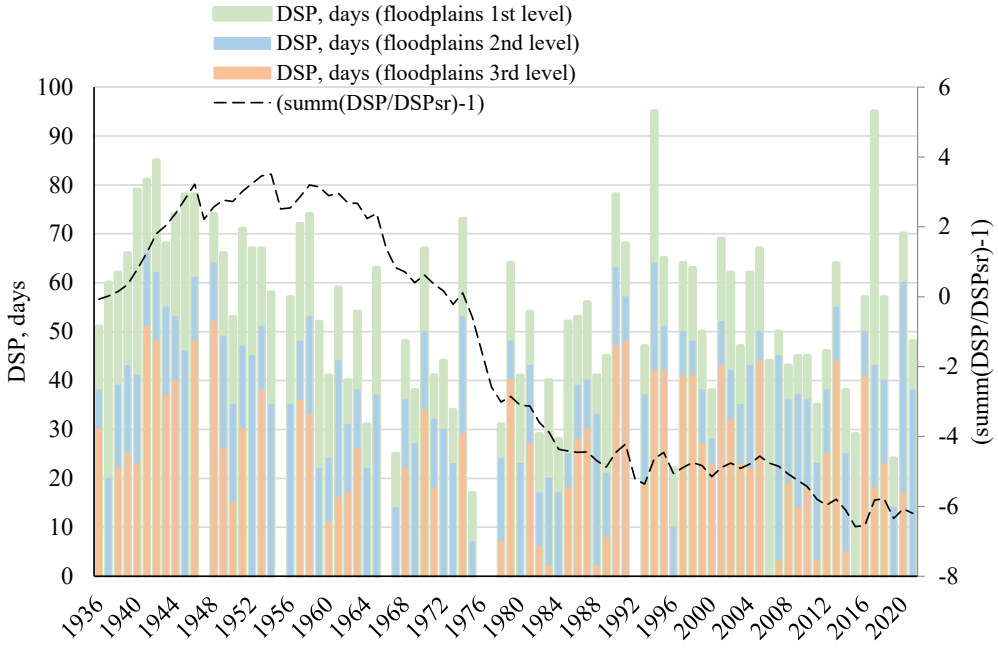


Figure 7. The duration of the spawning period in the floodplains of various levels of the Volga River Delta (Astrakhan GS, 1936–2022) and the difference integral curve of the DSP for the floodplains of the 1st level.

After 1958, the duration of the spawning period decreased for floodplains of all levels (after 1958 (the DIC line was characterized by a downward trend); for many years floodplains of the second and third levels DSP being less than 30 days required for successful spawning of semi-migratory fish. In some years, the third-level floodplains were not flooded.

If before 1958 the duration of the spawning period in the first–level floodplains was 69 days, in the second-level floodplains – 50 days, and the third–level floodplains – 34 days, then later these values were 50, 35, and 24 days, respectively. Thus, commissioning the Volzhskaya HPP reduced flooding of the first level by 20 days, of the second – by 15 days, and of the third – by 10 days.

Flood areas of the Volga Delta spawning grounds

Information on the areas of flooding of the Volga Delta spawning grounds corresponding to certain water levels of the Astrakhan GS is taken from [1, 12], the coupling equation obtained (Fig. 8).

Figure 9 below shows a graph of changes in the maximum areas of spawning grounds in the Volga Delta from 1936 to 2022, made by recalculating daily water levels (measured at the Astrakhan GS) into daily areas of spawning grounds in the Volga Delta with the relationship graph (Fig. 8).

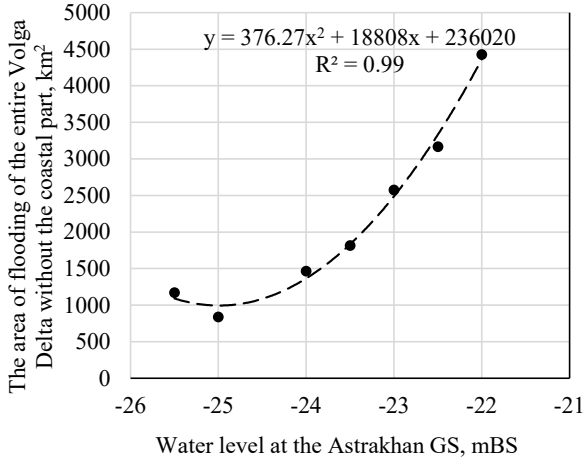


Figure 8. Relationship between the water level of the Volga River at the Astrakhan GS and the flood area of the Volga Delta spawning grounds.

From 1936 to 1958, flood areas of the Volga Delta spawning grounds gradually increased and steadily exceeded the value of 4,000 km². From 1958 to 1978, flood areas decreased, and after 1978 they began to increase again. Reduction in flood areas, which continues to the present day, has been observed since 2005.

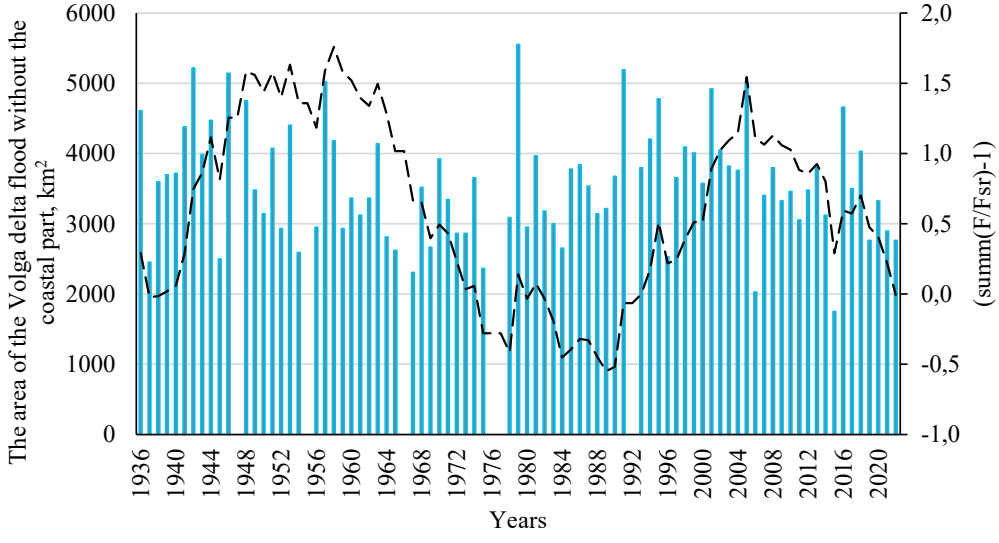


Figure 9. Maximum flood areas of the Volga River Delta spawning grounds from 1936 to 2022 and the difference integral curve.

In [1, 12], it is revealed that 100 per cent flooding of the Volga Delta spawning grounds occurs at the water level of -22.0 m BS, which corresponds to 4,428 km^2. Our research has shown that over the past 16 years, flooding of all Volga Delta spawning grounds was observed only in 2016 (Fig. 9), which coincides with the results [12].

After the construction of the Volzhskaya HPP, the complete flooding of the Volga Delta spawning grounds did not occur until 1978.

Number of fingerlings

During the study there have been analyzed hydrological indicators affecting spawning of semi-migratory fish species: water consumption during the spring period, duration of the spawning period, and the area of spawning grounds. However, it is also important to evaluate the immediate results of annual fish reproduction. For this purpose, data on the number of bream fingerlings in the western part of the Northern Caspian Sea are used [11]. Figure 10 below shows a graph of the dependence of the number of bream fingerlings on the Volga River runoff. The correlation coefficient (r) between these indicators is 0.89.

Based on the relationship obtained (Fig. 10), the number of bream fingerlings was calculated for each year from 1936 to 2022 (Fig. 11). Until 1958, the number of fingerlings increased. From 1959 to 1978, it decreased. From 1979 to 2005, there was an increase again. After 2005, the number of bream fingerlings began to decrease (except several years of increased water availability in 2013, 2016, 2018, 2020, and 2021), the process going on to the present.

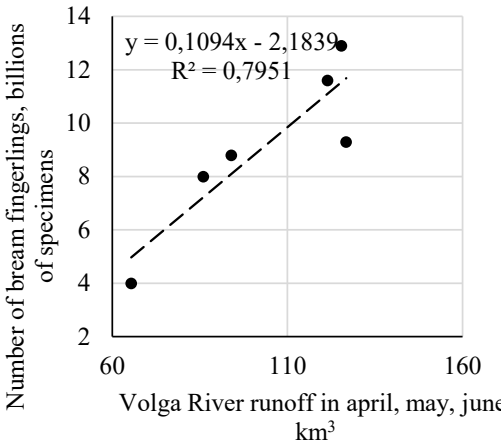


Figure 10. Relationship between the number of bream fingerlings and spring (April – June) runoff of the Volga River (at the Verkhnee Lebyazhye GS).

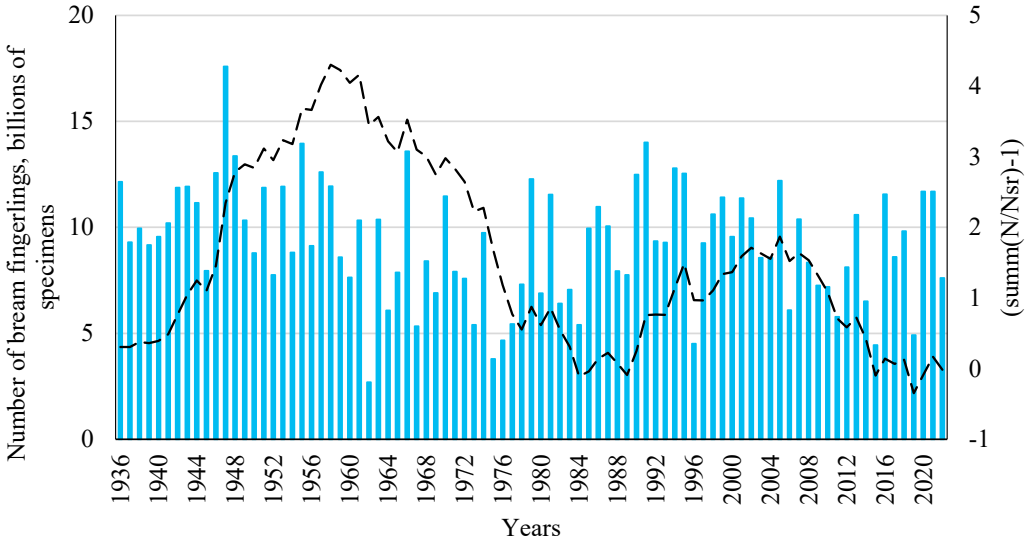


Figure 11. The number of bream fingerlings in the western part of the Northern Caspian Sea, 1936–2022 and the difference integral curve of this indicator.

Summarizing conditions of reproduction of semi-migratory fish of the Lower Volga

Below, there is a matrix of correlations between indicators under study (the level of the Caspian Sea, the average annual and bio-productive runoff of the Volga, fish catches, the number of fingerlings, the duration of the spawning period and the areas of flooding of the Volga Delta), characterizing reproduction of generative freshwater fish (semi-migratory species being from 40 per cent to 80 per cent of them).

The annual runoff of the Volga has periods of increased (with peaks in the late 1950s and mid-1990s) and periods of reduced (with a minimum in the late 1970s), which can be explained by the simultaneous impact of anthropogenic and climatic factors. Bio-productive runoff, i.e. the runoff equal to the volume of water flooding the spawning grounds of semi-migratory fish, decreased by 20-25 km^3 from the beginning of the 20th century to the beginning of the 21st century [1] as a result of transformation of the flood wave on the Lower Volga caused by anthropogenic factors; Volzhskaya HPP regulation being the main one.

The Volga water runoff has the strongest effect on such indicators as the number of bream fingerlings, fish catches and the area of flooding of the Volga River Delta. The correlation coefficient (r) between these indicators is 0.52, 0.50 and 0.42, respectively.

Table 3. Matrix of correlations between indicators under study, estimated for the period 1936–2022

	The annual level of the Caspian Sea (Makhachkala MH), m BS	The Volga runoff (Verkhnee Lebyazhye GS, km^3	Bio-productive runoff, km^3	Fish catches, thousand tons	The number of bream fingerlings, bln pieces	DSP Astrakhan, days	The flood area of the Volga Delta without seafront (Astrakhan GS, km^3
The annual level of the Caspian Sea (Makhachkala MH), m BS	1	0,02	0,33	0,26	0,42	0,36	0,66
The Volga runoff (Verkhnee Lebyazhye GS), km^3	0,02	1	0,14	0,5	0,52	0,1	0,42
Bio-productive runoff, km^3	0,33	0,14	1	0,68	0,88	0,93	0,68
Fish catches, thousand tons	0,26	0,5	0,68	1	0,42	0,69	0,39
The number of bream fingerlings, bln pieces	0,42	0,52	0,88	0,42	1	0,86	0,87
The number of bream fingerlings, bln pieces	0,36	0,1	0,93	0,69	0,86	1	0,67
The flood area of the Volga Delta without seafront (Astrakhan GS, km^2	0,66	0,42	0,68	0,39	0,87	0,67	1

Bio-productive runoff limits most of all such indicators as the duration of the spawning period, the number of bream fingerlings, fish catches and the area of flooding of the Volga delta. The correlation coefficient between these indicators is 0.93, 0.88, 0.68 and 0.68, respectively. There is also a close relationship between the level of the Caspian Sea and the number of bream fingerlings r = 0.42.

The correlation coefficient between the duration of the spawning period and the number of bream fingerlings is 0.86, whereas the correlation coefficient between the duration of the spawning period and catches is 0.69. The correlation coefficient between flood areas of the Volga delta and the number of bream fingerlings is 0.87.

Long-term changes in the annual runoff of the Volga, the level of the Caspian Sea, the number of bream fingerlings and the areas of flooding of the spawning grounds of the Volga delta are fluctuating (with periodically occurring extremes) whereas catches of generative freshwater fish of the Volga-Caspian region are constantly falling. This is due to the fact that a fairly long period of stable hydrological conditions favorable for spawning of semi-migratory fish is required to restore catches as an inertial indicator depending on many factors.

CONCLUSION

In the course of this study, an analysis of reproduction conditions of semi-migratory fish at the hydrological gauge stations of the Lower Volga (from 1936 to 2022) has been carried out. It has been revealed that natural climatic and anthropogenic factors affect the reproduction of semi-migratory fish of the Volga-Caspian fishery region in different ways. Commissioning the Volga hydroelectric power plant (HPP) in 1961 had a significant impact on the Volga River runoff and its intra-annual redistribution, the main factor on which spawning conditions depend, whereas the high-water phase caused by climatic changes, which began in 1978, had a positive impact on the hydrological spawning conditions of semi-migratory fish species.

The study has revealed that commissioning the Volga HPP reduced the duration of the spawning period in the floodplains of all levels by about 30 per cent; the maximum areas of flooding of the Volga Delta spawning grounds, as well as the number of bream fingerlings were steadily rising until 1958, and then there was a decrease until 1978, followed by an increase. After 2005 and up to the present, there has been a reduction in these characteristics again.

The conclusion obtained by many researchers [1-3, 5, 12, 13, 16-18] that flood characteristics in the regulated period have undergone significant changes compared with unregulated ones affecting spawning of semi-migratory fish have been confirmed. Thus, decreasing floodplain spawning grounds, reduction in the duration of the spawning period, transformation of the spring flood wave, reduction in the number of fingerlings and catches – all these changes are caused by the combined influence of natural and anthropogenic factors leading to deteriorated reproduction conditions of semi-migratory fish of the Lower Volga, and degradation of fisheries in this area. The situation can be

changed by means of artificial reproduction of semi-migratory fingerlings on spawning farms, as well as planning the release schedule of the Volzhskaya HPP to ensure conditions favorable for spawning.

CONFLICT OF INTERESTS

The authors declare no relevant conflict of interests.

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