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Original Article

Morphometry and fluctuating asymmetry of the gibel carp (*Carassius gibelio*) in bodies of water with different types of hydrology

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Abstract: This work examines the morphometric characteristics and fluctuating asymmetry of gibel carp, *Carassius gibelio* (Bloch, 1782) populations in water bodies within the same basin under varying hydrological conditions in the Ob-Irtysh basin, Western Siberia. By conducting measurements and analyses of meristic features, we determined the extent to which fish morphological characteristics are influenced by their natural habitat and hydrological regime. Cluster analysis revealed that gibel carp populations from reservoirs with a permanent water supply share similar morphometric parameters and exhibit lower asymmetry than populations from isolated or irregularly filled reservoirs. As a result of morphometric assessment, fluctuating asymmetry was shown to be an important and convenient indicator of adaptive changes and the overall state of the population. The data obtained emphasize the need to account for hydrological factors in ecological and biological studies and in monitoring species threatened by habitat change. The results of the study can be useful in monitoring the state and restoration of aquatic ecosystems.

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Introduction

Freshwater ecosystems are among the most susceptible components of the biosphere, as they undergo substantial adaptations in response to biogenic, abiogenic, and anthropogenic factors (Odum, 1986). Determining the state of natural resources requires regular monitoring of ecosystems through technical environmental controls and the observation of biological indicator organisms. In hydrochemical studies, special attention is paid to ichthyofauna, whose representatives are considered valuable bioresources of freshwater ecosystems and important indicators of biological monitoring. The state of fish populations is largely determined by water quality (Abakumov, 1991; Reshetnikov et al., 1999; Pak, 2005; Kotegov, 2024).

Common fish species, such as *Carassius gibelio*, are chosen to characterize aquatic ecosystems (Ministry of Natural Resources of the Russian Federation, 2003). This species is also of interest for study due to several biological features that probably help this species to naturalize in new areas quickly, these include: reproduction by gynogenesis (Abramenko et al., 1997; Yankova, 2006; Abramenko and Nedviga, 2011), different ploidy levels in populations: diploids (2n = 50), triploids (3n = 100) and hexaploids (4n = 150) (Apalikova, 2008; Pobedintseva et al., 2021), uneven sex structure in populations (Vasilyeva and Vasilyev, 2005; Abramenko, 2011; Yadrenkina, 2011), probable hybridization with other carp species (Vekhov, 2013; Goriunova et al., 2017; Bitner and Smolina, 2023), and high resistance to oxygen deficiency in the environment (Fagernes et al., 2017).

The study of intrapopulation variation in bony fish, particularly carp species, is based on a comparative analysis of the frequency of countable morphological traits (meristic), which are characterized by high heritability and early manifestation during ontogeny (Makoedov and Korotaeva, 1999; Pak, 2005; Kotegov, 2024). These indicators enable us to measure the degree of genetic relatedness between

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populations (Kirpichnikov, 1987). In addition, the seismosensory canals (SSC) of the head in bony fish are examined as a primary morphometric characteristic (Zinoviev and Mandritsa, 2003; Kotegov, 2015). It is known that their number is associated with the quantity of primary canal neuromasts - seismic reception organs located in the canals of the dermal bones, which play an important role in detecting moving food objects and other elements in the aquatic environment (Kotegov, 2024). Additionally, the quantity of primary neuromasts remains constant with age, in contrast to secondary neuromasts. The number of canal openings is readily accessible for direct counting on both the right and left sides of the head bones (Zinoviev and Mandritsa, 2003).

The influence of environmental stress on the stability of ontogenetic processes often leads to phenotypic changes in organisms (Nikol'skii, 1974; Shilov, 1984; Lajus et al., 2019; Nunes and Souto, 2022). The asymmetry of bilateral traits is typically a manifestation of individuals' inability to develop normally under stress (Zakharov, 1981, 1987; Nikol'skii, 1986; Makoedov and Korotaeva, 1999). One example of this asymmetry is fluctuating asymmetry, which is a macroscopic phenomenon that occurs randomly and independently on both the left and right sides of the body. Fluctuating asymmetry (FA) is a deviation from strict bilateral symmetry (Zakharov, 1987; Zinoviev and Mandritsa, 2003; Yankova, 2006; Peskova and Khoroshenkov, 2013; Romanov, 2019).

Consequently, the morphological characteristics of carp populations are significantly influenced by the state of the ecosystem, which is determined by the hydrological regime and hydrochemical parameters. The level of environmental stress and population health is denoted by fluctuating asymmetry. For the first time, a comprehensive analysis of hydrochemical, morphometric, and FA data was conducted for gibel carp populations that inhabit four hydrologically distinct water bodies in the Tura River floodplain, Ob-Irtysh basin, Western Siberia. The purpose of this study is to evaluate the morphometric characteristics and fluctuating asymmetry of *C. gibelio* populations that inhabit hydrologically diverse water bodies in the southern region of Western Siberia. The objectives are to conduct a hydrochemical analysis of surface water from four water bodies that have been studied, measure morphological (meristic) characteristics for gibel carp samples, perform a cluster analysis with an assessment of the community of populations based on morphological indicators, and control the fluctuating asymmetry indicators as an ecological marker of the state of the water bodies.

Materials and Methods

The water bodies with different hydrologic characteristics are studied, which are part of the Ob-Irtysh basin, Western Siberia: the Tura River, the Nitsa River (left tributary of the Tura River), Lake Krivoye (an oxbow lake of the Tura River, periodically connecting with it), and Lake Sredneye (isolated, not connected to the Tura River for more than 70 years). The geographic coordinates of the analysis points are as follows: Tura River - 57º65′82.1″N, 64º36′06.9."E; Nitsa River - 57º51′93.6″N, 64º43′51.7"E; Lake Krivoye - 57º53′87.7″N, 64º51′20.2"E; Lake Sredneye - 57°38'15.9"N, 64°28'50.9"E.

The Tura River flows through the Sverdlovsk and Tyumen regions of Russia and is a left tributary of the Tobol River (Ob-Irtysh basin). The length of this river is 1030 km, and the area of the basin covers up to 80400 km². It is navigable for 635 km starting from the mouth. Along the Tura River, there are three reservoirs, located near the cities of Verkhoturye, Turinsk, and Tyumen. The mouth of the river is situated at an altitude of 42 m above sea level, and the mean water flow is 202.7 m³/s. In the water regime of the reservoir during the year, four distinct phases can be distinguished: (1) high spring flood, (2) summer-autumn low water, characterized by the lowest water level, usually from August to October, (3) small floods in the fall, occurring during rains, and (4) stable winter low water, lasting on average from 140 to 160 days. The higher aquatic vegetation along the coastline is represented mainly by the following species: *Typha* *latifolia* (Linnaeus, 1753), *Potamogeton natans* (L., 1753), *Phragmites australis* (L., 1753), *Nuphar lutea* (L., 1753), *Carex* (L., 1753), and *Elodea canadensis* (Michx, 1830). The following are the representatives of ichthyofauna in the Tura River: *Esox lucius* (Linnaeus, 1758), *Perca fluviatilis* (L., 1758), *Abramis brama* (L., 1758), *Leuciscus idus* (L., 1758), *Rutilus rutilus* (L., 1758), *Leuciscus baicalensis* (Dybowskii, 1874), *Carassius carassius* (L., 1758), *C. gibelio*, *Tinca tinca* (L., 1758), *Gobio cynocephalus* (Dybowski, 1869), *Gymnocephalus cernuus* (L., 1758), *Sander lucioperca* (L., 1758), *Perccottus glenii* (Dybowski, 1877), *Phoxinus phoxinus* (L., 1758), *Lota lota* (L., 1758), and *Acipenser ruthenus* (Brandt, 1833).

The Nitsa River is formed by the junction of the Neyva and Rezh rivers and flows into the Tura River near the village of Ust-Nitsinskoye (Russia, Sverdlovsk Region). The Nitsa River is 262 km long, and its basin covers 22,300 km². The river flows through the West Siberian Plain and has a mixed hydrological regime, with snow as the primary source. The Nitsa freezes in late October-early November and breaks up in late April. The river is not navigable, and its flow is slow, at approximately 0.7 m/s. High vegetation is observed on the riverbanks during the summer in areas where backwaters have formed, with a species composition comparable to that of the Tura River. The following species form the Ichthyofauna of the Nitsa River: *E. lucius, P. fluviatilis, A. brama, L. idus, R. rutilus, A. alburnus, L. baicalensis, C. carassius, C. gibelio, T. tinca, G. cynocephalus, G. cernuus, S. lucioperca*, and *P. glenii*.

Lake Krivoye is an oxbow lake located in the catchment area of the Tura River. Almost every year during the spring floods, Lake Krivoye connects to the river system, indicating its close dependence on river water levels. The lake's surface area is approximately 3,733.5 hectares, and the water depth ranges from 1.5 to 2 meters, with a maximum depth of 3.8 meters. The lake shores are densely covered with aquatic vegetation; the bottom consists mainly of sand and silt. In winter, the lake is frozen; the following species permanently inhabit it: *C. gibelio, C. carassius, R. percnurus*, and *P. glenii*. During the spring-summer flood, *E. lucius*, *R. rutilus*, and *P. fluviatilis* can enter the lake for the fish-growing period.

Lake Sredneye is a round taiga reservoir located 5.5 km from the village of Turinskaya Sloboda (Russia, Sverdlovsk region). The reservoir is surrounded by mixed forest along the shoreline, and is swampy on the western side. The area of the water surface of the lake is 1.07 km², and the depth to the bottom sediments reaches 1.25 m. The reservoir is eutrophic, of the suffocation type. The following species represent the ichthyofauna of Lake Sredneye: *C. gibelio*, *C. carassius*, *R. percnurus*, *P. glenii*, and *P. fluviatilis*. During the research, eutrophication was observed throughout the lake. The following species of higher aquatic plants were especially abundant: *T. latifolia*, *N. lutea*, *L. minor*, and *P. natans*. Additionally, during the research, intensive reproduction of the blue-green alga *Aphanizomenon flos-aquae* was observed in the water.

Hydrochemical analysis was conducted in the laboratory of the Tyumen branch of the Federal State Budget Scientific Institution "Russian Federal Research Institute of Fisheries and Oceanography" (Tyumen) to evaluate the habitat of fish populations at the site of material collection. The primary source of water samples was the surface of water bodies during the summer (Alekin, 1970). Surface water quality was characterized according to Alekin (1970).

The ichthyological material was collected from 2016 to 2019 using standard, widely used, and tested field and office analysis methods (Pravdin, 1966; Lakin, 1980; Zinoviev and Mandritsa, 2003; Ministry of Natural Resources of the Russian Federation, 2003). The fish samples that were analyzed were as follows: 100 specimens from Lake Sredneye, 50 specimens from Lake Krivoye (2016), 100 specimens from Lake Krivoye (2018), 50 specimens from River Tura, and 100 specimens from River Nitsa.

In this study, 19 meristic characters were analyzed for each population, including: the number of spiny rays in the dorsal fin (Ds); branched rays in the dorsal fin (Db); spiny rays in the anal fin (As); the number of branched rays in the anal fin (Ab); rakers on the first gill arch (Sp.br.); perforated scales (l.l.); rays in the

Table 1. Scale to assess deviations of fish from normal conditions.

Point	The value of the fish development stability index (FAPT)	Water quality
1	Up to 0.30	Conditionally normal
2	0.30-0.34	Initial (minor) deviations from the norm
3	0.35-0.39	Average level of deviations from the norm
4	0.40-0.44	Significant deviations from the norm
5	0.44 and above	Critical condition

Source: Ministry of Natural Resources of the Russian Federation, 2003.

pectoral fin (Pb); rays in the pelvic fin (Vb); total number of scales in the lateral line (l.l.total); number of rows of scales above the lateral line (l.l.above) and below the lateral line – (l.l.below); total number of vertebrae in the vertebral column (Vo); number of vertebrae in the truncal region (Va), in the transitional region (Vi) and in the caudal region including the urostyle (Vc+ct); number of single-row pharyngeal teeth (dentes); also the SSC, located on three paired bones of the head - praeoperculum (pop), dentale (dn), and frontale (f) (Pravdin, 1966; Makoedov, 1999; Zinoviev and Mandritsa, 2003; Yadrenkina et al., 2005).

Statistical processing included calculating the mean, standard deviation (σ), error of the mean (m_X), and coefficient of variation (CV) (Lakin, 1980). Mathematical analysis was performed using Excel 2016. The Mann–Whitney U test ($P \leq 0.05$) was used to compare means because the meristic features are nonparametric and non-normally distributed. The Kolmogorov-Smirnov was employed to control for the normality of feature distribution. The assessment of the community of populations based on meristic features was performed using WPGMA (Weighted Pair Group Method with Arithmetic Mean) cluster analysis with Euclidean distance as the metric, and visualization was implemented in the Python interpreter using PyCharm Community Edition 2024.1 (Fig. 1).

To assess the fluctuating asymmetry, 10 bilateral features were used, such as: the number of rakers on the first gill arch (Sp.br.), perforated scales (l.l.); rays in the pectoral fin (Pb), rays in the pelvic fin (Vb); total number of scales in the lateral line (l.l.total), number of rows of scales above the lateral line (l.l.above) and below the lateral line – (l.l.below); SSC on the praeoperculum (pop), SSC on the dentale (dn), and SSC on the parientale (p) (Pravdin, 1966; Zinoviev and Mandritsa, 2003; Ministry of Natural Resources of the Russian Federation, 2003). The stability of gibel carp development was assessed by the dispersion index of fluctuating asymmetry using the formula of $\sigma_d^2 = \Sigma$ (d l-r - Md)2 / (n-1) (4), where σ_d^2 = dispersion index of FA, Md = average value of deviations from symmetry in a sample, d = amount of asymmetry of each individual, and n = number of individuals in the sample (Zakharov, 1987; Yankova, 2006).

To assess the stability of fish development, the frequency of asymmetric manifestations per trait (FAPT) was used as an indicator. FAPT is determined by the ratio of the number of characteristics that exhibit asymmetry to the total number of traits taken into account. The statistical significance of differences between samples in the value of the integral indicator of developmental stability (IIDS) is determined by Student's *t*-test. The degree of deviation from the norm in the environment is determined by the fluctuating asymmetry of the most numerous individuals in the area. It is evaluated on a five-point scale, which is based on integral indicators of developmental stability (Table 1) (Ministry of Natural Resources of the Russian Federation, 2003; Peskova and Khoroshenkov, 2013). All applicable international, national, and institutional guidelines for the care and use of animals were followed during the study.

Results

The hydrochemical characteristics of water at sampling sites used for the collection of ichthyological material are presented in Table 2. According to the results, the water in the Tura River is classified by

Table 2. Hadrochemical characteristics of water at sites for the collection of ichthyological material.

Name of components, measurement unit	**Tura river**	**Nitsa river**	**Lake Krivoye (2018)**	**Lake Sredneye**	**Regulatory document**
pH value	6,24	8,7	6,38	6,52	РД 52.24.495-2017
Ammonium nitrogen, mg/dm^3	1,00	0,14	0,33	0,61	ПНД Ф 14.1:2:4.262-10
Nitrite nitrogen, mg/dm^3	0,009	<0,02	<0,006	<0,006	ПНД Ф 14.1:2:4.3-95
Nitrate nitrogen, mg/dm^3	0,24	0,15	<0,10	0,15	ПНД Ф 14.1:2:4.4-95
Phosphate ion, mg/dm^3	0,21	0,31	0,16	0,60	ПНД Ф 14.1:2:4.112-97
Total Iron, mg/dm^3	1,09	0,62	0,86	1,74	ПНД Ф 14.1:2:4.50-96
BOD_5, mgO_2/dm^3	1,40	4,7	2,70	3,85	ПНД Ф 14.1:2:3:4.123-97
Dissolved oxygen, mg/dm^3	4,80	10,74	11,00	15,30	РД 52.24.419-2019
Permanganate oxidizability, mg/dm^3	25,13	9,9	11,54	21,76	ПНД Ф 14.1:24.154-99
Total hardness, mg/dm^3	1,20	3,78	1,50	1,30	ПНД Ф 14.1:2:3.98-97
Hydrocarbonate, mg/dm^3	61,02	183,0	97,63	109,84	РД 52.24.493-2020
Sulphate-ion, mg/dm^3	4,80	8,64	3,84	4,80	ПНД Ф 14.1:2:3.108-97
Chloride ion, mg/dm^3	<10,0 (8,51)	32,2	<10,0 (7,50)	<10,0 (4,25)	ПНД Ф 14.1:2:3.96-97
Calcium, mg/dm^3	16,03	41,6	16,03	18,04	РД 52.24.403-2018
Magnesium, mg/dm^3	4,86	20,7	8,61	4,86	Расчетный метод
Sodium + potassium, mg/dm^3	3,50	22,7	47,51	31,51	Расчетный метод
Sum of ions, mg/dm^3	115,74	308,84	226,32	141,79	Расчетный метод
Color, ⁰ color	115	73	40	100	РД 52.24.497-2019

Note: ПНД Ф = Federal Environmental Regulations (Russia); РД = Governing Documents (Russia).

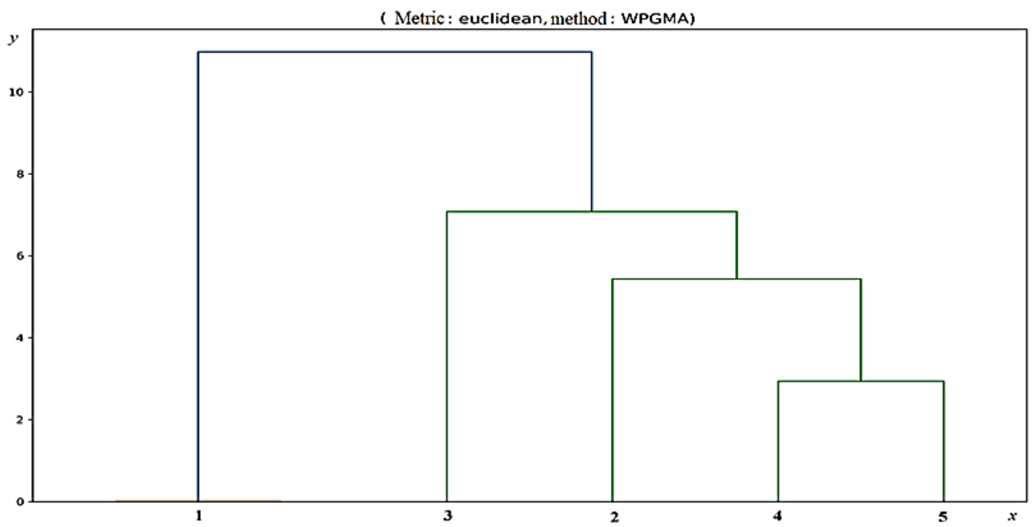

Figure 1. Dendrogram of similarity of meristic traits of gibel carp in the studied water bodies, where: x-axis – water bodies (1 – Lake Sredneye, 2 – Lake Krivoye (2016), 3 – Lake Krivoye (2018), 4 – Tura River, and 5 – Nitsa River); y-axis – union distance.

chemical composition as follows: hydrocarbonate class, calcium group, type I (low mineralization), and a hydrogen ion index (pH) of 6.24 (neutral). A slight increase in permanganate oxidizability in the Tura River (25.13 mg/dm^3) and a high color index (115⁰) may be due to increased vegetation, decomposition of organic matter, and possibly runoff from agricultural lands. A low BOD_5 level (less than 2 mg O_2/dm^3) indicates a moderate amount of organic matter in the water; the ecosystem is likely not experiencing significant stress from pollution. Ammonium nitrogen in the Tura River water was 1.0 mg/dm^3, which characterizes this body of water as mesotrophic.

The water in the Nitsa River is classified as hydrocarbonate, calcium group, type II (with low to moderate mineralization). Samples from this river showed a slight increase in pH (up to 8.7) and BOD_5, values that were higher than those observed in other bodies of water studied. This likely reflects the presence of active microflora, organic matter, and

Table 3. Meristic characteristics of gibel carp from the studied water bodies.

Trait	Tura River		Nitsa River		Lake Krivoye (2016)		Lake Krivoye (2018)		Lake Sredneye	
	X± mX	CV	X± mX	CV	X± mX	CV	X± mX	CV	X± mX	CV
Sp.br.	46.8±0.90	13.8	47.9±0.40	8.3	48.4±0.34	6.9	48.9±0.91	6.0	44.8±0.48	10.6
l.l.total	32.3±0.18	3.9	31.5±0.09	2.7	31.6±0.10	3.1	31.5±0.13	2.8	32.3±0.10	3.0
l.l.	30.6±0.16	3.8	30.1±0.15	4.9	30.2±0.13	4.3	30.2±0.14	3.4	31.0±0.10	3.3
l.l.above	6.0±0.03	3.4	5.8±0.05	7.9	5.7±0.05	8.3	6.0±0.06	7.5	5.3±0.05	8.8
l.l.below	5.9±0.02	2.4	5.8±0.05	8.0	6.1±0.05	7.9	5.7±0.06	7.9	5.5±0.05	9.1
Ds	4.4±0.07	11.3	4.3±0.05	11.7	-	-	4.4±0.07	12.1	4.3±0.05	10.9
Db	19.9±0.12	4.9	18.1±0.10	5.3	-	-	18.1±0.14	5.6	17.9±0.12	4.9
As	3.3±0.07	15.1	3.1±0.03	10.5	-	-	3.2±0.05	12.2	3.1±0.03	10.8
Ab	6.1±0.05	5.4	6.0±0.01	2.3	-	-	6.0±0.02	2.3	6.0±0.00	0.0
Pb	17.6±0.17	6.8	17.5±0.11	6.3	16.9±0.12	6.9	17.3±0.16	6.6	17.8±0.12	6.8
Vb	9.9±0.07	5.0	9.8±0.04	4.6	8.8±0.05	5.3	8.9±0.05	4.3	10.1±0.03	3.3
Vo	32.8±0.11	2.5	31.8±0.08	2.6	30.6±0.10	3.4	32.0±0.14	3.2	32.6±0.13	4.0
Va	15.7±0.08	3.6	14.6±0.11	7.5	13.7±0.08	6.2	14.3±0.12	6.1	14.5±0.11	7.5
Vi	3.7±0.10	18.6	3.7±0.06	17.0	3.3±0.08	24.2	3.5±0.09	17.6	3.4±0.06	16.7
Vc+ ct	13.4±0.10	5.2	13.6±0.07	5.0	14.1±0.09	6.2	14.2±0.10	4.8	14.6±0.06	4.2
dentes	4.0±0.00	0.0	4.0±0.00	0.0	4.0±0.00	0.0	4.0±0.00	0.0	4.0±0.00	0.0
pop	11.0±0.12	7.7	10.4±0.10	9.4	9.4±0.11	11.7	10.2±0.17	11.7	10.8±0.13	8.6
dn	6.1±0.07	7.6	6.3±0.05	7.5	6.1±0.05	7.7	6.1±0.10	11.3	6.6±0.06	9.5
f	6.2±0.11	12.4	5.7±0.08	13.7	6.2±0.11	18.4	7.3±0.21	20.6	6.1±0.08	12.4

Note: mX = error of mean, CV = coefficient of variation, "-" = data are not available.

vegetation in the water during the summer.

A hydrochemical analysis of the water from Lake Krivoye (2018) identified it as belonging to the hydrocarbonate class, sodium group, type I, and neutral. This reservoir has the highest sodium and potassium ion concentrations (47.51 mg/dm³), but overall, the total ion content indicates low mineralization. These ions can enter the reservoir from natural sources, such as groundwater, minerals, and soils, as well as from agricultural fertilizers that contain sodium and potassium. The BOD_5 and ammonium nitrogen values (2.70 mg O_2/dm³ and 0.33 mg/dm³, respectively) in this reservoir are second only to those in Lake Sredneye (3.85 mg O_2/dm³ and 0.61 mg/dm³), which may reflect stagnation in the lake ecosystem.

The water quality classification of Lake Sredneye is as follows: hydrocarbonate class, sodium group, type I (low mineralization), pH = 6.52 (neutral). Slight excesses of MACs for fishery water bodies were detected for five parameters: BOD_5, dissolved oxygen, phosphate ion, ammonium nitrogen, and total iron. During the summer growing season, active plant growth and rising temperatures drive increased decomposition of organic matter, potentially raising concentrations of the above parameters. This may also indicate additional oxidation and a decrease in dissolved oxygen levels. The detected excesses of MACs for these parameters may result from the combined effects of organic matter in the water and eutrophication, and may also indicate suffocation in the reservoir.

Anthropogenic impacts at the collection sites are primarily related to agriculture and the location of rural settlements. Nevertheless, the Tura River is the most heavily impacted by human activity throughout its entire length, whereas its tributary, the Nitsa River, is less urbanized. In general, despite its low mineralization and BOD5, the Tura River's elevated permanganate oxidizability and color necessitate analysis, as they may indicate specific environmental issues, particularly during the summer. The Krivoye and Sredneye lakes are characterized by suffocation. In Lake Sredneye (hydrologically isolated), excesses of MPCs for five parameters (BOD_5, dissolved oxygen, phosphate ion, ammonium nitrogen, and total

Table 4. Significant difference in meristic characteristics of gibel carp in the studied samples.

Trait	The value of the Mann-Whitney U-test for pairwise comparison of samples									
	T-N	T-C	T-K16	T-K18	S-N	S-K16	S-K18	N-K16	N-K18	K16-K18
Sp.br.	0.745	1.662	0.946	0.000***	2.000	1.998	0.732	0.673	1.100	1.861
l.l.total	2.000	1.748	2.000	0.000***	0.000***	0.005**	0.019*	0.353	1.949	1.195
l.l.	2.000	2.000	2.000	2.000	0.000***	0.015*	2.000	1.147	2.000	2.000
l.l.above	1.997	2.000	2.000	0.025*	2.000	2.000	2.000	1.982	2.000	2.000
l.l.below	1.996	2.000	1.939	0.000***	2.000	2.000	2.000	0.492	2.000	0.008**
Ds	2.000	2.000	-	0.070	1.974	-	2.000	-	2.000	-
Db	1.998	1.832	-	0.001***	1.704	-	1.990	-	2.000	-
As	2.000	1.999	-	0.157	1.998	-	2.000	-	2.000	-
Ab	2.000	2.000	-	0.113	1.984	-	2.000	-	2.000	-
Pb	1.990	0.782	2.000	0.000***	0.025*	0.000***	0.068	2.000	1.679	1.994
Vb	1.985	1.612	2.000	0.000***	0.014*	0.000***	0.000***	2.000	0.000**	1.939
Vo	2.000	2.000	2.000	0.000***	0.042*	0.000***	1.160	2.000	1.865	2.000
Va	2.000	2.000	2.000	0.000***	2.000	0.000***	2.000	2.000	0.073	2.000
Vi	2.000	2.000	2.000	0.063	2.000	1.970	2.000	2.000	2.000	2.000
Vc+ ct	1.960	0.000**	0.155	1.943	0.000***	0.002**	1.117	0.006**	2.000	2.000
dentes	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
pop	2.000	1.986	2.000	0.000***	0.203	0.000***	0.281	2.000	1.972	2.000
dn	2.000	0.833	2.000	0.075	0.009**	0.001***	0.487	2.000	1.981	2.000
f	2.000	2.000	2.000	1.945	1.185	2.000	2.000	1.724	2.000	2.000

Note: T = Tura River. N = Nitsa River. S = Lake Sredneye. K16 = Lake Krivoye (2016). K18 = Lake Krivoye (2018). "-" = data are not available. * - the differences are valid on 1st level of significance ($P≤0.05$). ** – the differences are valid on the 2nd level of significance ($P≤0.01$). *** - differences are valid at level 3 of significance ($P≤0.001$).

iron) detected may indeed be the result of the combined effects of organic matter in the water and eutrophication processes, resulting in low dissolved oxygen levels, which creates stressful conditions for ichthyofauna. For technical reasons, hydrochemical analysis of the water from Lake Krivoye was only conducted during the second gibel carp sample collection in 2018. Therefore, it is not possible to compare the 2016 and 2018 data.

The average values of meristic traits of the populations of gibel carp from the Tura River, the Nitsa River, Lake Krivoye (2016 and 2018), and Lake Sredneye are presented in Table 3. In the studied populations, the highest coefficient of variation was noted for the number of vertebrae in the transitional region (CV from 16.7 to 24.2%), for the number of seismosensory canals on the frontal bones (CV from 12.4 to 18.4%), as well as for the traits As (CV up to 15.1%), Sp.br. (CV up to 13.8%), Ds (CV up to 12.1%) and pop (CV up to 11.7%) characterize the average variability of these morphological traits. The least variable and stable trait for the gibel carp is the number of single-row pharyngeal teeth (CV = 0%). The remaining 12 meristic traits exhibit low variability (less than 10%) and can serve as reliable bioindicators (Kokorina and Tatarintsev, 2010). Overall, the main meristic traits of gibel carp populations in the studied water bodies fall within the species' range of variability (Yankova, 2006).

The results of a pairwise comparison of meristic values of samples from the studied water bodies are presented in Table 4. The Tura River, the Nitsa River, and Lake Krivoye (2016), which are hydrologically interconnected, exhibited no significant differences in the meristic traits that were examined. The gibel carp sample from Lake Sredneye exhibited substantial differences in comparison to the other three bodies of water. The Nitsa River (for 7 traits) and Lake Sredneye and Lake Krivoye (2016) revealed the most significant differences at varying significance levels. These morphological features of the gibel carp population in Lake Sredneye may reflect hydrological

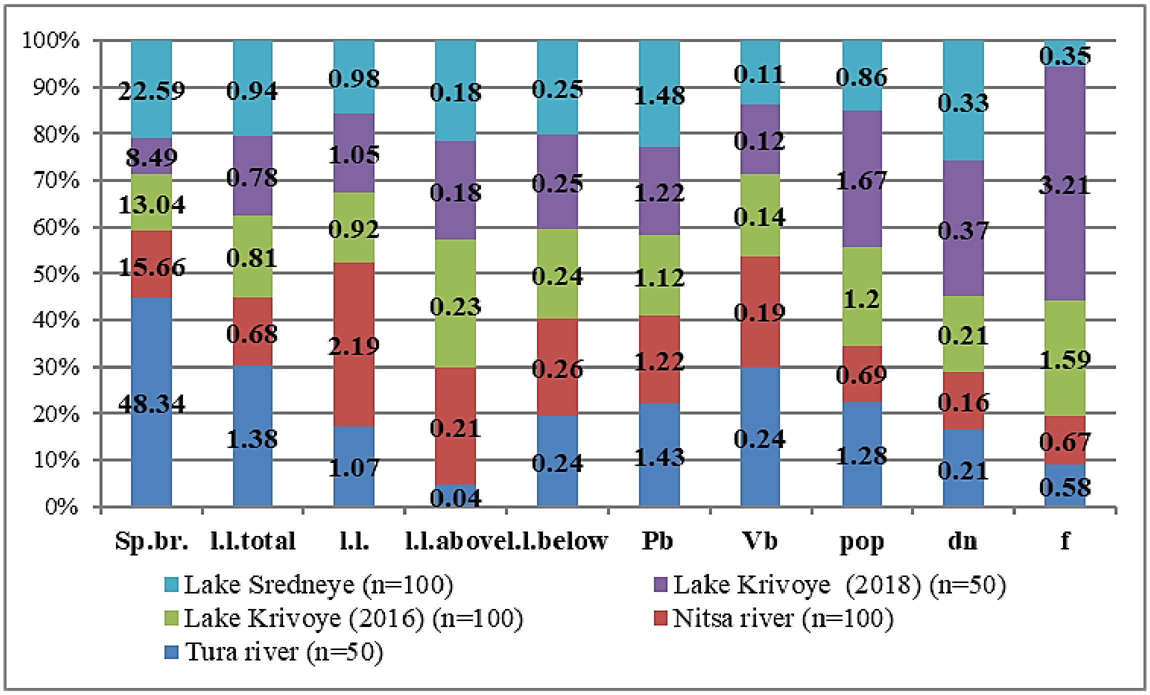

Figure 2. The dispersion proportion of fluctuating asymmetry per trait in samples of gibel carp from the studied reservoirs

isolation and the dependence of morphology on environmental factors, including hydrochemical parameters. A high proportion of significant differences (across 10 traits) was also observed between the Tura–Krivoye pair (2018), likely indicating environmental changes in Lake Krivoye over the two-year period.

Among the water bodies under investigation, thirteen meristic traits were identified as the most informative for assessing the reliability of differences between gibel carp populations. Of these, the most frequently detected differences were in Vb (5 times), l.l.total (4 times), Vc+ ct (4 times), Pb, and Vo (3 times each, respectively). No differences were found in six traits, including the number of spiny rays in the dorsal fin, spiny rays in the anal fin, branched rays in the anal fin, the number of vertebrae in the transitional region, the number of single-row pharyngeal teeth, and the number of SSCs on the frontal bones.

The results of cluster analysis for the average values of 19 meristic traits are presented in Figure 1. The samples were categorized into three clusters: (1) the sample from Lake Sredneye, (2) the combined samples from Lake Krivoye (2016) and the Tura River, and the Nitsa River, and (3) the sample from Lake Krivoye (2018). Local populations of gibel carp in the Tura River, the Nitsa River, and Lake Krivoye form a common cluster, reflecting the connectivity among the water bodies and possible gibel carp migration. The sample from Lake Sredneye again showed isolation, consistent with both the reservoir's hydrology and the morphometric results. The sample from Lake Krivoye (2018) was isolated, which may confirm morphological changes that have occurred in the reservoir over two years. Overall, the distribution of gibel carp populations in the cluster analysis dendrogram reflects the intensity of gene pool exchange among the studied populations.

The results of the dispersion analysis of fluctuating asymmetry for 10 meristic traits in gibel carp samples from reservoirs with different hydrological types are presented in Figure 2. The dispersion values for the gill raker count were the highest across all samples, with values of 48.34 (Tura River), 22.59 (Lake Sredneye), 15.66 (Nitsa River), 13.04 (Lake Krivoye, 2016), and 8.49 (Lake Krivoye, 2018). The high dispersion of gill raker number in gibel carp indicates that the development of this trait within the population is highly variable and that the population inhabits unfavorable conditions. It is well established that gibel

Table 5. Frequency of asymmetric manifestation of traits in representatives of gibel carp of different ages from the studied reservoirs.

Reservoir	Age	The number of individuals in the sample, asymmetric in the number of traits (%)	Average value FAPT ± mx	Point
Lake Sredneye	4+ 5+ 6+ 7+	37 44 16 3	0.40±0.07	4
Lake Krivoye (2016)	2+ 3+ 4+ 5+ 6+ 7+ 8+	1 41 41 12 2 1 2	0.37±0.06	3
Lake Krivoye (2018)	3+ 4+ 5+ 6+ 7+ 8+	2 8 42 32 14 2	0.41±0.07	4
Tura river	5+ 6+ 7+ 8+	14 34 44 8	0.35±0.06	3
Nitsa river	5+ 6+ 7+ 8+	13 52 27 8	0.24±0.04	1

Note: mX - error of mean. Source: compiled by authors.

carp, owing to its biological characteristics, can hybridize with other cyprinids (Goriunova et al., 2017). The Sp.br. trait is genetically variable, and hybrid forms of gibel carp, for example, with crucian carp, in the wild can have intermediate values of 40 to 50 (Goriunova et al., 2017), which in turn can significantly influence the data dispersion. Therefore, additional research, including genetic analysis, is recommended.

Among the traits related to fish scale covering, the most significant proportion of dispersion (35%) for the total number of scales in the lateral line was observed in the Nitsa River (2.19). Across all samples, the number of scales below the lateral line was approximately 20%. For the 10 traits, the number of rays in the pelvic fins exhibited the lowest variance, ranging from 0.11 (Lake Sredneye) to 0.24 (Tura River). The Tura River exhibited the highest average dispersion among the samples, with the highest proportion of each trait occurring within the range of values for the number of gill rakers. In terms of overall FA dispersion in the sample, Lake Sredneye is ranked second, with the Sp.br trait contributing the most. The lowest FA dispersion was observed in the Lake Krivoye sample in 2016 and 2018, ranging from 17.34 to 19.5. In this reservoir, an increase in the number of SSCs on the frontal bones of the head was noted, which may indicate a deterioration in the habitat of gibel carp in this reservoir. Reliable differences in dispersion values (according to Fisher's ratio test) were noted in all pairs of lakes for meristic parameters (Fig. 3).

Significant differences in FA variance for three meristic traits were observed in pairwise comparisons of Lake Sredneye with Lake Krivoye (2016 and 2018) and between the Nitsa River and Lake Krivoye (2016). The number of differences between the Tura River and the Nitsa River and Lake Krivoye (2018) increased by 1-2 traits compared to the 2016 sample from this water body. The greatest number of differences is observed between the Tura River and Lake Sredneye, emphasizing the similarity of the results with the morphological and cluster analysis of the samples. The more stable and genetically determined a trait is,

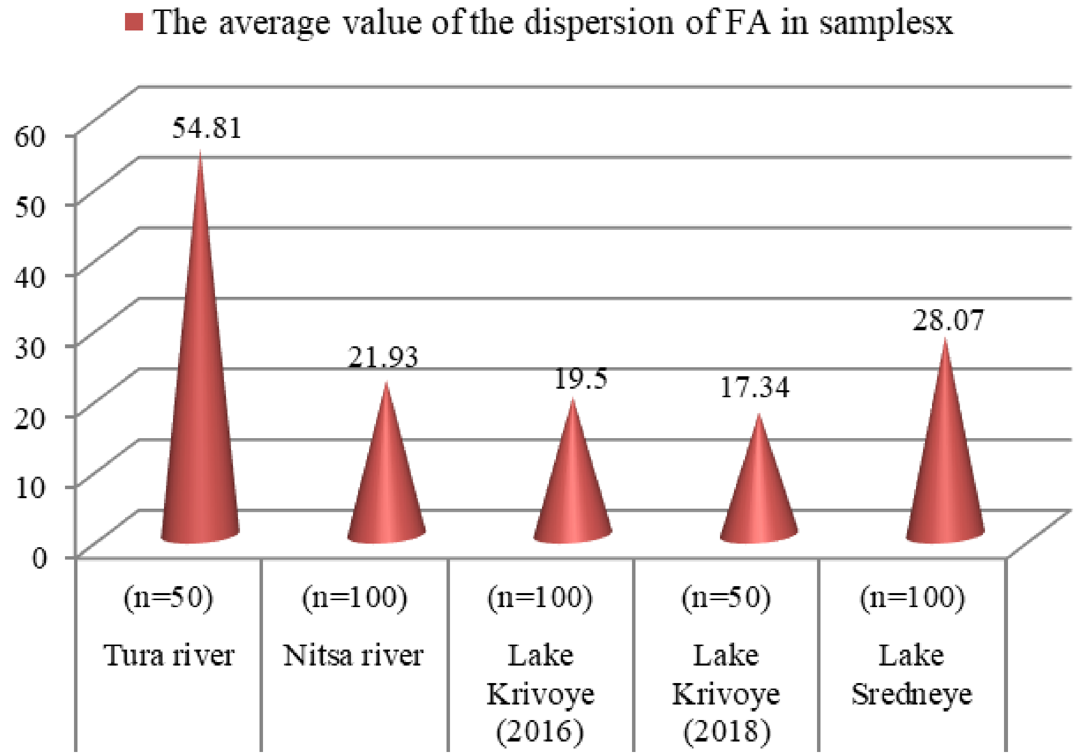

Figure 3. The average value of the dispersion of fluctuating asymmetry in the studied samples.

the more it is influenced by FA, and conversely (Zakharov, 1982).

The results of the assessment of gibel carp homeostasis from four water bodies using the FAPT indicator are presented in Table 4. The age group of 5 and older exhibited the highest percentage of individuals with asymmetric traits in Lake Sredneye (44%). In the Tura and Nitsa rivers, the highest values for the number of asymmetric traits per individual (78% and 79%) were observed in gibel carp aged 6+ and 7+, respectively. The age groups 3+ and 4+ exhibited the highest proportion of asymmetric individuals in Lake Krivoye (2016), at 82%. Two years later, in 2018, in the sample from this reservoir, the highest proportion of asymmetric individuals was observed in the 5+ and 6+ age groups (74%), which is in good agreement and confirms the quality of the measurements.

The highest environmental assessment score of 4, according to the FAPT, for the gibel carp was recorded in Lake Sredneye and Lake Krivoye, which indicates significant deviation from the norm and corroborates the results of hydrochemistry and morphometry. Based on the investigation's findings, the Tura River is classified as having an average level of pollution. The Nitsa River was the most favorable water body, as the gibel carp population achieved an FAPT score of 1, indicating a conditionally normal habitat for the species. The obtained data are consistent with hydrological, hydrochemical, and morphological data and are corroborated by the literature (Zinoviev and Mandritsa, 2003; Yankova, 2006; Peskova and Khoroshenkov, 2013; Nunes and Souto, 2022; Kotegov, 2024).

In general, the analysis of fluctuating asymmetry indices in gibel carp populations demonstrated that developmental stability decreased across the lakes due to deteriorating oxygen conditions and increasing anthropogenic impacts. Based on its biological characteristics, gibel carp is remarkably tolerant of low oxygen levels and is not particularly demanding in terms of habitat conditions (Fagernes et al., 2017). Nevertheless, the level of comfort in water bodies varies, and the fluctuating asymmetry index indicates even minor disruptions in developmental stability in both the local population as a whole and individual

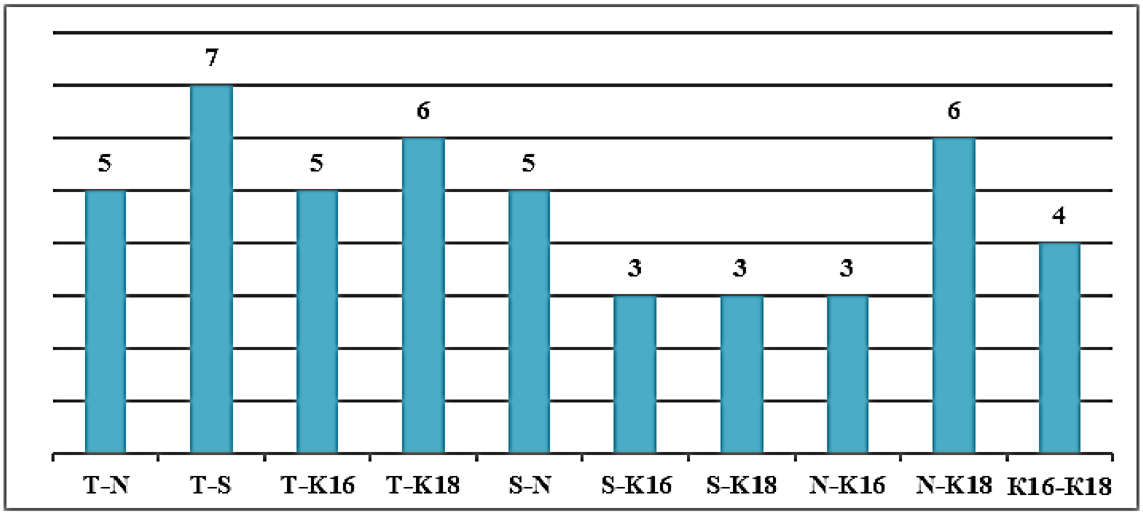

Figure 4. The number of reliable differences in the variance of fluctuating asymmetry of bilateral traits between the studied samples, where T is the Tura River, N is the Nitsa River, S is Lake Sredneye, K16 is Lake Krivoye (2016), and K18 is Lake Krivoye (2018).

groups (Yankova, 2006; Kotegov, 2015).

Discussions

The hydrochemical characteristics of water bodies are influenced by hydrological isolation, which in turn affects the ecological and biological characteristics of organisms. Rivers' chemical composition depends on the seasonality of the water they receive from various sources. Rapid water turnover is ensured by river flow, which allows temporary effects on the species inhabiting it. Typically, lakes are supplied solely by inflowing water, which results in the accumulation of salts in drainless water bodies or the accumulation of organic matter in lakes with runoff.

There is a body of literature on the influence of abiotic factors on the development of various fish traits (Yankova, 2006; Jalili et al., 2015; Radkhah et al., 2017; Eagderi et al., 2020; Atta Mouludi-Saleh et al., 2020; Mouludi-Saleh and Eagderi, 2021; Kotegov, 2024). The most favorable environment for most fish is neutral (pH = 7). The oxygen threshold increases, and the respiration rate decreases as the pH shifts significantly toward acidic or alkaline conditions. The ionic composition of the water, oxygen regimen, and the presence of nitrogen, carbon dioxide, phosphates, and free carbon dioxide are also important for normal fish development (Vasilyevet al., 2013).

Hydrological isolation of water bodies implies that the hydrochemical characteristics of rivers and lakes differ, thereby affecting the ecological and biological characteristics of organisms. The hydrochemical data from the four water bodies under investigation illustrate the distinct characteristics of their hydrological isolation and their influence on fish biological traits. Gibel carp inhabit suitable habitats in the studied water bodies due to low environmental mineralization and neutrality. Nevertheless, the morphology of this species is influenced by the identified differences in hydrochemical parameters.

The Tura River in the study area is characterized by high color and increased permanganate oxidizability. These indicators are likely influenced by organic matter decomposition, agricultural runoff, and the proximity of populated areas. However, the low biochemical oxygen demand (BOD_5) indicates that this area is not in a critical condition. In contrast, the Nitsa River, which has a lower anthropogenic load, has a higher BOD_5 level. This may indicate the presence of organic matter and high microflora activity in the spring and summer. Water analyses from Lake Krivoye and Lake Sredneye revealed that the absence of water flow in these ecosystems can lead to ion accumulation, higher BOD5 values, and eutrophication. Recorded excesses of MAC for five hydrochemical parameters in Lake Sredneye highlight stressful habitat conditions for the gibel carp population, consistent with results from morphometric analysis and fluctuating asymmetry.

Meristic characteristics of the gibel carp population also showed substantial disparities among the investigated bodies of water, particularly between Lake Sredneye and the others. This apparent separation may be due to hydrological isolation and differences in environmental conditions, including oxygen levels and overall hydrochemistry. The detection of a high proportion of differences in meristic traits, such as gill-raker number, indicates high variability in conditions that are unsuitable for stable population development and warrants a comprehensive analysis, including genetic methods.

A common cluster of gibel carp populations from the Tura and Nitsa rivers and Lake Krivoye was identified by cluster analysis, supporting the inference that individuals may migrate among these bodies of water. At the same time, sampling from Lake Sredneye reinforces its isolation, underscoring the need for further research to elucidate the causes and consequences of morphological changes in this group.

The gibel carp is undemanding with respect to environmental conditions and, based on its biological characteristics, is remarkably tolerant of low oxygen levels (Fagernes et al., 2017). Conversely, the degree of comfort in water bodies continues to fluctuate, and the fluctuating asymmetry index indicates even minor disruptions in developmental stability in both the local population as a whole and individual groups (Yankova, 2006). In this study, FA analysis was performed on samples comprising 50 specimens (Tura River, Lake Krivoye, 2018) and 100 specimens (Lake Sredneye, Nitsa River, Lake Krivoye, 2016), which are sufficient for this study (Ministry of Natural Resources of the Russian Federation, 2003). Also, the number of analyzed traits (10 indicators) is presentable. Overall, examination of fluctuating asymmetry indicators in gibel carp populations indicated that developmental stability decreases in lakes as anthropogenic impacts increase and oxygen conditions deteriorate. The more stable and genetically determined a trait is, the more it is influenced by FA, and conversely (Zakharov, 1981; Vasilyeva and Vasilyev, 2005; Nunes and Souto, 2022; Kotegov, 2024).

The Nitsa River, as a body of water with relatively normal environmental conditions, plays an important role in maintaining the health of the gibel carp population in southern Western Siberia. Meanwhile, Lake Sredneye and Lake Krivoye require close monitoring and management to prevent further environmental degradation. These studies emphasize the importance of integrating hydrological, hydrochemical, and morphological data to understand ecosystem changes. It is advisable to conduct additional monitoring and assessment of water bodies and to develop any necessary measures to improve water quality.

Conclusion

A study of the hydrochemical and morphological characteristics of gibel carp populations in various water bodies in southern Western Siberia revealed significant differences attributable to hydrological isolation, chemical parameters, and anthropogenic impacts. The data collected enable us to draw several significant conclusions that may benefit both theoretical and practical applications. The study demonstrated a relationship between hydrological and hydrochemical conditions and the morphological traits of fish populations, underscoring the importance of an integrated approach to ecosystem research. The identified patterns deepen understanding of how environmental factors influence the biology and morphology of aquatic organisms and emphasize the need for further research. The data support the hypothesis that habitat modification by biotic and anthropogenic factors results in significant changes in organismal morphology. The study's results may be relevant to the development of strategies for the management and protection of aquatic bioresources. The identified environmental challenges in Lakes Sredneye and Krivoye (suffocation and exceeding MAC for hydrochemical parameters) require further monitoring and the development of ecosystem restoration measures. Furthermore, the use of additional genetic analyses may facilitate the understanding and investigation of adaptive modifications in populations exposed to adverse environmental conditions. This study can serve as a basis for further research on adaptive mechanisms, migration processes, and the influence of habitat on the morphological and genetic characteristics of carp populations, particularly *C. gibelio*, in reservoirs of Western Siberia.

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