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Morphological variability of Cyprinus carpio (Linnaeus, 1758) in water bodies of the Balkash-Alakol basin

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This article is the translation of the article "Morfologicheskaja izmenchivost' sazana Cyprinus carpio (Linnae-us, 1758) v vodoemah Balkash-Alakol'skogo bassejna [Морфологическая изменчивость сазана Cyprinus carpio (Linnaeus, 1758) в водоемах Балкаш-Алакольского бассейна]" published September 7, 2024.

ABSTRACT

The article presents the results of investigating the morphological variability of carp (Cypri-nus carpio Linnaeus, 1758) in three large reservoirs of the Balkash-Alakol Basin - Lake Bal-kash, Lake Alakol, and Kapchagay Reservoir. Morphological differences in several features (counting and plasticity) were found in three carp samples. The study included the examina-tion of 24 plastic (morphological) and 14 counting characters. The method of digital image processing (Morpho J) was applied to analyze the differences of the target fish species spec-imens by body shape. The application of the principal component analysis (PCA) method allowed determining the main loadings on the studied morphological traits of carp. The sta-tistically reliable differences revealed allow to confirm the formation of morphological changes in carp caused by the duration of adaptive radiation, environmental factors of water bodies and annual artificial stocking of young fish.

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1. Introduction

At present, the interest towards examining one of the fundamental scientific issues – biodiversity – is steadily growing, with the population approach particularly important in terms of biodiversity monitoring. The corresponding investigations are key for the populations experiencing significant anthropogenic pressures like fishing, artificial reproduction, etc. Yet, the population diversity in carp, one of the main commercial ichthyofauna species of Kazakhstan, has been examined insufficiently.

The data on the external body composition of carp (Cyprinus carpio) from different basins of Kazakhstan are presented in the publications (Sarmoldayeva et. al, 2017; Mamilov et. al, 2018; Kirichenko, 2019; Barakov, 2023). At the same time, no generalizing studies devoted to its intraspecific variability were conducted. It is commonly known that morphological variability is primarily stimulated by a set of factors in their turn determined by specific fish habitats (Dgebuadze, 2001; Bonina, 2008). Studies of fish morphology in different habitats are gaining attention. For example, a research of Neotropical fish morphology allowed identifying body shape differences. The spindleshaped body profile was found to be more characteristic of fish living in high stream flow conditions, as opposed to these inhabiting open areas with low stream flow (Langerhans et al., 2003). Researchers have considered phenotypic changes associated with flow regimes because the latter comprehensively affect aquatic ecosystems (Ashley et al., 2007; Nail et al., 2004). In addition to the factors above, diet and resource utilization also affect morphology, and as a result, alterations can occur within and between populations (Wainwright and Reilly, 1994).

In case of Kazakhstan, the freshwater ichthyofauna of the Balkash-Alakol Basin causes a particular concern due to the observed micro-evolutionary processes taking place as a result of water bodies' isolation (Mamilov, 2023). With their long history of formation within three reservoirs – Lake Balkash, Lake Alakol and the Kapchagay Reservoir – the carp populations are not an exception.

The beginning of carp introduction into the Balkash-Alakol Basin is considered to be the year of 1885 (Kasymbekov and Pazylbekov, 2020). During the subsequent period of 1964-1988, large-scale fish introduction efforts had led to the formation of commercial carp stocks in the Kapchagay Reservoir and Lake Alakol (Mitrofanov et al., 1992; Asylbekova et al., 2018).

Currently, commercial carp shoals have significantly shrunk, primarily due to IUU (illegal, unrecorded and unregulated) fishing mediated by biotic and abiotic factors (Pueppke et al., 2018). The study of external fish parameters against the background of transforming aquatic ecosystems renders an important basis for ichthyo-monitoring and is likewise necessary for observing micro-evolutionary processes (Popov, 2004; Abecia et al., 2022; Johansen et al., 2006; Ronan et al., 2019). In this regard, the present examination of morphological changes in carp from three main fishery reservoirs of the Balkash-Alakol Basin is highly relevant. The application of modern software has allowed expanding the theoretical and practical approached applied in ichthyo-monitoring studies. Such studies are aimed at identifying population disparities, determining the mechanisms of morphological changes and their relationship to habitat factors. Hence, the assessment of the qualitative population structure under the conditions of dynamically changing habitats in three aforementioned fishery reservoirs requires investigation of the phenotypic divergence of carp populations.

The main aim of this research was to compare external carp features in three reservoirs of South-Eastern Kazakhstan.

2. Materials and methods

The collection of samples for analyzing external carp characteristics was carried out in summer time (June-August 2022 and 2023). The sampling was conducted in Lake Balkash (Lat. 46°30.809'S; Lng. 74°29.728'W), Lake Alakol (Lat. 46°14.420'S; Lng. 81°26.022'W), and Kapchagay Reservoir (Lat. 43°49.273'S; Lng. 77°36.485'W). Fig. 1. below shows the sampling points at three target water bodies.

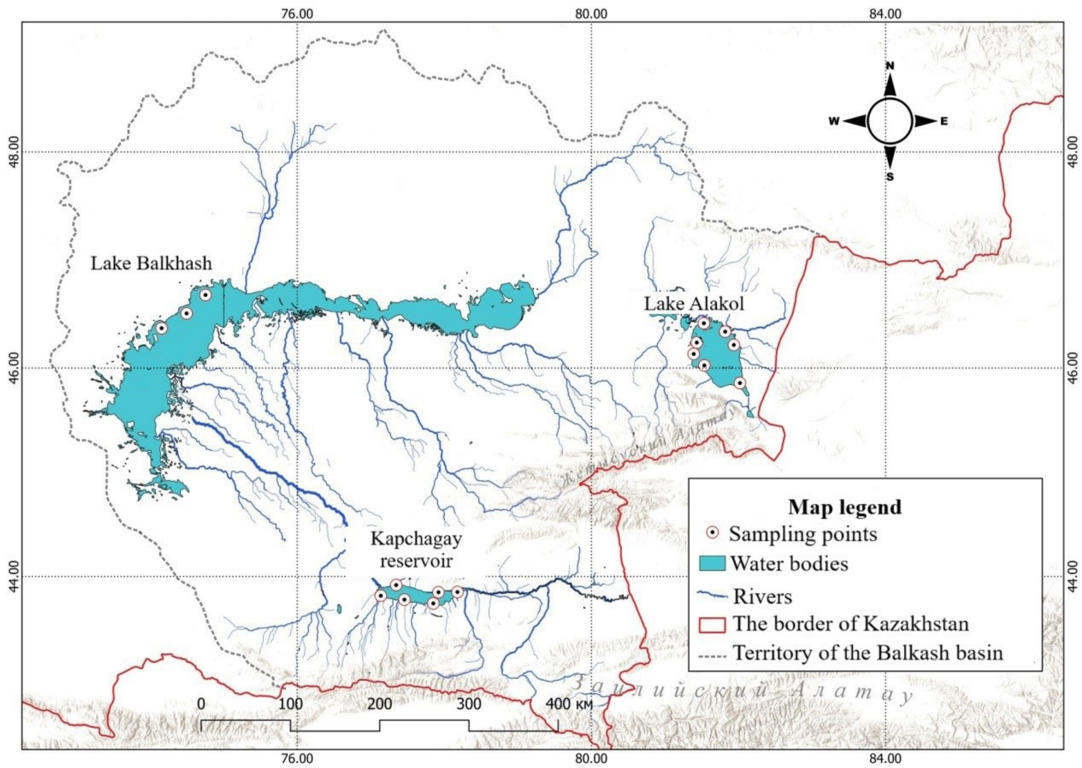

Fig. 1. Map of carp sampling points.

Lake Balkash is located in the Balkash-Alakol Basin in southeastern Kazakhstan. In terms of its orographic characteristics, the lake is 600 km long, and 9 to 19 km wide (eastern section) and up to 74 km wide (western section). The Ile River – entering the lake's western section – provides 73-80% of its total water inflow. The river originates in the Tien Shan Mountains and feeds mainly on glaciers, which causes daily and seasonal water level fluctuations. The period of active glacial melting is June-July (Shivareva et al., 2012).

The Kapchagay Reservoir is a large artificial water body created in 1970 on the Ile River originating in China and flowing into Lake Balkash (60 km north of Almaty). The reservoir's design capacity is 28.1 km^3, and the actual capacity is 14.0 km^3 (Starodubcev, 1986; Starodubcev et al., 1983). Today, the total length of the reservoir shoreline is 430 km, length – 187 km, width – 15-20 km, and water mirror area – 1,847 km^2.

Lake Alakol, the largest lake among the Alakol group of lakes, occupies the lower depression in the system. With the mean annual water level of 347.3 m ASL, its mirror area is 2,650 km^2 (and 2,696 km^2 with islands), and its volume is 58.56 bln m^3. The lake is drainless, has an irregular pear shape, and stretches from north-west to south-east. The water body is 104 km long and 52 km wide, with the shoreline length of 384 km, maximum depth of 54 m and mean depth of 22.1 m. Alakol's catchment area is 47,859 km^2 (Aktymbaeva et al., 2015; Filonets, 1981; Kenzhebekov et al., 2018).

Under this study, the external attributes of carp were analyzed according to the generally accepted methods of fishery research (Pravdin, 1966). Seventy (70) samples were subjected to morphological analysis. Prior to the analysis, the captured carp specimens were photographed to conduct additional image-based analysis. During the morphological analysis, fish were fixed on the right side.

Each sample underwent the morphometric analysis for 24 (twenty-four) plastic and 14 (fourteen) meristic (counting) characters. The scheme of plastic measurements is presented in Fig. 2.

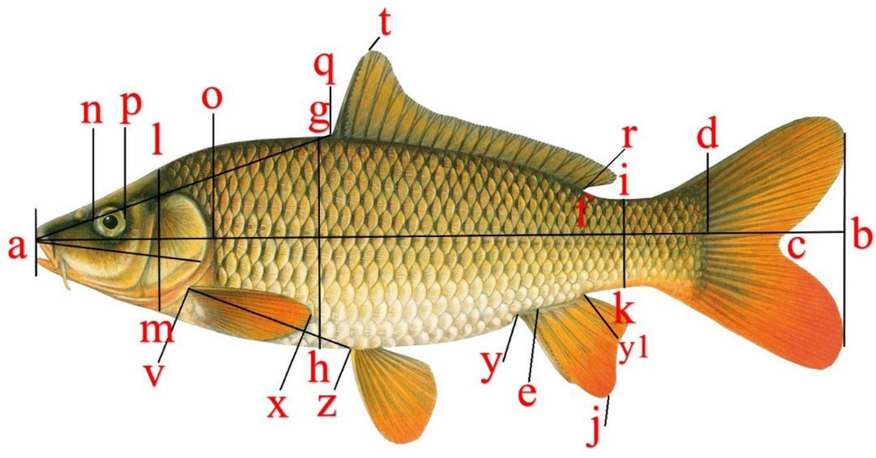

Fig. 2. Carp measurement scheme (Cyprinus carpio Linnaeus, 1758).

The designations of morphological characters were the following: ab – absolute length (L, mm); ac – length without caudal fin (l, mm); Q – total body mass (g); q – body mass without internal organs (g); ao – head length (mm); od – trunk length (mm); gh – greatest body height (mm); ik – smallest body height (mm); aq – antedorsal distance (mm); rd – postdorsal distance (mm); ay – anteanal distance (mm); ap - antepectral distance (mm); az – anteventral distance (mm); fd – length of caudal peduncle (mm); qr – length of dorsal fin base (D, mm); qt – greatest dorsal fin height (D, mm); yy1 – length of anal fin base (A, mm); ej – greatest anal fin height (A, mm); zz1- ventral fin base length (mm); vx – length of pectoral fin (mm); vz – distance from beginning of pectoral fin to pelvic fin (P and V, mm); zy – distance from the beginning of pectoral fin to anal fin (V and A, mm); av – antepectoral distance (mm); lm – head length at occiput (mm); nn – forehead width (mm); an – snout length (mm); np – eye diameter (mm); po – occipital region of the head (mm).

The designations for counting characters were the following: Dzh – number of hard rays in dorsal fin; Dm – number of soft rays in dorsal fin; Azh – number of hard rays in anal fin; Am – number of soft rays in anal fin; P – number of rays in pectoral fin; V – number of rays in pelvic fin; ll – number of scales in lateral line; sup. – number of scales above lateral line; sub. – number of scales below lateral line; ll fd – number of scales in caudal peduncle; sp.br – number of gill stamens; vert. – number of vertebrae; vert. ch. – number of thoracic vertebrae; vert. tail – number of caudal vertebrae.

The main software applied for statistical data processing included Excel 2013, *Past version 4.03 and IBM SPSS Statistics 22* based on the methods in (Hammer et al., 2001; IBM, 2013; Chris, 2011).

QGIS Version 3.34.6 was used to map the sampling locations.

The processing of photographic images for geometric morphometry was done using the Morpho J software. Before building models, the images were labelled using the tapdig264 software. An example of carp image labelling is shown in Fig. 3.

Fig. 3. Labelling of carp image using the tpsdig264 software.

To analyze the images, digital models reflecting the body shape contour were constructed specific for three target water bodies. When comparing based on the component analysis method, each contour pattern was attributed to a principal component (PC1, PC2, etc.). Carp sampling locations served as principal component attributes. Fig. 4. shows the general scheme of work with the corresponding morphometry software applications.

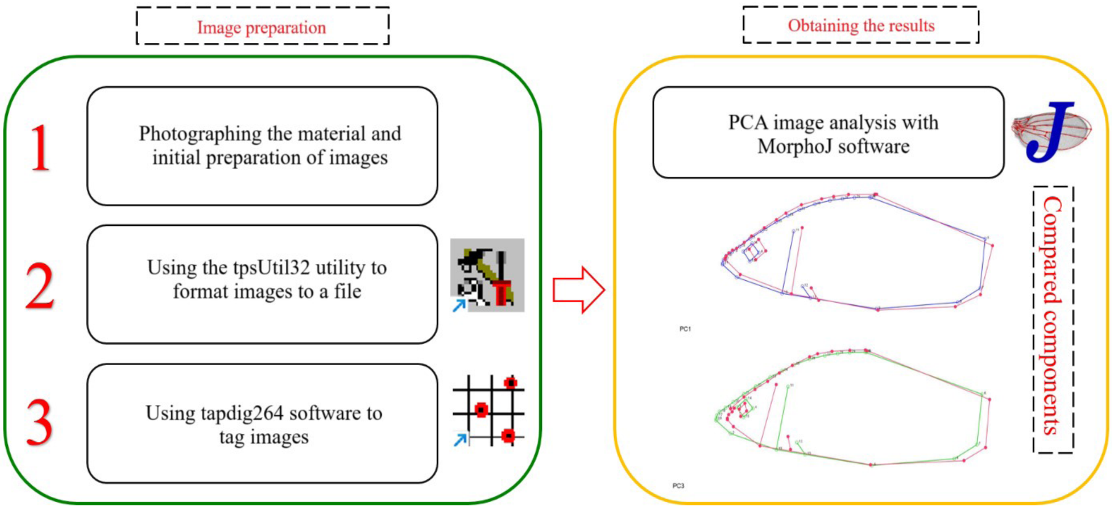

Fig. 4. Image preparation and Morpho J analysis scheme.

The sample comparison method was applied for both sexes. The final treatment was executed as per the principal component analysis based on the observed measurements of counting and plastic characters. Relative values were adopted for plastic parameters.

3. Results

The statistical processing of external carp features revealed differences between samples (Table I.). Statistically significant differences in counting traits were observed for several thoracic (vert. ch.) and caudal vertebrae (vert. tail).

Against the long-term data, carp fatness for three reservoirs was below average (Mitrofanov et al., 1988). For carp from Lake Balkash it was 1.32 (according to Fulton) and 1.13 (according to Clark). For carp from Lake Alakol it was 1.37 and 1.29, respectively. For carp from the Kapchagay Reservoir it was 1.27 and 1.17, respectively. The differences in fatness coefficients could be associated with different food base, climatic, hydrological, hydrochemical and hydrobiological habitat conditions in the water bodies in question.

Table I. Comparative morphological characteristics of carp from target reservoirs

Indicators	M±m			Difference significance, Tst		
	Balkash n = 20	Alakol n = 25	Kapchagay n = 25	I-II	I-III	II-III
Main biological indicators						
L, mm	377.8±12.58	334.5±32.50	393.8±23.58	-	-	-
l, mm	311.7±11.96	278.4±28.40	367.2±23.50	-	-	-
Q, g	711.6±59.38	531.0±57.89	787.2±69.14	-	-	
q, g	605.5±43.71	501.2±49.40	725.6±52.88	-	-	-
Conditioning factors						
Fulton	1.32±0.11	1.37±0.09	1.27±0.09	-	-	-
Clar[k]	1.13±0.08	1.29±0.09	1.17±0.08	-	-	-
Counting characteristics						
Dzh	3.0±0.10	3±0.00	2.9±0.26	0.00	0.36	0.38
Dm	19.1±0.57	18.7±0.97	18.6±0.87	0.36	0.48	0.08
Azh	2.9±0.26	3.0±0.08	2.8±0.42	0.37	0.20	0.47
Am	6.0±0.29	5.9±0.15	5.4±0.48	0.31	1.07	0.99
P	13.6±1.10	15.9±0.82	15±0.92	1.68	0.98	0.73
V	9.6±1.00	9.0±0.15	8.7±0.40	0.59	0.84	0.70
ll	38.4±1.15	38.4±1.05	37.9±0.90	0.17	0.34	0.36
sup.	5.9±0.36	5.5±0.50	5.4±0.50	0.65	0.81	0.14
sub.	5.8±0.53	5.6±0.46	5.8±0.40	0.28	0.00	0.33
ll fd	11.1±1.02	11.5±0.78	11±0.43	0.31	0.09	0.56
sp.br.	28.9±1.34	30.5±1.97	29.5±1.00	0.67	0.36	0.45
vert.	38.1±1.11	37.6±1.11	37.1±1.10	0.32	0.64	0.32
vert.ch.	22.0±0.78	18.1±0.77	18.1±0.77	3.56	3.56	0.00
vert. tail	16.3±1.00	19.4±0.89	18.6±0.98	2.32	1.64	0.60
Plastic characteristics						
ao	78.6±3.33	75.5±7.62	85±4.01	0.37	1.23	1.10
od	233.1±10.47	202.9±21.16	250±20.54	1.28	0.73	1.60
gh	99.8±3.51	91.2±9.57	97.8±6.55	0.84	0.27	0.57
ik	39.1±3.54	35.3±3.77	38.8±2.80	0.73	0.07	0.75
aq	150.2±7.14	135.8±13.39	154.2±12.56	0.95	0.28	1.00
rd	50.7±7.19	42.5±5.90	50.2±5.30	0.88	0.06	0.97
ay	234.0±9.65	207.6±19.22	248.4±16.99	1.23	0.74	1.59
az	143.1±7.37	130.7±11.75	149.0±13.87	0.89	0.38	1.01
fd	56.0±5.89	51.8±5.43	61.2±4.68	0.52	0.69	1.31
qs	119.3±5.24	100.9±10.67	124.5±7.94	1.55	0.55	1.77
qt	47.8±2.69	40.4±4.58	46.4±2.80	1.39	0.30	1.12
yy1	25.4±3.71	24.1±2.64	28.2±1.87	0.29	0.67	1.27
ej	44.2±3.39	37.8±4.31	43.1±3.66	1.17	0.22	0.94

Table I. Cont.

vx	55.7±3.32	48.4±5.89	55.7±4.38	1.08	0.00	0.99
zz1	53.5±3.27	42.6±4.75	49.4±4.12	1.89	0.78	0.77
vz	151.5±10.27	158.1±7.50	159.3±16.78	0.52	0.40	0.07
zy	81.8±4.91	73.1±8.01	89.1±7.84	0.92	0.79	1.43
aP	74.6±3.33	75.8±7.17	80.9±4.74	0.15	1.09	0.59
lm	51.0±1.58	44.7±4.17	56.6±4.80	1.41	1.11	1.87
nn	31.6±2.95	27.7±3.21	31.3±1.46	0.89	0.09	1.02
an	26.2±1.93	18.8±2.30	28.5±1.76	2.46	0.88	0.10
np	12.1±1.51	11.2±0.89	13.0±0.88	0.51	0.51	1.44
po	42.2±2.90	39.2±3.06	46.5±2.46	0.71	1.13	1.86
Critical value of Student’s t-test = 2.011 P < 0.05						

Carp’s morphological heterogeneity was traced against a separate category of traits. Differences in carp were found for counting as well as plastic characters (Fig. 5.).

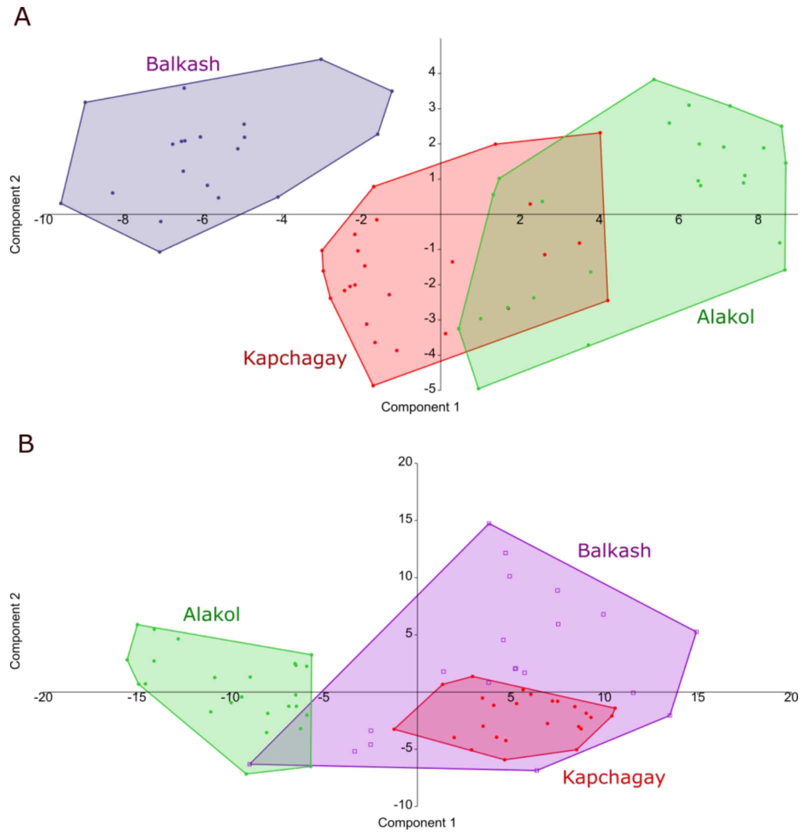

Fig. 5. Morphological differences in carp based on principal component analysis (A – on the totality of counting characteristics; B – on the totality of plastic characteristics).

The results of multivariate principal component analysis presented in Fig. 5. indicate morphological heterogeneity for the group of counting traits between the three samples; however, the greatest differences were observed in the carp specimens from Balkash. With respect to the group of plastic features, the main differences were detected in the carp speci-mens from Alakol and, at the same time, no differences were found in the carp specimens from Lake Balkash and Kapchagay.

A greater number of tail vertebrae (vert. tail) was found characteristic for the group of counting features in the carp samples from Kapchagay and Alakol. As for thoracic vertebrae (vert. ch.), the samples from Lake Balkhash had more than the other two and showed positive PC2 loadings. The samples from Balkash and Kapchagay demonstrated the highest negative loadings for the number of gill stamens (sp.br.), as those samples had one fewer range than the ones from Lake Alakol (Table II.).

Table II. Morphobiological differences of carp from three target reservoirs by main characteristics with account of main component stresses.

Indicators	Balkash n = 20		Alakol n = 25		Kapchagay n = 25		Principal components		
	M	±m	M	±m	M	±m	1	2	3
1	2	3	4	5	6	7	8	9	10
Counting characteristics									
vert. ch.c	22.0	0.78	18.1	0.77	18.1	0.77	-0.2716	0.4712	0.3323
vert. tail a,b	16.3	1.00	19.4	0.89	18.6	0.98	0.2390	-0.1992	-0.0581
sp.br. b	28.9	1.34	30.5	1.97	29.5	1.00	0.1107	-0.4481	0.7706
Plastic characteristics									
vzc	151.5	10.27	158.1	7.50	159.3	16.78	-0.6099	0.3120	-0.3071
vxc	13.6	1.10	15.9	0.82	15	0.92	0.1701	-02208	0.3168
lma	51.0	1.58	44.7	4.17	56.6	4.80	0.4040	0.1561	0.0628
anb	26.2	1.93	18.8	2.30	28.5	1.76	0.5210	0.1403	0.0862
ghb	99.8	3.51	91.2	9.57	97.8	6.55	-0.1480	0.3800	0.2405
aqb a	150.2	7.14	135.8	13.39	154.2	12.56	-0.1549	0.3287	0.3230
nnb	31.6	2.95	27.7	3.21	31.3	1.46	0.1867	0.4212	0.0493
pob	42.2	2.90	39.2	3.06	46.5	2.46	0.1852	0.4834	0.6126
a – carp from Kapchagay; b – carp from Alakol; c – carp from Balkash.									

The pectoventral distance and pectoral fin length (vx) showed the highest negative loading in the specimens from Lake Balkash, as the mean values of these traits were lower than in the other two. In the second and third components, positive loading was observed in the samples from Lake Alakol, indicating that the values of traits such as greatest body height (gh), antedorsal distance (aq), snout length (an), forehead width (nn) and occipital head (po) were smaller. At the same time, the specimens from Kapchagay demonstrated greater head height (lm) and antedorsal distance (aq) than the other two groups.

4. Discussion

The results of examining the morphological variability of carp from the main reservoirs of the Balkash-Alakol Basin – conducted under this study – correlate with the literature data describing the environmental factor impacts on the variability of traits in carp species (Feklistova, 1951; Stephen and Mark, 2016; Zhenhong et al., 2024). The identified changes in body shape, and the influence of currents and movement of carp in aquatic environment (Stephen and Mark, 2016; Mamilov et al., 2018) may explain individual body parts such as fin spacing. On the one hand, it is rather difficult to allege the phenotypic differentiation of carp from the three target reservoirs only due to the exposure to river flow hydrodynamics without genetic analyses. On the other hand, the findings regarding plastic traits demonstrate similarity between Balkash and Kapchagay carp populations due to the existing hydrological connection between the two reservoirs. In this regard, the Ile River plays a key role in carp migratory exchange. At the same time, the absence of a hydrological connection between Alakol (on the one hand) and Balkash and Kapchagay (on the other hand) makes the similarities between their carp populations – in terms of their plastic features – not characteristic for the carp population of the former.

Another reason for the similarity in certain traits is related to the history of carp population formation. It is known that the appearance of carp in Balkash and Kapchagay was accidental. In 1905, as a result of dam erosion, carp travelled along the Malaya Almatinka and Kaskelen Rivers to the Ile River, where they widely dispersed and entered Lake Balkash. Later, it became an important fishing object in that region (Mitrofanov et al., 1992). For the Alakol group of lakes, the formation of commercial carp shoals was noted in 1939 (Asylbekova S.J. et al., 2018). The introduction of carp was carried out from Lake Balkash into the river tributaries of Alakol lakes in 1932-1933 (Mitrofanov et al., 1992).

In his study, Kirichenko O.I. (2019) also examined carp populations in three target water bodies. The author proposed the differences in the number of gill stamens between the samples from Lake Balkash and Kapchagay Reservoir as the main feature. Morphological differences were noted in 5 plastic characters: gland diameter, parameters of paired and unpaired fins. Greater head length, occipital distance and anal fin were observed in terms of plastic characters.

The present study allowed tracing the differences in carp's morphological traits in terms of the number of vertebrae (pectoral and caudal), head parameters (head height, forehead width, snout length and occipital head distance), and the number of gill stamens; as well as expressing the similarity between the carp populations in Alakol and Kapchagay with respect to counting characters. It is likely that the similarity of these populations is related to the annual stocking of young carp/sazan from fish farms of Almaty Region by the Kapshagay Spawning and Rearing Farm – 1973 LLP as the key operator. In addition, as part of the Research Project "Artificial reproduction and breeding of carp fish stocking material with the purpose of its further sale for stocking of natural water bodies of the Republic of Kazakhstan" on the basis of this farm RBS (repair and breeding stocks) of carp from wild producers of Lake Alakol were created (Kahn et al., 2012; Barakov, 2021). The obtained juveniles from wild producers were used to stock the reservoirs considered under this study.

In summary, the investigated morphological features of carp in the three reservoirs of the Balkash-Alakol Basin do not go beyond species specificity. The study's outputs are consistent with the previous research on fish morphological features in variable habitat conditions (Beland, 2004; Christian et al., 1999; Khosrow and Keramat, 2010). Based on the analysis of literature data and this study's findings, it is possible to assume that the phenotypic differences observed in carp are due to a complex of factors: historical formation of populations, habitat heterogeneity, unity of hydrological network (ability to migrate), species plasticity and annual stocking of young carp obtained from wild producers of Lake Alakol.

It is rather difficult to firmly state the influence of a single factor on the alterations in fish morphology. The opinions of researchers on this issue vary. For example, Wanink and Witte (2000) examined morphological variability against the background of fish migrations from pelagic to benthic niche. Another study (Douglas, 1993), considered the influence of sexual demorphism. In this regard, further research of relationships among individual biotic and abiotic carp habitat factors is required to deepen the understanding of its phenotypic variability.

5. Conclusion

The morphological, i.e. phenotypic, variability of carp in the three studied reservoirs of the Balkash-Alakol Basin is probably determined, on the one hand, by the diversity of habitat conditions and, on the other hand, by the genetic heterogeneity of corresponding populations. The variability demonstrated by carp in response to environmental factors may indicate a prolonged adaptive radiation in the target water bodies, simultaneously being the result of compensatory effects of the organism in response to altering habitat conditions. In addition to changing habitat conditions, the variability of carp may have been affected by the annual artificial stocking of juvenile fish.

The above may suggest that the morphological differentiation of carp is associated with a number of abiotic and biotic factors. Determining the actual effect of a single factor, however, remains an extremely difficult task and requires additional investigation aimed at pinpointing correlations, as well as dependencies between phenotypic variability and environmental factors.

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