Biomorphological Indicators of Rainbow Trout (*Oncorhynchus mykiss*) Fry: Comparative Analysis in the Conditions of the Lower Kolsay and Fish Farms

Barakov Rinat Tairovich[1], Abilov Berdibek Ibragimovich[1], Assylbekova Saule Zhangirovna[1], Isbekov Kuanysh Baibolatovich[1], Bulavin Efim Fedorovich[1,2], Islamov Esenbay Israilovich[3], Ablaisanova Gulmira Mukhambetalievna[1]

[1]*Aquaculture Laboratory, Fisheries Research, and Production Center LLP, Almaty, Kazakhstan*
[2]*Astrakhan State University named after V. N. Tatishchev, Astrakhan, Russia*
[3]*Kazakh Research Institute of Agricultural Economics and Rural Development LLP, Almaty, Kazakhstan*

*Corresponding Author: barakovrin@gmail.com

Abstract: Rainbow trout (Oncorhynchus mykiss Walbaum, 1792) is one of the key species in aquaculture of the salmon family due to its high commercial value and the availability of farming technology. This paper presents data on the morphometric characteristics of rainbow trout fry grown in three types of farms in Kazakhstan and wild forms from Lake Lower Kolsay. The comparison was performed using geometric morphometric analysis based on 9 numerical and 28 plastic traits. Differences were assessed using the Mann-Whitney criterion and principal component analysis (PCA). The influence of factors such as hydrochemical conditions, spatial constraints and stocking density was established. The results are important for assessing the risk of bio-contamination and preserving the gene pool when stocking fish in the developing aquaculture of Kazakhstan. The novelty of the study is dictated by the need to form a comprehensive database on morphology, monitoring studies of trout farms for the purpose of further developing measures to control the level of selection stability and additional measures to reduce the risk of spreading low-viability and genetically depleted fish among fish farming entities in Kazakhstan.

Keywords: Rainbow trout, *Oncorhynchus mykiss*, Geometric morphometrics, Aquaculture, Meristic traits, Population comparison, Genetic introgression, Kazakhstan

Introduction

Trout (*Oncorhynchus mykiss* Walbaum, 1792) is a commercially important species in aquaculture [1-2]. In 2019, global trout production hit 940,000 tons, with rainbow trout accounting for a whopping 97% of the total. This impressive figure is a

testament to the intricate and demanding nature of aquaculture development [3]. The rapid growth of aquaculture production in Asian countries is linked to high demand for fish in urban areas and a decline in fishing in natural bodies of water [4-6].

Since the development of the Fisheries Development Programme for 2021-2030, there has been an increase in the number of trout farms in the Republic of Kazakhstan [7]. Data on trout farming volumes highlights the increasing demand for rainbow trout and other salmon species (Figure 1). For instance, trout farming peaked at 2.638 tonnes in 2023, compared to 199 tonnes in 2014.

According to historical records, rainbow trout were imported in batches of 200.000 fertilized eggs from Czechoslovakia to Kazakhstan between 1964 and 1966. The Chilik River was used for trout farming [8]. In subsequent years, the positive impact of the introduction was evident in the Lower and Middle Kolsay lakes. Currently, commercial trout farming in Kazakhstan relies on importing ready-to-plant material from other countries [9]. For instance, planting material originating from Poland and Denmark is well known and widely used on many farms in Kazakhstan.
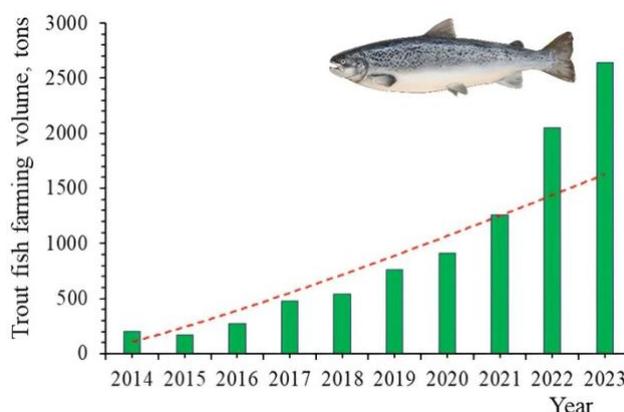

Fig. 1: Trout farming volumes in Kazakhstan from 2014 to 2023 [10]

The use of industrial technologies facilitates the growth of rainbow trout production. Examples of such technologies include the installation of cage and pond farms. In such systems, environmental factors can lead to changes in the metabolic processes of fish. These changes ultimately affect the final product [11-14]. At the same time, it is important to consider the phenotypic characteristics of trout at different stages of production, as this will help to ensure the optimal outcome. Such studies are necessary to identify differences between cultured stocks and to understand the adaptive characteristics of organisms [15], as well as the level of selection stability [16]. The ability of organisms to adapt to unfamiliar living conditions is known as phenotypic plasticity. This is essentially regarded as the level of adaptive protection of organisms against various environmental factors [17]. The study of rainbow trout biology in artificial conditions is necessary to assess the adaptive potential of the species. The relevance of this work lies in the monitoring of external biomarkers using modern morphometric methods and visualization of the results. Morphological analysis is an accessible and practical tool for the initial assessment of broodstock, marketable fish and juveniles, unlike genetic methods, which are often costly and inaccessible to farmers.

The novelty of the research is related to the lack of generalized morphological data on rainbow trout farmed in Kazakhstan. The work aims to expand the database on the exterior of farmed rainbow trout, which is important for monitoring the breeding stability and adaptation of imported (mainly European) stocks. The creation of a morphological database may be of long-term importance, allowing the early detection of signs of inbreeding, mutations and diseases.

Thus, monitoring external characteristics can contribute to strengthening sanitary control and reducing the risks of spreading low-viability and genetically depleted fish among fish farming entities in Kazakhstan and abroad.

Materials and Methods

Data Collection for Morphological Analysis

For the study, we chose rainbow trout fry (age 0+) from three different trout farms (see Figure 2):1) Kargaly Trout (N=25); 2) Grand Fish (N=25); 3) Ak Balyk (N=30). Geographically, the trout farms are located in different regions of Kazakhstan:

Kargaly Trout (50°38'58.14"N; 57°47'18.92"W), Grand Fish (42°35'15.25"N; 69°58'2.62"W) and Ak Balyk (43°36'10.35"N; 77°53'3.87"W).

We collected 30 specimens of rainbow trout material from a natural biotope at Lake Lower Kolsay (hereinafter referred to as Lake Kolsay). The coordinates of Lake Kolsay are lat. 42°59'3.77"N, lon. 78°19'27.22"E.
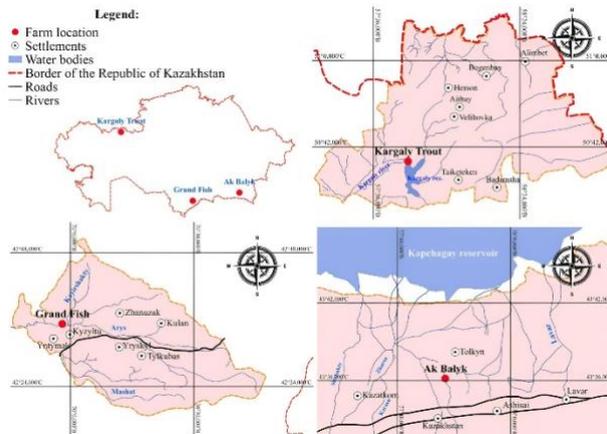

Fig. 2: Maps showing the location of trout farms

The Origin of the Rainbow Trout Fry

The study focused on rainbow trout fry originating from two distinct broodstock populations: Ak Balyk, Grand Fish and Kargaly Trout farms. For comparison of morphometric indicators, a natural population of rainbow trout from Lake Lower Kolsay was considered as an additional group (Fig. 3). According to the literature, rainbow trout specimens from Lake Kolsay were obtained from fish farms in the Czech Republic and Slovakia [8].

Scheme of Morphological Measurements

Morphological analysis of rainbow trout fry was performed according to Pravdin's guidelines [18]. Morphological analysis was carried out on 110 trout specimens. During the measurements, the fish were lying on their right side. We counted and measured the following external characteristics: 9 countable and 28 plastic characteristics. Figure 4 shows a diagram of salmonid measurements with an interpretation for rainbow trout.
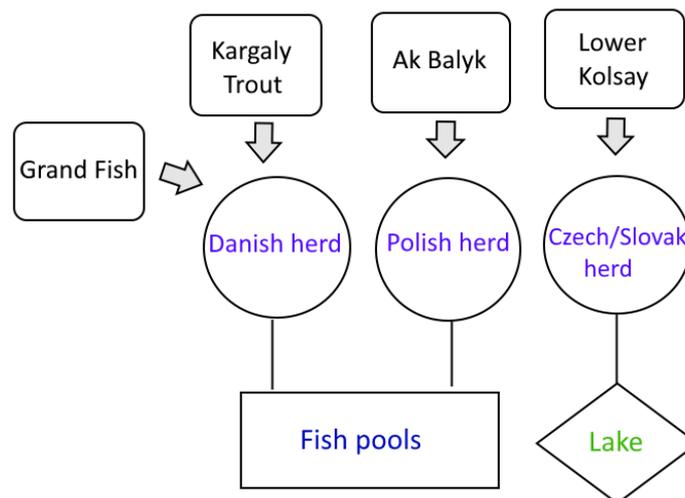

Fig. 3: The origin of *Oncorhynchus m.* fry

Plastic characteristics: ab - absolute body length, ac - Smith's length, od - body length, ao - head length, an - snout length, np - eye diameter (horizontal), po - postorbital length, aa5 - length of the middle part of the head, lm - head length at the occiput, np - forehead width, ad6 - length of the upper jaw, k_1l_1 - length of the lower jaw, gh - maximum body height, ik - minimum body height, aq - anterodorsal distance, rd - postdorsal distance, az - anteventral distance, ay - anteanal distance, fd - length of the caudal peduncle, qs - length of the dorsal fin base, fu - maximum height of the dorsal fin, yy_1 - length of the anal fin base, ej - maximum height of the anal fin, ox - length of the pectoral fin, zz_1 - length of the ventral fin, VZ - distance between the pectoral and ventral fins, Zy - distance between the ventral and anal fins, aV - antepectral distance.
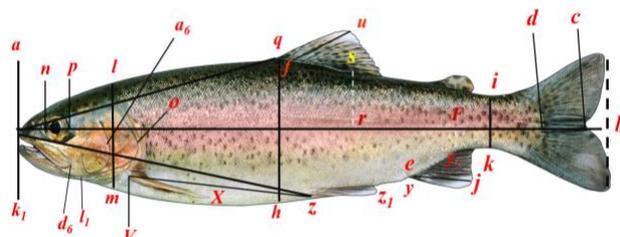

Fig. 4: Measurement scheme for salmonids [18]

Counting characteristics: Dr - number of rigid rays in the dorsal fin, Dsof. - number of soft rays in the dorsal fin, Ar - number of rigid rays in the anal fin, Asof. - number of soft rays in the dorsal fin, Pr - number of rigid rays in the pectoral fin, Psof. - number of rays in the pectoral fin, Vr - number of rigid rays in the pelvic fin, Vsof. - number of soft rays in the pelvic fin, sp.br - number of gill rakers.

Absolute values were used for countable characteristics when analysing the obtained morphometric data. For the study of plastic characteristics, the values were expressed as a percentage of the body length according to Smith.

Body Length- Weight Relationship

The ratio between the absolute body length (TL) and total body weight (TW) of *Oncorhynchus m.* fry was calculated using the formula by Bagenal and Tesh [19]:

$TW = aTL^b$

Where:

TW - Body weight (g)

TL - Absolute body length (mm)

a - Intersection of the regression line

b - Slope of the regression line

Condition Factor (Fulton's Factor)

The body condition of Oncorhynchus m. was determined using the Fulton coefficient [20] according to the formula by Bagenal and Tesh [19]:

$FCF = \frac{TW}{TL} \times 100$

Measurement of Hydrochemical Indicators

The conditions for trout farming in the basin were monitored by measuring the hydrochemical parameters of the water, including pH, water temperature (°C), dissolved oxygen content (mg/l) and oxygen saturation (%). We measured the parameters using a Horiba U-53 multi-parameter water analyzer.

Data Analysis

The statistical data processing was carried out using a range of software, including Excel 2013, IBM SPSS Statistics 22, and Past version 4.03. [21-22]. We prepared descriptive statistics and graphs using standard MS Excel 2013 software. The range (minimum to maximum), arithmetic mean (M) and standard deviation (± m) were calculated.

Version 4.03 of the Past programme was used for multidimensional statistical analysis using the principal component analysis (PCA) method. The data obtained from the PCA were visualised using graphs. The results of the principal components analysis were used to identify the highest loads, taking into account the morphological indicators of trout from farms and Lake Kolsay. PCA analysis was also used to illustrate the distribution of hydrochemical parameters in the water.

In IBM SPSS Statistics 22, multiple comparisons of characteristics between farms and Lake Kolsay were performed using the nonparametric or rank Mann-Whitney (U_{test}) [23]. One-way analysis of variance (ANOVA) was used to compare the water parameters [24]. The reliability of differences when comparing indicators was accepted at 95% (with a p-value ≤0.005).

Results

Main Water Parameters

Analysis of water parameters using ANOVA in the three farms studied showed differences in the average values of the pH, water temperature (to), dissolved oxygen (O_2) and O_2 saturation percentage (%). The water parameters in the basins are shown in Table 1.

Table 1: Main water parameters in the basins of three trout farms

Indicator	min-max	M
Grand Fish		
pH	7.1-7.7	7.3
t^o (°C)	15.3-17.8	16.4
O_2 (mg/l)	7.5-10.6	9.1
O_2 (%)	84-132	102.9
Ak Balyk		
pH	6.7-7.5	7.1
t^o (°C)	16.8-17.6	17.1
O_2 (mg/l)	7.3-8.5	8.1
O_2 (%)	75.4-98.2	82.3
Kargaly Trout		
pH	6.5-6.9	6.7
t^o (°C)	11.2-11.3	11.2
O_2 (mg/l)	8.7-10.9	10.5
O_2 (%)	108-114	111.5

p≤0.005 - accuracy of differences

Length-Weight Relationship

The length-weight curves of *Oncorhynchus m.* from various farms and Lake Kolsay are presented in Figure 5. The average length and weight corresponded to the sample from the Ak Balyk farm, 108.2 mm and 17.2 grams. The highest values were found in trout from Grand Fish - 237 mm and 157.8 grams, respectively.

At the Kargaly Trout farm, the length and weight of the fish were 160.5 mm and 61.6 grams. For Lake Kolsay, the figures were 177.4 mm and 62.9 grams. The b value was within 3 for samples from Ak Balyk, Kargaly Trout and Kolsay Lake, indicating allometric growth. Trout from the Grand Fish farm showed negative allometric growth.
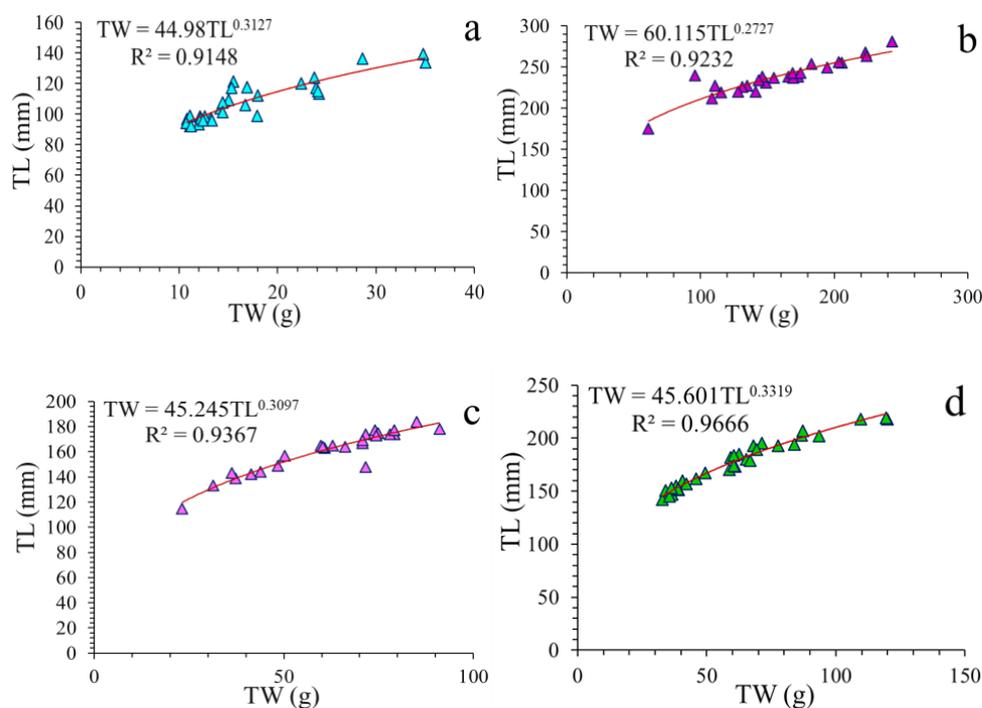
Fig. 5: Length-weight rrelationship of fry *Oncorhynchus m.*: a - Ak Balyk, b - Grand Fish, c - Kargaly Trout, d - Kolsay Lake

Condition Factor (Fulton's Factor)

The average FCF ±m values for yearling trout from different farms and lakes were as follows: Ak Balyk 1.32±0.15, Grand Fish 1.55±0.07, Kargaly Trout 1.44±0.09, Kolsay Lake 1.07±0.06. The Mann-Whitney criterion for independent samples showed differences ($p \leq 0.005$). No differences were found between Ak Balyk and Kargaly Trout. The results are presented in Table 2.

Comparative Analysis of Biomorphological Indicators

Differences in key biological indicators (L, ac, Q, q) were observed between the compared trout samples (U_{test}, $p \leq 0.005$) (Table 2). No differences were observed between Kargaly Trout and Kolsay Lake ($U_{test} > p$).

Differences in the countable characteristics between Ak Balyk and Grand Fish, Kargaly Trout and Kolsay Lake were observed in the number of gill rakers, hard rays in the anal fin and dorsal fins. Differences between Grand Fish and Kargaly Trout were found in the number of soft rays in the dorsal and anal fins. Differences between Grand Fish and Kolsay Lake were observed in the number of tough rays in the dorsal fins and the number of soft rays in the pectoral and pelvic fins. No differences were observed between Kargaly Trout and Kolsay Lake in the number of gill rakers and tough rays in the pectoral and pelvic fins.

Table 2 shows that there were differences in the characteristics of the plastics between the farms and the natural group from Lake Kolsay. At the same time, the fewest differences (n=8) were noted between yearlings obtained from Danish producers - between Grand Fish and Kargaly Trout. In this regard, there were more differences when comparing other Ak Balyk (Polish herd) and Kolsay Lake (Chech/Slovak herds) with yearling trout from Danish broodstock.

Figure 6 provides a visual reference, illustrating the separation of a distinct cohort (Lake Kolsay) against the backdrop of three farms. The main vectors are morphological indicators of rainbow trout based on countable and plastic characteristics. The direction of the vectors indicates the presence of differences in the corresponding characteristics of rainbow trout among farms and the natural population.

Based on fig. 6a, a separate group against the background of three farms is demonstrated by rainbow trout from Lake Kolsai, for which the number of hard rays in the pectoral (Pr) and dorsal (Dr) fins, as well as the number of soft rays in the

dorsal fins, was higher. For the other groups of rainbow trout, the counts of the characteristics were significantly lower (p≤0.005).

When considering the plastic characteristics (Fig. 6b), it is obvious that the yearlings of Oncorhynchus m. from Ak Balyk and Kolsay Lake represent separate groups. Differences were found in the following characteristics: snout length (an), forehead width (np), body length (od), head length (ao), head length at the occiput (lm), lower jaw length (k1l1), caudal peduncle length (fd), dorsal fin base length (qs), dorsal fin height (fu), anal fin base length (yy1), anal fin height (ej), length of pectoral fin (ox), length of pelvic fin (zz1), distance between pectoral and pelvic fins (VZ).

At the same time, there is an overlap between Grand Fish and Kargaly Trout, i.e. there are obvious similarities between them due to the low number of observed differences (Utest >p): length of the middle part of the head (aa5), distance between the ventral and anal fins (Zy), postorbital region of the head (po), length of the upper jawbone (ad6), postdorsal distance (rd), distance between the pectoral and ventral fins (VZ) .The observed vector of differences can be clearly traced by taking into account the loads of the main components (Table 3). The present analysis focuses on the loads pertaining to the features within the three components PC1-PC3.
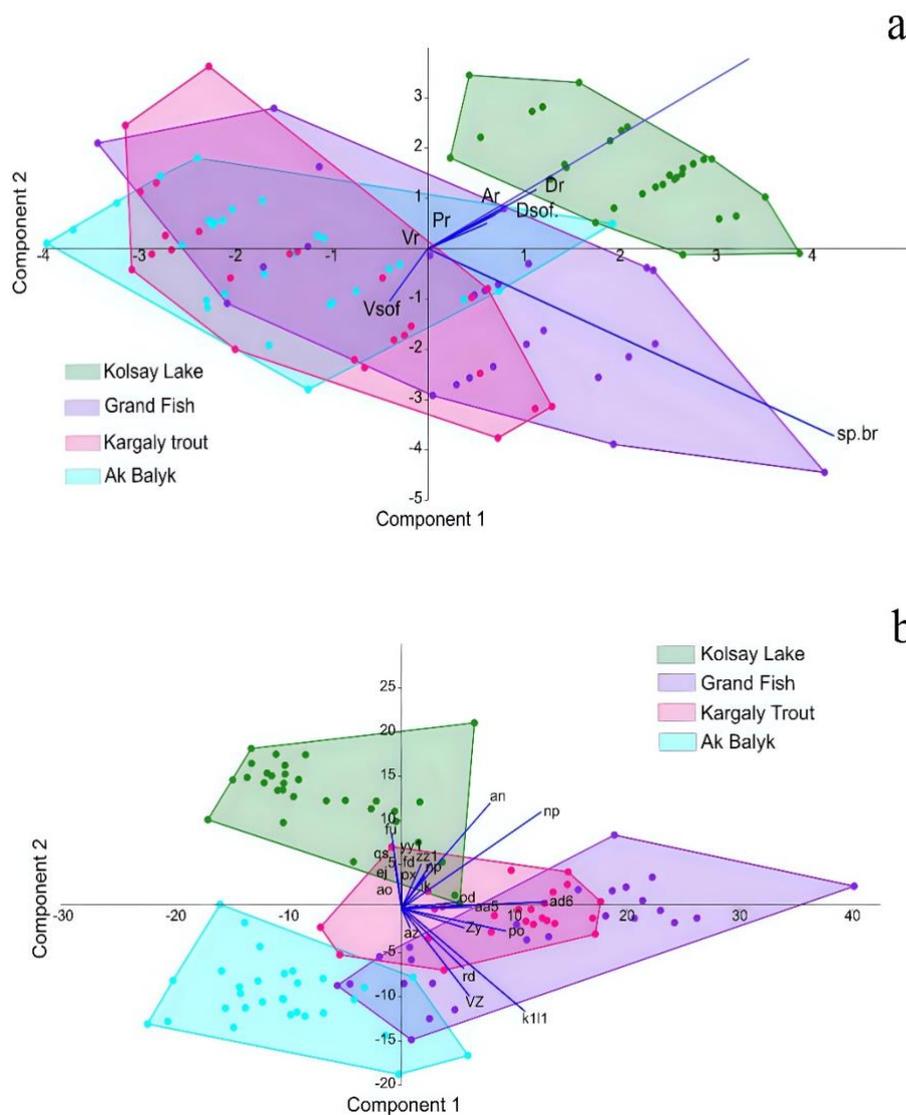

Fig. 6: Differences between fry of *Oncorhynchus m.* based on: a - a combination of countable characteristics, b - a combination of plastic characteristics

Table 2: Morphobiological indicators of *Oncorhynchus m.* fry, taking into account multiple comparisons using the U$_{test}$

Indicator	M±m				U test (the level of statistical significance)*					
	Ak Balyk (I)	Grand Fish (II)	Kargaly Trout (III)	Kolsay Lake (IV)	I-II	I-III	I-IV	II-III	II-IV	III-IV
	N=30	N=25	N=25	N=30						
Main biological indicators										
L, mm	108.2±11.32	237.2±14.55	160.5±13.96	177.4±19.50	0(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.010)
ac, mm	102±10.8	222.9±16.52	155.4±14.12	167.4±18.8	0(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.053)
Q, g	17.2±5.33	157.8±34.69	61.6±14.86	62.9±19.37	0(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.662)
q, g	13.5±4.35	131.7±27.17	52.2±12.78	50.5±16.40	0(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.378)
CF	1.32±0.15	1.55±0.07	1.44±0.09	1.07±0.06	(0.000)	(0.008)	(0.000)	(0.000)	(0.000)	(0.000)
Counting indicators										
Dr	1±0.00	1±0.00	1±0.00	2.3±0.50	(1.000)	(1.000)	(0.000)	(1.000)	(0.000)	(0.000)
Dsof.	10.1±0.78	10.5±0.78	9.4±0.83	10.7±0.57	(0.242)	(0.006)	(0.052)	(0.000)	(0.579)	(0.000)
Ar	1±0.00	1±0.00	1±0.00	1.7±0.39	(1.000)	(1.000)	(0.000)	(1.000)	(0.000)	(0.000)
Asof.	10.6±0.84	10.5±0.70	9.76±0.70	10.6±0.74	(0.950)	(0.005)	(0.732)	(0.005)	(0.655)	(0.001)
Pr	1±0.00	1±0.00	1±0.00	1.03±0.06	(1.000)	(1.000)	(0.325)	(1.000)	(0.369)	(0.369)
Psof.	10.2±0.74	11±0.85	10.3±0.75	13.6±0.49	(0.007)	(0.907)	(0.000)	(0.016)	(0.000)	(0.000)
Vr	1±0.00	1±0.00	1±0.00	1±0.00	(1.000)	(1.000)	(1.000)	(1.000)	(1.000)	(1.000)
Vsof.	9.2±0.39	9.6±0.56	9.2±0.78	8.5±0.49	(0.22)	(0.955)	(0.000)	(0.132)	(0.000)	(0.002)
sp.br	15.9±1.01	18.1±1.67	16.6±1.81	17.5±0.91	(0.000)	(0.137)	(0.000)	(0.021)	(0.098)	(0.092)
*Plastic indicators**										
an	2.9±0.57	10±3.34	8.1±1.27	8.7±1.31	(0.000)	(0.000)	(0.000)	(0.677)	(0.729)	(0.373)
od	68.8±7.66	166.7±13.76	110.5±11.26	117.3±13.3	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.048)
np	2.7±0.29	8.1±2.14	3.5±0.36	5.9±0.84	(0.000)	(0.000)	(0.000)	(0.000)	(0.229)	(0.000)

po	10.2±1.54	23.8±3.09	18.5±2.10	17.7±2.34	(0.000)	(0.000)	(0.466)	(0.357)	(0.000)	(0.000)
aa5	14.2±1.5	32.9±3.84	23.69±2.41	25.±2.04	(0.000)	(0.022)	(0.306)	(0.000)	(0.000)	(0.252)
ao	20.7±1.86	43.83±4.38	33.5±3.20	36.4±4.50	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.104)
lm	15.1±1.83	36.4±5.79	23.3±2.09	18.01±2.59	(0.000)	(0.000)	(0.000)	(0.954)	(0.000)	(0.120)
ad6	7.22±0.90	20±3.41	14.6±2.27	13.7±2.39	(0.000)	(0.000)	(0.126)	(0.318)	(0.000)	(0.001)
k1l1	11.6±1.52	27.1±2.77	20.1±2.50	18±2.39	(0.000)	(0.001)	(0.000)	(0.628)	(0.000)	(0.000)
gh	23.6±3.28	55.6±5.57	35.4±3.69	38.2±3.84	(0.004)	(0.494)	(0.713)	(0.000)	(0.000)	(0.773)
ik	6.9±1.00	18.7±2.44	14.8±1.76	14.7±1.84	(0.000)	(0.000)	(0.000)	(0.001)	(0.081)	(0.001)
aq	45.4±4.48	99.3±6.91	71±6.32	74.9±8.22	(0.185)	(0.452)	(0.064)	(0.11)	(0.961)	(0.005)
rd	37.6±4.08	88.3±8.47	61.7±6.41	52.8±6.97	(0.000)	(0.000)	(0.000)	(0.171)	(0.000)	(0.000)
az	51±5.19	109.8±8.87	75.08±7.18	80.2±10.17	(0.166)	(0.001)	(0.002)	(0.109)	(0.164)	(0.811)
ay	68.2±6.82	149.7±14.67	102.2±11.82	113.1±12.58	(0.716)	(0.19)	(0.686)	(0.070)	(0.921)	(0.18)
fd	14.3±2.14	32.8±6.38	27.6±3.15	30.7±3.87	(0.211)	(0.000)	(0.000)	(0.001)	(0.000)	(0.179)
qs	9.1±1.51	20.4±4.45	17.5±1.74	22.9±2.60	(0.612)	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)
fu	6.9±2.28	19.4±3.24	14.7±1.68	25±3.39	(0.001)	(0.000)	(0.000)	(0.135)	(0.000)	(0.000)
yy1	5.1±0.97	18.5±3.41	12.6±1.62	16.2±2.21	(0.000)	(0.000)	(0.000)	(0.938)	(0.000)	(0.000)
ej	9.6±1.39	21.9±2.15	15.9±1.72	21±3.32	(0.452)	(0.007)	(0.000)	(0.121)	(0.000)	(0.000)
ox	11.1±1.34	25.6±2.66	19.1±2.13	24.7±3.23	(0.106)	(0.000)	(0.000)	(0.010)	(0.000)	(0.000)
zz1	7.8±1.29	25.6±7.34	17±1.84	20.5±2.54	(0.000)	(0.000)	(0.000)	(0.010)	(0.000)	(0.000)
VZ	28.9±4.13	67.8±6.77	45.2±5.23	32.3±1.24	(0.001)	(0.62)	(0.000)	(0.025)	(0.000)	(0.000)
Zy	14.3±1.90	43.4±5.75	28.6±3.81	21.9±1.16	(0.000)	(0.000)	(0.226)	(0.027)	(0.000)	(0.000)
aV	44.8±5.33	41.3±4.33	74.5±8.14	21.2±0.84	(0.55)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

*p≤0.005

** The absolute values of indicators are given.

Table 3: Countable and plastic characteristics of *Oncorhynchus m.* taking into account the loads of the main components (PC1-PC3)

Indicators	Ak Balyk		Grand Fish		Kargaly Trout		Kolsay Lake		Principal Components*		
	M	±m	M	±m	M	±m	M	±m	PC1	PC2	PC3
Counting indicators											
Dr	1	0	1	0	1	0	**2.3**	**0.5**	**0.2000**	0.1371	0.1245
Dsof.	10.1	0.78	10.5	0.78	9.4	0.83	**10.7**	**0.57**	**0.2083**	0.1351	0.1203
Ar	1	0	1	0	1	0	**1.7**	**0.39**	-0.0706	**0.7316**	-0.0698
Pr	1	0	1	0	1	0	**1.03**	**0.06**	**0.0057**	0.0044	-0.0024
Psof.	10.2	0.74	11	0.85	10.3	0.75	**13.6**	**0.49**	0.5910	**0.6687**	-0.1962
Vsof.	9.2	0.39	**9.6**	**0.56**	9.2	0.78	8.5	0.49	-0.0701	-0.1849	**0.1142**
sp.br	15.9	1.01	**18.1**	**1.67**	16.6	1.81	17.5	0.91	**0.7481**	-0.6592	-0.0302
Plastic indicators in %											
ao	20.3	0.71	19.7	1.47	21.6	0.83	**21.7**	**0.76**	0.0007	**0.0674**	-0.0470
od	67.4	1.98	**75.1**	**1.67**	71.0	1.57	70.1	1.39	**0.1815**	0.0268	0.1666
ik	6.8	0.53	8.4	0.84	**9.6**	**0.80**	8.8	0.38	0.0618	**0.0767**	-0.0125
rd	36.8	1.55	**39.7**	**1.67**	39.6	1.42	31.6	2.34	**0.1989**	-0.2443	-0.0170
az	**50**	**1.82**	49.3	2.03	48.3	1.33	47.9	2.17	0.0277	-0.0799	**0.0983**
fd	13.9	1.15	14.8	2.94	17.8	1.26	**18.4**	**1.43**	0.0002	**0.1481**	-0.0615
qs	8.97	1.15	9.2	2.05	11.3	0.88	**13.7**	**0.89**	-0.0223	**0.1863**	-0.0304
fu	6.87	2.01	8.8	1.64	9.6	1.00	**14.5**	**1.67**	-0.0313	**0.3018**	0.0323
yy1	4.98	0.78	8.3	1.23	8.1	0.87	**9.7**	**0.92**	0.0629	**0.1821**	0.0197
ej	9.46	0.89	9.9	0.92	10.3	0.79	**12.5**	**1.04**	-0.0139	**0.1286**	0.0114
ox	10.89	0.54	11.5	0.94	12.3	0.78	**14.7**	**0.73**	-0.0005	**0.1445**	-0.0325
zz1	7.75	1.11	11.5	3.17	10.9	0.71	**12.3**	**0.69**	0.0955	**0.1879**	0.0064
VZ	28.37	2.11	**30.4**	**1.87**	29.1	1.28	19.6	2.35	**0.2165**	-0.3567	0.1620
Zy	14.03	0.90	**19.4**	**1.45**	18.3	1.14	13.4	1.86	**0.2003**	-0.0786	0.0988
po	49.56	5.00	54.3	3.68	**55.2**	**2.78**	48.8	2.37	**0.3330**	-0.0916	-0.8610
aa5	68.46	3.20	**75.2**	**3.01**	70.6	2.37	69.3	3.52	0.2249	0.0056	**0.3189**
ad6	34.74	2.44	**45.6**	**4.14**	43.7	4.73	37.6	5.55	**0.4632**	0.0279	0.0355
k1l1	55.72	4.02	**61.9**	**3.47**	59.8	3.51	49.6	5.08	**0.3909**	-0.4233	0.1444

* The loads on the principal component features are given according to the highest feature values

According to Table 3, the highest loads among the countable characteristics (Dr, Dsof., Ar, Pr, Psof.) for the first and second components were observed for Kolsay Lake. The characteristics Vsof. and sp.br corresponded to the highest positive

loads in the Grand Fish sample for PC3 and PC1, respectively. Among the loads on plastic traits, we can highlight the Kolsay Lake sample, which was characterised by mostly positive loads on PC1 (od, rd) and PC2 (ao, ik, fd, qs, fu, yy1, ej, ox, zz1). The highest plastic trait indices for Grand Fish were observed on PC1 (od, rd, VZ, Zy, ad6, k1l1). Fewer positive loads on plastic traits were identified for Ak Balyk on PC3 (az). For Kargaly Trout, they were identified on PC1 (po) and PC2 (ik).

Discussion

Oncorhynchus m. is a particularly noteworthy example of a salmonid demonstrating considerable morphological diversity [25-28]. The domesticated form Oncorhynchus m. has been present in Lake Kolsay for a period exceeding six decades.

It is notable that the morphological characteristics of Oncorhynchus m. for the Lake Kolsay were first recorded 25 years after the species introduction [8]. In this regard, the rainbow trout population is considered to be balanced [29-30]. Recent studies suggest that research into the identification of morphological divergences in rainbow trout in various natural water bodies is increasing. This research is focused on determining the main localities and assessing the possible impact on the local ichthyofauna [31]. Furthermore, the field of aquaculture has seen a growing interest in the morphology of rainbow trout. In this context, the monitoring of the influence of rainbow trout rearing conditions on changes in discrete traits (phenes) is a crucial task for controlling phenotypic stability [32]. A range of biomarkers can be utilised for these purposes [33]. For example, in study by Strzyżewska-Worotyńska et al., morphological changes in gill structures were observed under both extensive and intensive trout farming conditions [34].

In our research, we compared Oncorhynchus m. Fry based on external characteristics obtained from three different broodstock populations. The comparison included a group from a natural ecotope - Lake Kolsay. The results of the morphological research indicate a number of differences in the combination of plastic and countable characteristics. The most significant differences in countable characteristics were identified when comparing the group from Lake Kolsay, which was characterised by natural habitat conditions. Furthermore, the presence of positive loads in a number of countable characteristics - the number of tough and soft fin rays in trout from Lake Kolsay - may indicate fin erosion in groups of trout raised in flow-through basins. At the same time, the pectoral and dorsal fins are less stable under farming conditions and can be used as indicators of welfare (Pelis and McCormick, 2003). The observed reduction in the number of fin rays may be attributed to variations in water flow velocity [35], which could have influenced the swimming activity of Oncorhynchus m. fry in the farms under study. In addition, the stocking density of farmed trout must be taken into account. In their natural habitat and in the absence of artificial boundaries, these fish tend to exhibit freer movement.

In our study, we compared Oncorhynchus m. yearlings based on external characteristics obtained from three different broodstock populations. The comparison included a group from a natural ecotope - Lake Kolsay. The results of the morphological research indicate a number of differences in the combination of plastic and countable characteristics. The most significant differences in countable characteristics were identified when comparing the group from Lake Kolsay, which was characterised by natural habitat conditions. Furthermore, the presence of positive loads in a number of countable characteristics - the number of tough and soft fin rays in trout from Lake Kolsay - may indicate fin erosion in groups of trout raised in flow-through basins. At the same time, the pectoral and dorsal fins are less stable under farming conditions and can be used as indicators of welfare [36]. The observed reduction in the number of fin rays may be attributed to variations in water flow velocity [35], which could have influenced the swimming activity of Oncorhynchus m. fry in the farms under study. Additionally, the stocking density of farmed trout must be considered. In their natural habitat and in the absence of artificial boundaries, these fish tend to exhibit freer movement.

Intergroup differences were identified in the group of plastic characteristics. Nevertheless, the level of recorded differences may be influenced by a number of factors. The following three factors were analysed: 1) the origin of Oncorhynchus mykiss fry, 2) feeding, and 3) hydrochemical parameters of water. For instance, the impact of hydrochemical parameters in water is reflected in the growth indicators of trout [37]. In our study, differences in the conditions of keeping are unquestionable ($p \leq 0.005$). Kargaly Trout had the best growing conditions. The other groups didn't go beyond the optimal range, but their indicators were quite different. The lowest oxygen content in the water was found in Ak Balyk (8.1 mg/l), followed by Grand Fish (9.1 mg/l) and Kargaly Trout (10.5 mg/l) [38]. The findings of the current study align with those of the experimental research [39], which revealed the optimal growth and survival levels for trout to be 9.6 mg/l rather than 4.2 mg/l. The observed changes in the trout population in the basin are consistent with the literature, which indicates that artificial selection of the broodstock and the weakening of natural selection due to rearing in artificial conditions can result in targeted changes [40-41]

(Jonsson and Jonsson, 2006; McLean et al., 2005). In study by Vehanen and Huusko, changes in the body shape of trout raised in hatchery conditions were exposed to fairly uniform and stable currents, where the fish were forced to swim constantly, which may contribute to the development of a more elongated and endurance-adapted morphology [39]. The results of the study indicate that trout from the Grand Fish Farm exhibited a high level of swimming activity, which was associated with water flow in the pools. Changes in plastic traits were identified according to PC1, which included the postdorsal distance, the distance between the pectoral and abdominal fins, and the distance between the abdominal and anal fins. The present study examined the impact of wild trout (Oncorhynchus mykiss) from Lake Kolsai on PC2 traits. The results demonstrated that the wild trout exhibited positive effects on PC2 traits, including tail length, dorsal fin base, maximum dorsal fin height, anal fin base, and pectoral and ventral fins. In the context of the farms under analysis, these morphological indicators manifested with reduced intensity. We believe that the differences in the morphology of the above-mentioned indicators of trout from Lake Kolsay are primarily related to habitat conditions. Lake Kolsay itself is a mountain lake, where the impact of direct factors such as water flow, food supply and hydrochemical regime formed under the control of anthropogenic factors is less significant than in artificial basin conditions (with the exception of certain localities) [42-43]. In this regard, the variability of various morphological characteristics of trout clearly demonstrates deviations from wild trout forms inhabiting natural biotopes.

The results of the study of phenotypic variability of Oncorhynchus m. raised under different conditions in fish farms in Kazakhstan indicate the presence of morphological differences. The results of the study are interesting for fish farm managers in preserving the morphological characteristics of wild rainbow trout, as there are possible risks of losing the phenotypic stability of the species in cases of stocking and replenishment of artificially bred trout in natural lakes. In practical terms, the results can be applied to the assessment of rainbow trout from other fish farms. In addition, the study raises the issue of phenotypic deviations in adult rainbow trout in the context of food safety and quality standards for products sold on the domestic and international markets of Kazakhstan. The study complements and expands research for further expansion of monitoring the quality of farmed rainbow trout, preventing the risk and spread of inbred forms and fish diseases.

Conclusion

The morphological differences identified in Oncorhynchus m. raised in different types of trout farms and in the wild demonstrate the high phenotypic plasticity of the species under various conditions. However, a number of factors influenced the morphological deviations, including the origin of the Oncorhynchus m. yearlings and the conditions of their maintenance (domestication effect).

The assessment of phenotypic variability in rainbow trout necessitates monitoring of wild trout populations from Lake Nizhny Kolsay in cases of stocking with juveniles from various farms in Kazakhstan, as well as determining the risks of mutations and fish diseases.

To further improve the quality of the study, additional research is needed, taking into account the genetic structure of the Oncorhynchus m. stock and tagging from fish farms in Kazakhstan to create a monitoring data bank.

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Authors Contributions

Barakov R.T.: Morphological analysis, Conceptualization, Data curation, Formal analysis, Software, Visualization, Writing original draft.

Abilov B.I. Collecting trout samples, Validation, Writing - review & editing.

Isbekov K.B.: Funding, analysis of article materials.

Assylbekova S. Zh.: Funding, analysis of article materials.

Bulavin E.F.: Conducting experiments and collecting trout samples.

Yessenbay I.: Journal search and technical work on the article.

Ablaisanova G.M.: Collecting trout samples, Morphological analysis.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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