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Morphological Variation, Length-Weight Relationship and Condition Factor of *Cabdio morar* (Hamilton, 1822) Populations in Southeast Iran

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Abstract

The present study was conducted to study the morphological variation of the *Cabdio morar* populations in Mashkil, Sarbaz, and Jegin rivers in terms of morphometric, meristic, length-weight relationship, and condition factor. A total of 21 morphometric and 7 meristic traits were measured and counted, respectively, and data was analyzed using One-Way ANOVA, Duncan test, Kruskal-Wallis, principal component analysis (PCA), canonical variate analysis (CVA), and cluster analysis. The results indicated significant differences in 9 morphometric characters ($P<0.05$), but meristic traits showed no differences between the populations ($P>0.05$). Multivariate results separated the studied populations showing that the studied populations are delimited mostly by the body depth and dorsal-fin height characters. The values of the length-weight relationship parameters showed that the population of Mashkil River has an almost isometric growth pattern, and the two others have a negative pattern. In addition, the condition factor of the Sarbaz population were lower (0.89±0.23), than two other populations i.e. Jegin and Mashkil (1.35±0.17 and 1.21±0.32, respectively) showing poor conditions of its habitat.

Keywords: Phenotypic plasticity, Morphology, Principal Component Analysis, Waspi

Introduction

The study of morphological characters, including morphometric and meristic, with the aim of defining or characterizing population units, has a long tradition in ichthyology (Wilde & Echelle, 1997; Jerry & Cairns, 1998). Morphological plasticity according to environmental variability is generally found among many fish species, predominantly in freshwater fish species (Gelsvartas, 2005). This variability is considered to be an important adaptive strategy for populations experiencing inconsistent environments (Radkhah & Nowferesti, 2016a).

Length-weight relationship (LWR) is used in fisheries assessment (Andrade & Campos, 2002), providing information on the condition of fish, to determine whether somatic growth is isometric or allometric (Ricker, 1975). In the LWR, the relationship between the average weight of the fish and its length is examined in the form of a mathematical relation (Beyer 1991). In addition, the condition factor is a quantitative parameter for assessing the well-being of a fish species as well as its nutritional status (Le Cren, 1951).

Cabido morar is a member of the family Cyprinidae distributed in Afghanistan, Pakistan, India, Bangladesh, Myanmar, Thailand, and Iran (Galib, 2008; Coad, 2021). This species is found in the Mashkil and Makran basins of Iran. It inhabits streams with slow currents and ponds in plains and mountainous regions (Galib, 2008). Given such a wide distribution, the present study aimed to study the morphological variation among three populations of *C. morar* from Mashkil and Makran basins of Iranian inland waters in terms of morphometric, meristic, length-weight relationship, and condition factors.

Martial and methods

A total of 129 specimens of *C. morar* were collected from three rivers which are Mashkil (27° 05'N, 63° 12'E) from Mashkil basin, Sarbaz (26° 15' 33.46"N, 61° 23' 26.14"E), and Jegin (26° 4' 53.76"N, 57° 47' 35.5956"E) from Makran basin. Twenty-one morphometric and seven meristic characters were measured according to Armbraster (2012). In this study, morphometric traits include total length, standard length, fork length, body depth, head length, snout length, Postorbital head length, eye diameter, predorsal length, prepelvic length, preanal length, dorsal fin height, dorsal fin base length, anal fin height, anal fin base length, ventral fin length, pectoral fin length, pecto-ventral length, caudal peduncle length, caudal peduncle depth, and head width. Also, meristic characters were: dorsal branched rays, anal branched rays, pelvic branched rays, ventral branched rays, lateral line scale, upper lateral line scale, and lower lateral line scale. The measurement of the length and weight were taken by a digital caliper and digital balance to the nearest 1 mm and 0.1 gr, respectively.

An allometric method was used to remove size-dependent variation in morphometric characters using: the $M_{adj} = M (L_s / L_0)^b$ formula, where M_{adj} is the adjusted value of the measured trait, M initial value of the measured trait; L_s average standard length of all samples at all stations, L_0 standard length of each fish and *b* is the slope of the regression of log M on log L_0 of all samples (Elliot et al., 1995; Mustafic et al., 2008; Paknejad et al., 2014).

All morphometric and meristic traits were analyzed for normality using the Kolmogorov–Smirnov test. Non-parametric and parametric data were analyzed using the Kruskal–Wallis and ANOVA tests in SPSS software version 19. ANOVA and Kruskal Wallis tests were conducted to determine whether there were any differences in traits between the populations. By applying characters with a significant difference, multivariate analyzes of the principal component analysis (PCA) to summarize and understand the pattern of diversity and body shape distribution of the studied populations, canonical variate analysis (CVA) to the comparison of the body shape of studied populations, and multivariate ANOVA (MANOVA) and cluster analysis (CA) using paired group algorithm and Euclidean similarity measure to understand the similarity of the body shape were performed (Cadrin & Silva, 2005). All analyses were performed in SPSS 22 and PAST v 2.17b (Hammer et al., 2001) software.

To determine the relationship between total length and body weight, the exponential relationship $W = aL^b$ was used, where W = total weight of fish (g) L = total length of fish (mm), a = constant value, and *b* = slope of the curve that indicates the type of growth pattern, i.e. isometric or allometric (LeCren, 1951; Froese, 2006; Paknejad et al., 2014). If the *b*-value from the length-weight relationship is greater than 3 ($b>3$), the growth pattern will be positive allometric, if $b<3$, negative allometric, and if $b = 3$, the growth pattern will be isometric (Radkhah & Eagderi, 2015). The degree of correlation between the variables was calculated using the coefficient of determination "r^2". The student's t-test was used to evaluate the difference between the *b*-value and the expected value of $b = 3$ (Paknejad et al., 2014). All statistical analyses were performed in Excel 2016. The condition factor (K) was calculated using Fulton $K = (W/L^3) \times 100$ where W = whole body wet weight in grams and L =length in cm; factor 100 is used to bring K close to unity (Froese, 2006).

Results

The results showed that all morphometric characteristics are parametric except eye diameter, dorsal fin height, ventral-fin length, pectoral-ventral fin length, and caudal peduncle length. Mean, standard deviation, range, and the results of ANOVA and Kruskal-Wallis analysis of the morphometric characteristic are shown in Table 1. Based on the results, the studied populations showed significant differences in the body depth, eye diameter, pre-dorsal and anal lengths, dorsal fin height, ventral fin length, pectoral-ventral length, and caudal peduncle length and head width ($P<0.05$; Table 2).

Based on the PCA results, the two first components representing 51.66% variance (PC1= 32.02 and PC2: 19.64; Fig. 1) and the body depth and dorsal fin height were the most effective traits along the PC1 and PC2 components i.e. having a higher role for delimiting the studied populations. In addition, the Mashkil populations have been positioned between the overlapped areas of two others (Fig. 1).

Table 1. The results of the one-way ANOVA, Duncan test, Kruskal-Wallis and Summary of the morphometric characteristics measured for three studied populations of *Cabdio morar* (Heterogeneous letters 'a, b' in each row show a significant difference at the level of 5% among the studied populations; Non-letter numbers are related to Kruskal-Wallis analysis).

	Mashkil	Sarbaz	Jegin	*P*
Standard length	56.55±0.00	56.55±0.00	56.55±0.00	
Body depth	12.07±0.83 [a]	14.00±0.89 [b]	12.19±0.62 [a]	<0.05
Head length	11.03±0.84 [a]	11.15±0.74 [a]	11.11±0.93 [a]	0.785
Snout length	2.07±0.52 [a]	2.1±0.39 [a]	2.1±0.4 [a]	0.942
Postorbital head length	6.06±0.53 [a]	6.25±0.46 [a]	6.14±0.56 [a]	0.254
Eye diameter	2.36±0.43	2.39±0.41	2.55±0.34	<0.05
Pre-dorsal length	30.6±0.86 [a]	31.3±0.88 [b]	30.57±0.93 [a]	<0.05
Pre-pelvic length	29.68±1.06 [a]	30.16±1.01 [a]	29.8±1.01 [a]	0.104
Pre-anal length	43.17±1.07 [a]	43.8±1.22 [b]	42.85±1.21 [a]	<0.05
Dorsal fin height	7.91±1.02	8.15±0.87	7.19±1.00	<0.05
Dorsal fin base length	6.48±0.9 [a]	6.67±0.65 [a]	6.46±0.47 [a]	0.433
Anal fin height	6.12±0.97 [a]	6.12±0.58 [a]	6.04±0.75 [a]	0.913
Anal fin base length	6.24±1.01 [a]	5.89±0.69 [a]	6.32±0.94 [a]	0.13
Ventral fin length	6.71±0.82	6.5±0.83	6.07±0.94	<0.05
Pectoral fin length	9.03±1.26 [a]	8.83±1.24 [a]	9.2±1.23 [a]	0.52
pectoral-ventral length	16.98±1.11	17.1±0.9	17.68±1.07	<0.05
Caudal peduncle length	8.76±0.87 [a]	8.88±0.69 [a]	8.93±1.66 [a]	0.567
Caudal peduncle depth	5.02±0.54	5.69±0.56	5.54±0.31	<0.05
Head width	10.27±0.59 [a]	11.03±0.47 [b]	10.16±0.51 [a]	<0.05

Table 2. The results of the one-way ANOVA, Duncan test and summary of meristic characteristics for three populations of *Cabdio morar*.

	Mashkil (N=65)		Sarbaz (N=33)		Jegin (N=31)		*P*
	Min-	**Mean±SD**	**Min-**	**Mean±SD**	**Min-**	**Mean±SD**	
Dorsal branched rays	7-7	7.00±0.00[a]	7-7	7.00±0.00[a]	7-7	7.00±0.00[a]	>0.05
Anal branched rays	8-9	8.20±0.41[a]	8-9	8.60±0.50[a]	8-9	8.50±0.51[a]	>0.05
Pelvic branched rays	10-12	10.65±0.58[a]	11-12	11.25±0.44[a]	11-13	11.90±0.78[a]	>0.05
Ventral branched rays	6-7	6.60±0.50[a]	6-8	6.95±0.60[a]	6-7	6.45±0.51[a]	>0.05
Lateral line scale	31-42	37.25±3.52[a]	34-55	39.40±5.87[a]	33-43	37.50±3.26[a]	>0.05
Upper lateral line scale	5-8	6.90±0.78 [a]	6-7	6.80±0.41[a]	4-7	6.65±0.48[a]	>0.05
Lower lateral line scale	3-4	3.35±0.48[a]	3-4	3.60±0.50[a]	3-4	3.40±0.50[a]	>0.05

MANOVA/CVA showed significant differences between the three populations (*P*<0.0001; Fig. 2). The CVA plot indicated that Sarbaz populations were completely separated, also in the cluster analysis, the studied populations were divided into two main clades, including the Sarbaz population in a separate clade from two others (Fig. 3). Descriptive statistics and the estimated LWR parameters are given in Table 3. All LWRs were significant for the studied populations (P<0.001), with r^2 values greater than 0.92. The coefficient of determination (r^2) for the Mashkil, Sarbaz, and Jegin rivers are 0.92, 0.92, and 0.96, respectively.

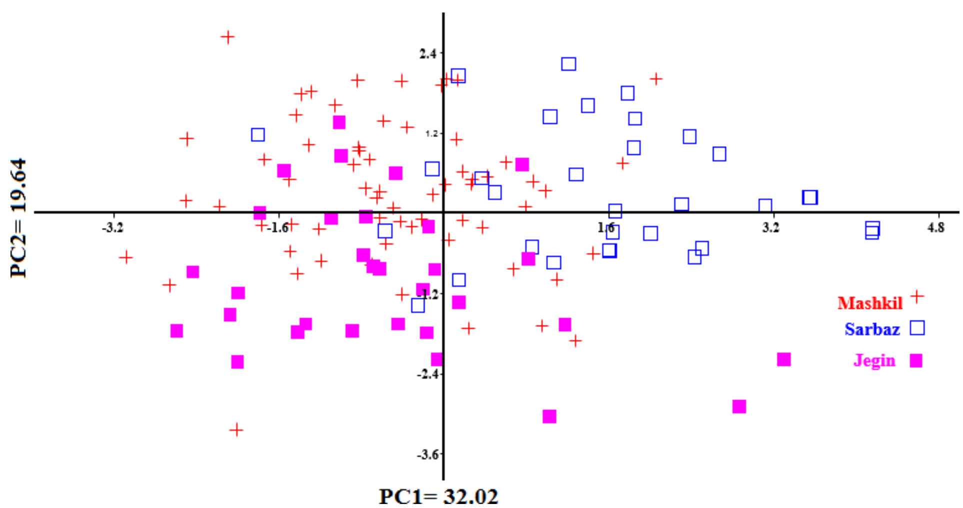

Figure 1. Plots of Principal component functions 1 and 2 of the morphometric measurements.

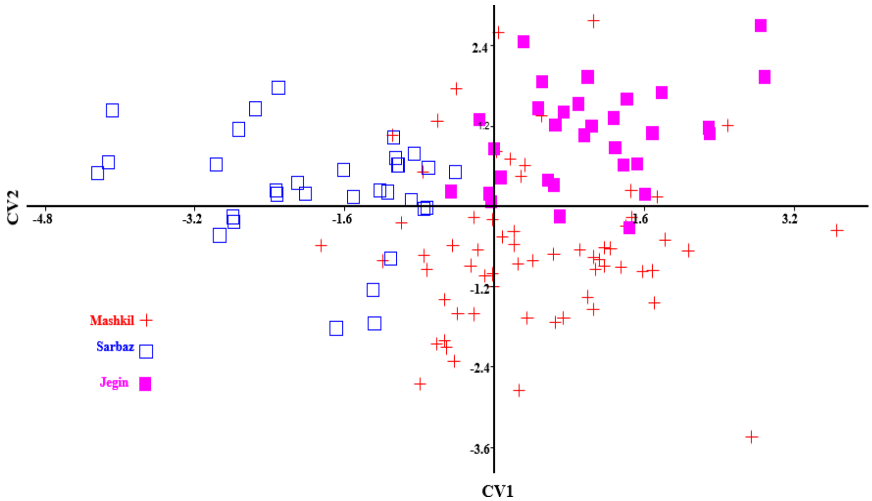

Figure 2. Plots of CVA analysis of the morphometric data.

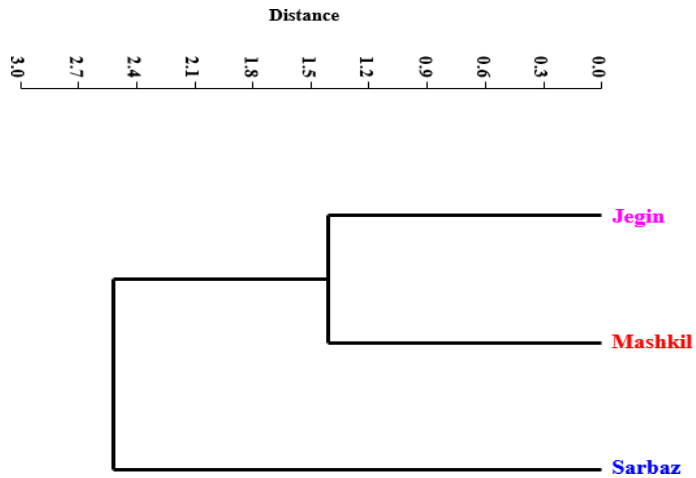

Figure 3. Cluster analysis of morphometric traits of the studied populations.

Table 3. Descriptive statistics and estimated parameters of the length–weight relations and condition factor of the three populations of *Cabdio morar* in Southeast of Iran.

Rivers	**N**	**Total length (cm)**		**Body weight (g)**		**LWR parameters**			**K (Mean±SD)**
		Range	Mean±SD	Range	Mean ± SD	*a*	*b*	r^2	
Mashkil	65	3.6-8.4	5.78±0.85	1.44-18.0	6.59±2.98	0.0370	3.01	0.96	**1.21±0.32**
Sarbaz	35	5.1-13.5	7.63±1.89	1.81-18.9	4.37±3.44	0.0233	2.50	0.92	**0.89±0.23**
Jegin	31	4.7-9.0	7.77±0.91	2.0-10.0	6.46±1.70	0.0420	2.44	0.92	**1.35±0.17**

N= number of specimens; K= condition factor

Discussion

Traditional morphometric and meristic methods remain the most direct ones for species identification. In addition, the analysis of phenotypic variation in morphometric characters or meristic counts is the method most commonly used to delineate stocks of fish (Leslie & Grant, 1990; Creech, 1992; Mamuris et al., 1998; Radkhah & Nowferesti, 2016a). Based on the results, a significant variation was found between the studied populations of *C. morar* in terms of the morphometric characters. Differences were in the body depth, eye diameter, pre-dorsal and anal lengths, dorsal fin height, ventral fin length, pectoral-ventral length, caudal peduncle length, and head width. In line with our findings, Nasri et al. (2019) in their study on *C. morar* from Mashkil and Makran basins reported 11 significant differences in morphometric traits. The morphometric characteristics may be related to the environmental differences, including the temperature, salinity, hardness, alkalinity, etc., or genetic differences that induced the morphological variability (Mattews, 1988; Radkhah & Nowferesti, 2016b). In addition, the observed phenotypic variability may be related to the geography, ecology, and genetic diversity of the population (Thia et al., 2021). Fishes have relatively higher within-population coefficients of variation of phenotypes (Baillie et al., 2016).

No difference was observed among the studied populations in terms of the meristic traits. The lack of significant differences between these traits can indicate the low diversity of meristic compared to morphometric traits (Winfield et al., 1991). Zamani et al. (2014) reported that meristic traits could not distinguish the studied *C. morar* populations; they counted LL as 38-46 LL, upper LL 6-7, lower LL 4-5, dorsal branched rays 7-8, and anal branched rays 8-9, which in this study were 31-55, 4-8, 3-4, 7, 8-9, respectively, showing even a larger range of the meristic characteristics. Borah et al. (2014) reported Brahmaputra and Barak rivers (India) populations of *C. morar* in 11 morphometric and 2 meristic traits showed significant differences that in contrast with the findings of the present study.

Based on the results, the most influential variables for delimiting the studied populations were the body depth and dorsal-fin height. Furthermore, MANOVA/CVA showed significant differences between the three studied populations in terms of body shape. The reason for this body shape change is very complex to interpret. Although our findings provided some evidence to support this outcome, future studies are needed to expose the underlying physiological causes. Several studies have demonstrated that the body shape of different fish species can be modified because of their adaptation mechanisms to the surrounding environments (Hendry et al., 2006; Sfakianakis et al., 2011; Araújo et al., 2014; Rowiński et al., 2015; Corral & Aguirre, 2019). Although the environmental factors govern some degree of the potential phenotypic discreteness of wasp aggregations, the detected pattern of morphological differences may be determined by the interaction between genetic and environmental factors (Staszny et al., 2013).

In the present study, values of *b* varied from 2.44 for the Jegin population, to 3.01 for the Mashkil one indicating that the Mashkil population has the highest growth. The *b*-value of the previously studied *C. morar* of Iran was reported to be 3.31 (Esmaeili et al., 2014) and 3.62. The values showed that the population of the Mashkil River has an almost isometric growth pattern ($b>3$), while the others showed a negative allometric growth pattern ($b<3$). In general, the difference in slopes of the L-W relationship *b*-value can be attributed to a combination of one or more factors such as the species, sexuality, age, sexual maturity, season, nutrition, geographical location of the sampling area, environmental conditions, and time of catching samples in terms of gut fullness or parasitic contamination (Wooten, 1999; King, 2007). LWR is also related to fish body shape (Radkhah & Eagderi, 2015), therefore, the finding of significant differences in the *b*-value of the studied populations can confirm due to their body shape difference.

Based on the results, the lowest condition factor was calculated for the Sarbaz population showing its poor conditions of habitat which may be due to the unavailability of proper food and lower habitat's environmental conditions (Sadeghinejad Masouleh & Radkhah, 2020). In addition, the results revealed proper habitat conditions of the Jegin and Mashli groups (1.35±0.17 and 1.21±0.32, respectively). A K>1 indicates the suitability of a specific water body for the growth of fish (Radkhah & Eagderi, 2015; Sadeghinejad Masouleh & Radkhah, 2020). The condition factor of fish species is affected by various parameters such as sex, season, access to food resources, and water quality of the ecosystem (Nehemia et al., 2003).

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