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Geometric Morphometric Comparison of Abu Mullet, *Planiliza abu* (Heckel, 1843) Populations in Bushehr Basin, Iran

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Abstract

Many fish behavior and habitats could be defined based on the fish morphology, thus, using the fish body shape, in addition to its genetic characteristics, could be used to infer the type of fish habitat and its characteristics. This study aimed to compare the body shapes of five populations of abu mullet, *Planiliza abu* (Heckel, 1843), in Bushehr basin using geometric morphometric method. Some 162 specimens from Hendijan, Genaveh, Helleh, Kaki and Mond rivers were used. Three morphometric characters, total length (TL), fork length (FL) and standard length (SL) were measured. Samples were photographed from the left side, then 18 landmarks were digitized using ImageJ software. Data obtained from Procrustes were analyzed by multivariate analysis using PCA and CVA. The results of PCA analysis showed significant differences between Kaki and other populations ($P < 0.0001$). The CVA analysis of the studied populations showed that the highest Mahalanobis and Procrustes distance was between the Hendijan and Kaki populations. The major differences observed were in head length, body height, caudal peduncle length, dorsal and pelvic fins position. It seems that the Hendijan and Kaki populations are distinct from others that might be due to environmental or genetic differences which could be cleared by molecular analysis.

Keywords: Geometric morphometry, Landmark, Morphological properties, Procrustes analysis.

Introduction

Based on the latest checklists, 298 species in 107 genera, 28 families, 22 orders and 3 classes have been reported from Iranian inland water basins (Esmaeili et al. 2018). The most diverse order is Cypriniformes (171 species, 59%). Six species of mugilids have been identified from the Iranian basins, including *Chelon auratus* (Risso, 1810), *Chelon saliens* (Risso, 1810) from Caspian Sea basin, *Ellochelon vaigiensis* (Quoy and Gaimard, 1825) from Tigris River drainage, *Mugil cephalus* Linnaeus, 1758, from Caspian Sea and Tigris River drainage, Bushehr and Hormuz basins, *Planiliza subviridis* (Valenciennes, 1836) from Tigris and Bushehr basins, and finally, *Planiliza abu* (Heckel, 1843), from Tigris River drainage and Bushehr basin (Esmaeili et al. 2017, 2018). The first three species were successful introductions to the Caspian Sea in the early nineteen nineties by the USSR.

The mullet, *Planiliza abu*, known in the region as *biah*, is one of the important fishes in the Persian Gulf basin from both ecological and commercial points of views. As a migratory fish, rivers of Tigris-Euphrates (Karkheh, Karun, and Arvandrud), Hormuz (Hasanlangi and Mehran), and Bushehr basin (Hendijan, Genaveh, Helleh, Kaki, and Mond) play important roles in accommodating this species (Keivany et al. 2016).

Studying flexibility of morphology among populations of a species could facilitate understanding of environmental effects on different populations (Adams and Collyer 2009, Mouludi-Saleh et al. 2017, 2018, Banimasani et al. 2018). Body shape is one of the important features of fish which can directly affect the nutritional efficiency, reproduction and survival in aquatic environments (Guill et al. 2003). On the other hand, it is affected by temperature, salinity, food resources and predators (Turan et al. 2004).

Geometric morphometrics, used in this study, is defined as a statistical study of biological shapes and shape variations among different populations, and it allows the characterization of growth trajectory and the visualization of allometric growth (Zamani-Faradonbe et al. 2020). Many reports on applications of geometric morphometric method in different biological fields including fisheries are available. This method offers a powerful analytical and graphical tools for the quantification and visualization of morphological variations within and among organisms (Alberch et al. 1979). The aim of this study was to compare the body shape variations of *P. abu* in five rivers of Bushehr basin using geometric morphometrics.

Materials and Methods

Some 162 specimens of *Planiliza abu* were collected from five rivers located in Bushehr basin in 2009-2010 (Figure 1) using a seine net. After anesthetizing the specimens in 1% clove oil solution and fixing in 10% neutralized formalin, they were transferred to the Isfahan University of Technology Ichthyology Museum (IUT-IM) for further studies. The left sides of the specimens were photographed using a Canon digital camera (8 MP). Some 18 landmarks (Table 1) on two-dimensional images were selected using Tpsdig2 (Figure 2). Then, they were overlaid to extract the form data and remove non-form data such as size, position and direction by General Procrustes Analysis (GPA). Body shape data were analyzed using multivariate analyses; Principal Component Analysis (PCA) and Canonical Variate Analysis (CVA) in PAST computer program.

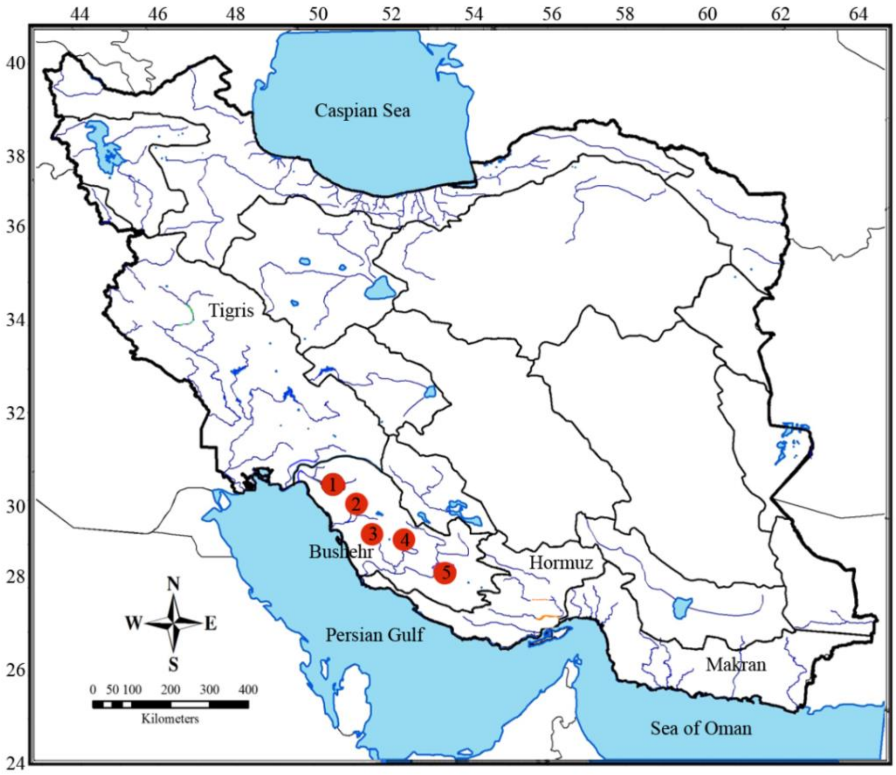

Figure 1. Sampling cites of *Planiliza abu* populations in Bushehr basin of Iran (1. Hendijan, 2. Genaveh, 3. Helleh, 4. Kaki, 5. Mond) (After Keivany et al. 2016).

Table 1: List of the defined 18 landmarks on *Planiliza abu* from Bushehr basin

Point number	Position of the points on the fish body
1	Snout tip
2	Anterior point of the eye
3	Posterior point of the eye
4	Posterior end of skull
5	Origin of the first dorsal fin
6	End of the first dorsal fin
7	Origin of the second dorsal fin
8	End of the second dorsal fin
9	Above the base of the caudal fin
10	Below the base of the caudal fin
11	End of the anal fin
12	Origin of the anal fin
13	End of the pelvic fin
14	Origin of the pelvic fin
15	Ventralmost point of the opercle
16	End of the pectoral fin base
17	Origin of the pectoral fin base
18	Posterior end of the opercle

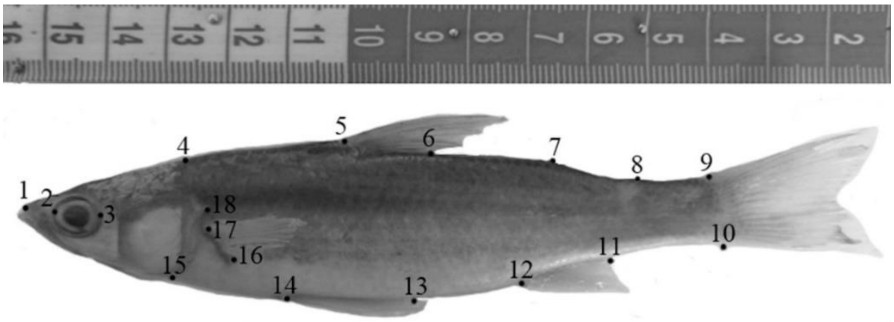

Figure 2: The 18 selected landmarks on the specimens of *Planiliza abu* from Bushehr basin.

Results

Based on the PCA analysis, 36 main factors were extracted and five components were higher than the cutoff point of Jollieff line. These five components accounted for 62% of the variances (Table 2). They were all overlapping, but the Kaki was relatively separate from other populations, especially from the Hendijan and Helleh (Figure 3). The major differences observed along the positive side of PC I included repositioning in the first dorsal fin (landmarks 5 and 6), second dorsal fin (landmarks 7 and 8), pelvic (landmarks 13 and 14), and anal (landmarks 11 and 12) fins. The major differences observed along the positive side of PC II included repositioning in the first dorsal fin (landmarks 5 and 6) and pectoral fin (landmarks 16 and 17) (Figure 4).

Table 2: %Variance and eigenvalues of the main components of the body shapes in *Planiliza abu* populations in Bushehr basin

Components	Eigenvalues	%variance
1	0.0011	29
2	0.00045	11
3	0.00037	9
4	0.00029	7
5	0.00024	6
Total		62

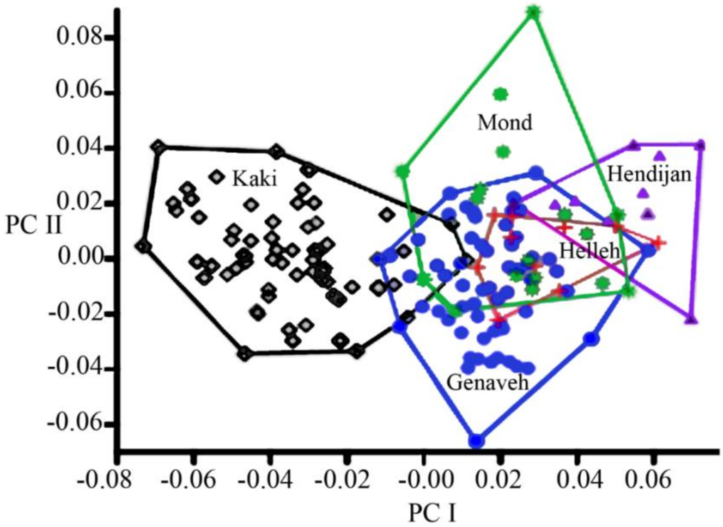

Figure 3: Principal components analysis graph of body shapes for *Planiliza abu* populations in Bushehr basin.

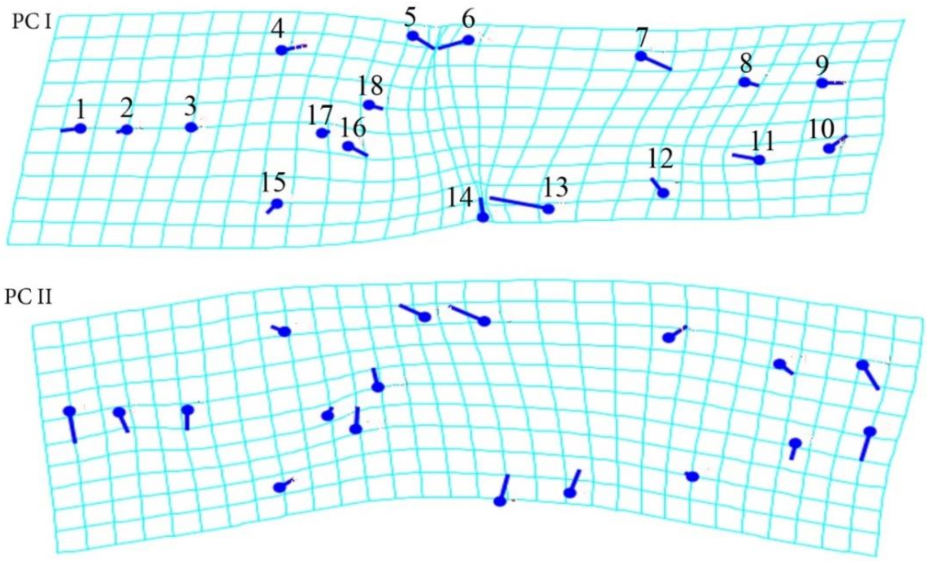

Figure 4: Body shape variations in *Planiliza abu* populations in Bushehr basin along the PC I and PC II.

In the CVA analysis of the shape data, the CVA based on the permutation *P* value indicated significant differences between the Hendijan and Kaki populations, but not among other populations (Figure 5). The highest Mahalanobis and Procrustes distances were 10.086 and 0.096, respectively, which were between the Hendijan and Kaki populations (Table 3). The major differences observed along the positive side of CV I included repositioning in the second dorsal fin (landmarks 7 and 8) and pectoral fin (landmarks 16 and 17) and pelvic fins (landmarks 13 and 14) and caudal peduncle length. The major differences observed along the positive side of CV II included the snout length (landmarks 1 and 2), second dorsal fin (landmarks 7 and 8) and pectoral fin (landmarks 16 and 17) and pelvic fins (landmarks 13 and 14) and caudal peduncle length (Figure 6).

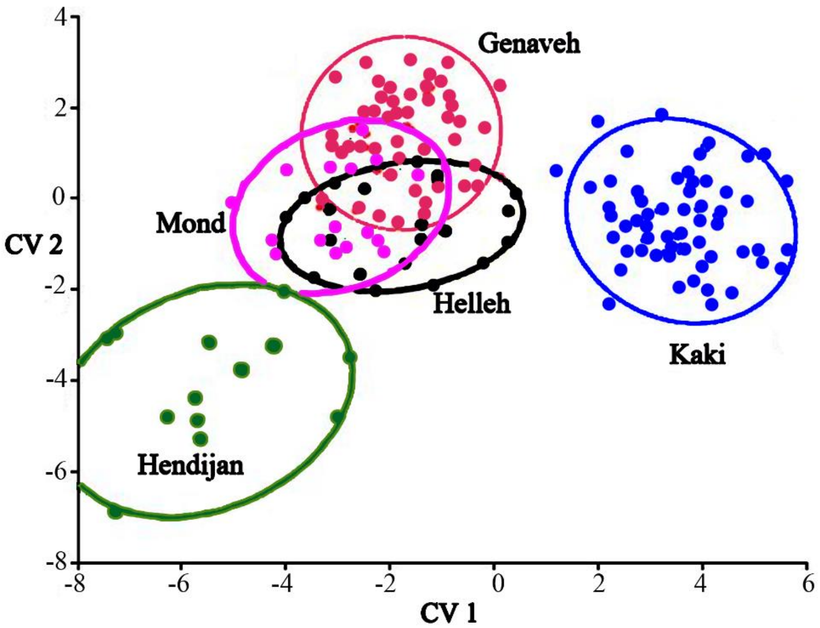

Figure 5: Canonical variate analysis graph of body shape for *Planiliza abu* populations in Bushehr basin.

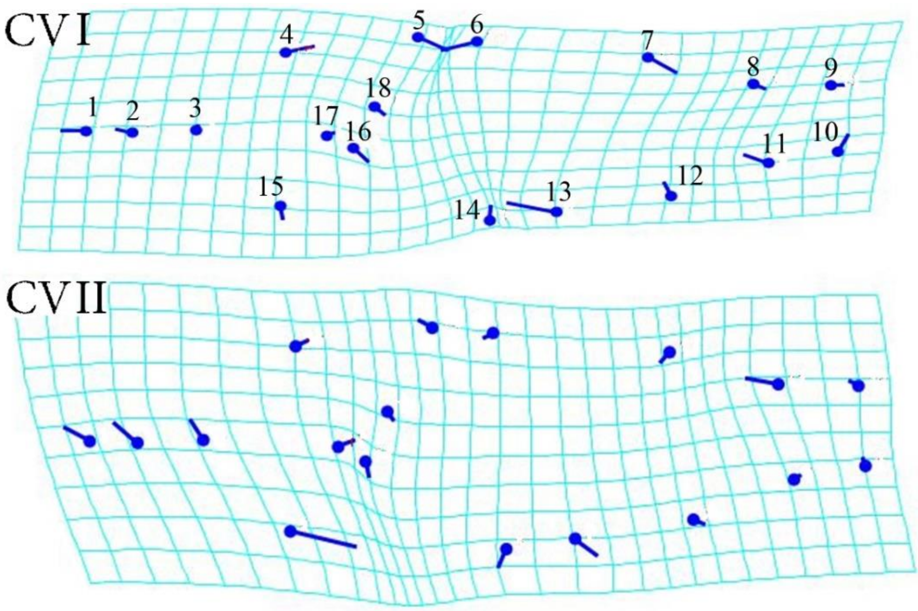

Figure 6: Body shape variations in *Planiliza abu* populations in Bushehr basin along the CV I and CV II.

Table 3: Mahalanobis (M) and Procrustes (P) distances of the body shapes in CVA for *Planiliza abu* populations in Bushehr basin

River	Kaki		Hendijan		Helleh		Genaveh	
	M	P	M	P	M	P	M	P
Helleh							3.4	0.035
Hendijan					6.2	0.051	7.0	0.065
Kaki			10.1	0.96	6.0	0.70	5.7	0.057
Mond	7.4	0.067	7.0	0.05	5.3	0.041	4.6	0.037

Discussion

Fish exhibit high variations in morphological traits at both inter- and intra-population levels, and are highly susceptible to environmental changes due to the development of morphological changes to adapt to new conditions (Stearns 1986, Keivany et al. 2016). Fish show a wide range of intra-thoracic variations that are important ecologically and evolutionally. Without physical barriers to genetic flow and fish migration, there is little opportunity for local adaptation that can lead to population uniformity (Robinson and Wilson 1994). The results of the present study showed some significant morphological differences among the *Planiliza abu* populations, especially between the Hendijan and Kaki. Different morphological characteristics of populations can be due to either genetic differentiation or phenotypic plasticity in response to environmental parameters of their habitats (Jalili et al. 2015, Eagderi et al. 2013, Razavipour et al. 2015, Keivany and Ghorbani-Ranjbari 2017). Environmental factors through natural selection can increase the efficiency of a phenotype among the members of a population and thus is led to morphological isolation in different habitats (Smith and Skulason 1996, Keivany and Arab 2017). River populations have a longer snout and a shallower body and caudal peduncle relative to lake populations. The shape of the mouth is also, related to the feeding habits of the fish and similar results were found in other studies (e.g., Barlow 1961, Langerhans et al. 2003, Mouludi-Saleh et al. 2017).

Body shape and fin forms are important traits that are influenced by environmental conditions of rivers (Douglas and Matthews 1992, Tajik and Keivany 2018a, 2018b). So, by studying these traits, we can predict what conditions govern a habitat. The small size of the body and the stretched body shape have also been proven in fish inhabiting rivers with high flow rates (Langerhans et al. 2003, Paez et al. 2008). This adaptation in aquatic ecosystems is a result of having to compromise with hydrodynamic forces to save energy during bio-related behaviors. Morphological variability is not always indicative of environment, and genetic differences of the populations might be involved. Thus, it is suggested to examine the populations with genetic and molecular methods.

Since temperature, electrical conductivity (EC) and total dissolved solids (TDS) are different in these rivers, so it is expected to find some differences among the populations (Baumgartner et al. 1988, Schluter and McPhail 1992, Langerhans et al. 2003, Tahmasebi et al. 2017, Vogel 1994). Geographical isolation also could be a cause for these differences (Anvarifar et al. 2013, Smith and Skulason 1996, Jerry and Cairns 1998, Guill et al. 2003). Similar studies on other species of Iran, more or less, reached the same results; Keivany and Arab (2017) found differences among eight populations of *Capoeta trutta* (Heckel, 1843) from the Karun River, Keivany and Ghorbani-Ranjbari (2017) in six populations of *Barilius mesopotamicus* Berg, 1932 in Bushehr basin, Eagderi et al. (2013) in *Alburnoides eichwaldii* (De Filippi, 1863) from the Caspian Sea basin. Body shape of *Aphanius sophiae* (Heckel, 1847) (Eagderi and Kamal 2013), *Capoeta gracilis* (Keyserling, 1861) in Tadjan River (Anvarifar et al. 2013), *C. aculeata* (Valenciennes, 1844) , *C. gracilis, C. trutta, C. saadii* (Heckel, 1849) (Razavipour et al. 2015) and *Squalius turcicus* De Filippi, 1865, *Squalius berak* Heckel, 1843, *Squalius namak* Khaefi, Esmaeili, Sayyadzadeh, Geiger and Freyhof, 2016 in four basins of Iran were also compared (Mouludi-Saleh et al. 2017).

Conclusions

It could be concluded that some of the *Planiliza abu* populations in the Bushehr basin are morphologically variable. The most difference is between Hendijan population in the most northern part of the basin and the Kaki population in the southern part of the basin. The Helleh population is also somewhat different from Hendijan and Kaki populations. The observed differences could be due to living in variable environments or genetic. Thus, molecular analysis is needed to confirm the observations.

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