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Original Article

The impact of Manjil and Tarik dams (Sefidroud River, southern Caspian Sea basin) on morphological traits of Siah Mahi *Capoeta gracilis* (Pisces: Cyprinidae)

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Abstract: It has been postulated that the building of the Manjil and Tarik dams on Sefidroud River has led to the body shape variation of *Capoeta gracilis* in up- and downstream populations due to the isolation. In this study, Geometric morphometric approach was used to explore body shape variations of *Capoeta gracilis* populations in up- and downstream Manjil and Tarik dams in Sefidroud River from south of the Caspian Sea basin. The shape of 90 individuals from three sampling sites were extracted by recording the 2-D coordinates of 13 landmark points. PCA, CVA, DFA and CA analysis were used to examine shape differences among the populations. The significant differences were found among the shape of the populations and these differences were observed in the snout, the caudal peduncle and the head. The present study indicated the body shape differences in the populations of *Capoeta gracilis* in the Sefidroud River across the Manjil and Tarik dams, probably due to the dam construction showing anthropogenic transformation of rivers influences body shape in an aquatic organism.

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Introduction

Many freshwater fish species are typically threatened by effects of human activities, such as habitat demolition and fragmentation (Yamamoto et al., 2006). Biodiversity is based on genetic diversity, which is likely to be influenced by habitat fragmentation (Hanski and Gaggiotti, 2004), one of the most prevalent negative man-induced processes for nature conservation (Heywood, 1995). Construction of dams affects fish movements, which may conduct to differentiation of populations (Meldgaard et al., 2003). It has been suggested that fragmentation of river ecosystems may result in the conversion of migration patterns between fish populations (Horvath and Municio, 1998; Craig, 2001; Jager et al., 2001), 'producing genetic stocks' that are reproductively isolated units and are genetically different from other stocks (Carvalho and Hauser, 1994). Water impoundment also changes the natural landscapes of a river by its transformation into reservoirs (Haas et al., 2010). This can cause novel ecological and evolutionary challenges (Baxter, 1977) for fishes that need to be responded for adaptation to new condition of ecosystem.

The genus *Capoeta* contains potamodromous cyprinid fishes with about 10 species, of which seven occur in Iran and it is one of the most taxonomically complex genera of Cyprinidae (Coad, 2013; Abdoli et al., 2008; Samaee et al., 2009). Species and subspecies of *Capoeta* occur sympatrically and allopatrically in all Iranian freshwater basins (Saadati, 1997). This genus inhabiting both lotic and lentic habitats (Samaee et al., 2006). Siah Mahi, *Capoeta gracilis*, is a predominant fish of the Sefidroud River. This species matures within 2–4 years of age and at a length of 15–20 cm, some

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populations attains maturity as early as their first year and at a size of 10 cm (Coad, 2013). In addition to its ecological significance, *C. gracilis* is an important species being harvested for sport and inland water fishing (Kiabi et al., 1999). Two sexes of *C. gracilis* have similar morphometrical characteristics (Anvarifar et al., 2011).

Geometric morphometric is a modern approach to analyze the shape of body (Bookstein, 1991). Application of this method in fish body shape has been reported (Loy et al., 1999) and has been considered as a useful tool to assess fish populations. This method describes organisms' body shape in terms of x and y (and also z) coordinates, obtained from a set of landmark points (Loy et al., 1999). Landmark points are defined as homologous points that bear information on the geometry of biological forms (Bookstein, 1991). This method quantifies changes in shape, and patterns of morphometric variations within and between groups if each individual deviates from an average shape, i.e. the consensus configuration (Cadrin, 1999).

The Sefidroud River, with 765 km length is one of the important rivers in the southern Caspian Sea basin (Aghili et al., 1999). The Manjil and Tarik dams were constructed on the Sefidroud River in 1962 and 1968, respectively (Najmaii, 2004). Since there is no information on the impact of the Manjil and Tarik dams on morphological characteristics of Siah Mahi as an endemic fish of Sefidroud River, this study was conducted to assess the impact of the Manjil and Tarik dams on the body shape of *C. gracilis* using geometric morphometric method. The results of this study can help to understand better the response of this species to alterations in natural flow regimes as a result of dam construction.

Materials and methods

A total of 90 individuals of *C. gracilis* were collected from three sampling sites, one each from upstream of the Manjil dam (36° 77′ 89″ N, 49° 15′ 25″ E; 40 individuals: station 1), downstream of the Manjil dam which is upstream of the Tarik dam (36° 46′ 52.86″ N, 49° 61′ 18″ E; 17 individuals: station 2) and downstream of the Tarik dam (36° 99′ 15″ N, 49° 57′ 71″ E; 33 individuals: station 3), in November 2013 by electrofishing (Fig. 1). Care was taken to collect specimens of similar size to remove any allometric difference. The specimens were anaesthized, then fixed in 10% formaldehyde at the sampling site and transferred to the laboratory.

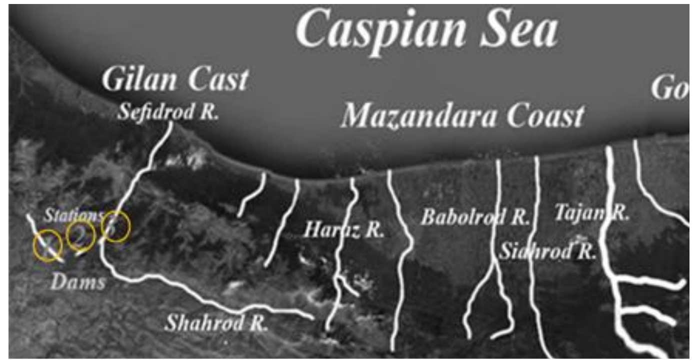

Figure 1. Sampling sites: (1) upstream and (2) downstream of the Manjil dam and (3) downstream of the Tarik dam on Sefidroud River (north of Iran).

The left side of the specimens (with dorsal and anal fins were held erected using pins) were photographed using digital camera (Cybershot DSC-F505; Sony, Japan), thirteen landmark points were defined and digitized on two-dimensional images using TpsDig2 (Rohlf, 2005; Fig. 2). The landmark data after generalized procrustes analysis (GPA) to remove non-shape data, analyzed using principal components analysis (PCA) to explore patterns of variation in their body shape. In addition, to assess the variation among the three studied populations, canonical variate analysis (CVA) and MANOVA were used (Rohlf, 1993).

A discriminant function analysis (DFA) was also performed to compare the body shape of the populations using consensus configuration and deformation grids. As a complement to discriminant analysis, morphometric distances among the body shape consensus of three studied populations were measured using a cluster analysis (Veasey et al., 2001) by adopting the Euclidean square distance as a measure of dissimilarity and the UPGMA method as the clustering algorithm (Sneath and Sokal, 1973). All analyses for morphometric data were performed using the MorphoJ software package and PAST.

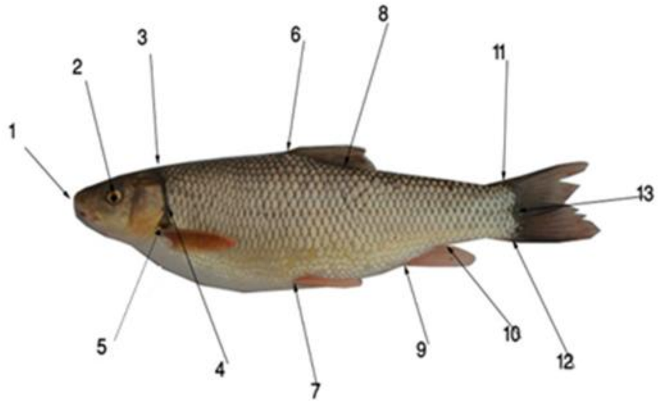

Figure 2. Defined landmark-points to extract the body shape data of *Capoeta gracilis*. 1. tip of snout; 2. center of eye; 3. posterior end of forehead (end of frontal bone); 4. posterior edge of operculum; 5. dorsal origin of pectoral fin; 6. anterior of dorsal fin base; 7. origin of pelvic fin; 8. posterior end of dorsal fin base; 9. anterior of anal fin base; 10. posterior of anal fin base; 11. posterodorsal end of caudal peduncle, at the nadir; 12. posteroventral end of caudal peduncle, at the nadir and 13. posterior most of body lateral line.

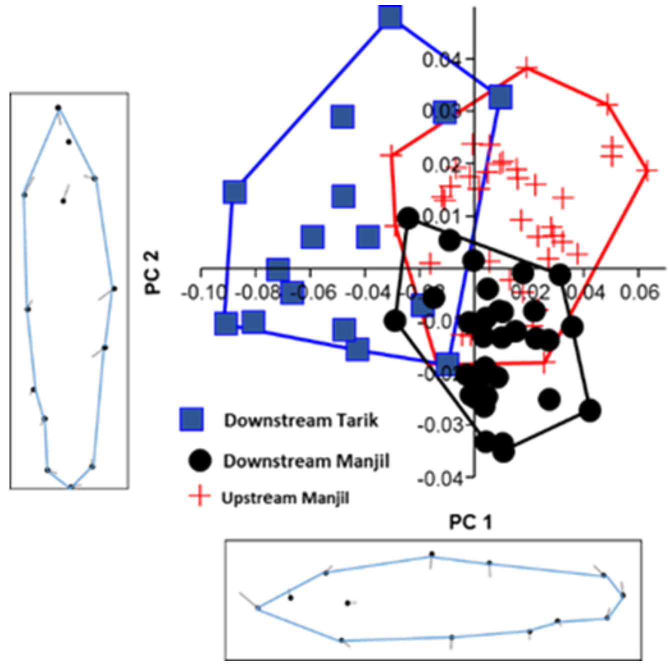

Figure 3. Scatter plot of individual scores from the first two principal components based on 13 landmarks, distinguishing *C. gracilis*. Vectors indicating the changes in the relative position of landmarks for each PC.

Results

PCA for all specimens explained 70.2% of shape variations by the first two PC axes extracted from the variance-covariance matrix (PC1 = 45.38%, PC2 = 15.67% and PC3 = 9.16). Separation of the three studied populations showed along the first and second axis, respectively (Fig. 3) revealed that the populations were clearly distinct from each other. PC1 scores were related to elongation of the head area and increase of caudal peduncle width, whereas PC2 scores were related to decrease of the head size and body depth.

The MANOVA/CVA analysis showed significant differences between the populations in terms of body shape ($P < 0.0001$; Fig. 4). The CVA plot indicated that body shapes in the three studied groups were completely separated from each other.

DFA on relative warps classified specimens into the correct groups at the rate of 97.6% in origin data and 93.9% in cross-validation (Table 1) indicating a high differentiation among the populations of *C. gracilis*. The body shape differences (mean body shape) from the stations to other ones have shown in Figure 5. The deformation grids were extracted from the DFA for pairwise groups. Based on observed differences, the specimens of station 3 (upstream of the Manjil dam) had larger heads, deeper caudal peduncles and

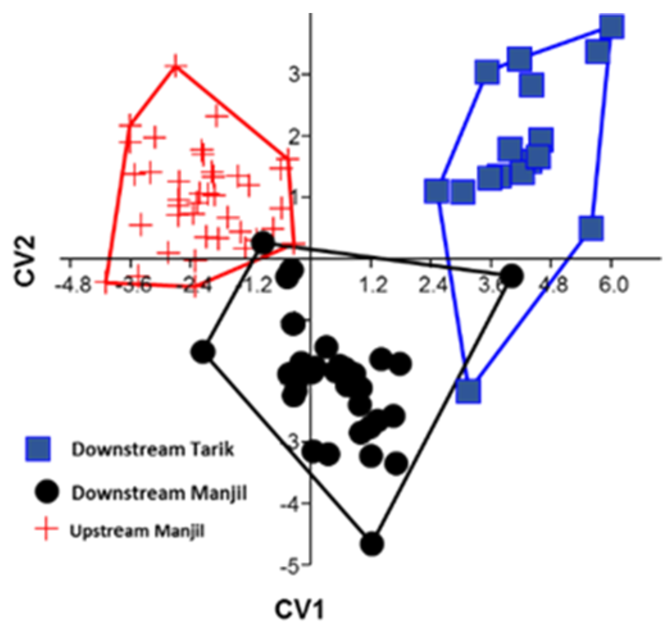

Figure 4. Canonical variates analysis (CVA) based on 13 landmarks, distinguishing *Capoeta gracilis* along two canonical axes.

dorsal position of the snout relative to those from the second station. Also, comparison of the populations in up- and downstream Manjil dam showed that the upstream population had smaller heads, ventral position of the snout and deeper body. The downstream Tarik dam population showed a little deeper body than those of the upstream Manjil dam.

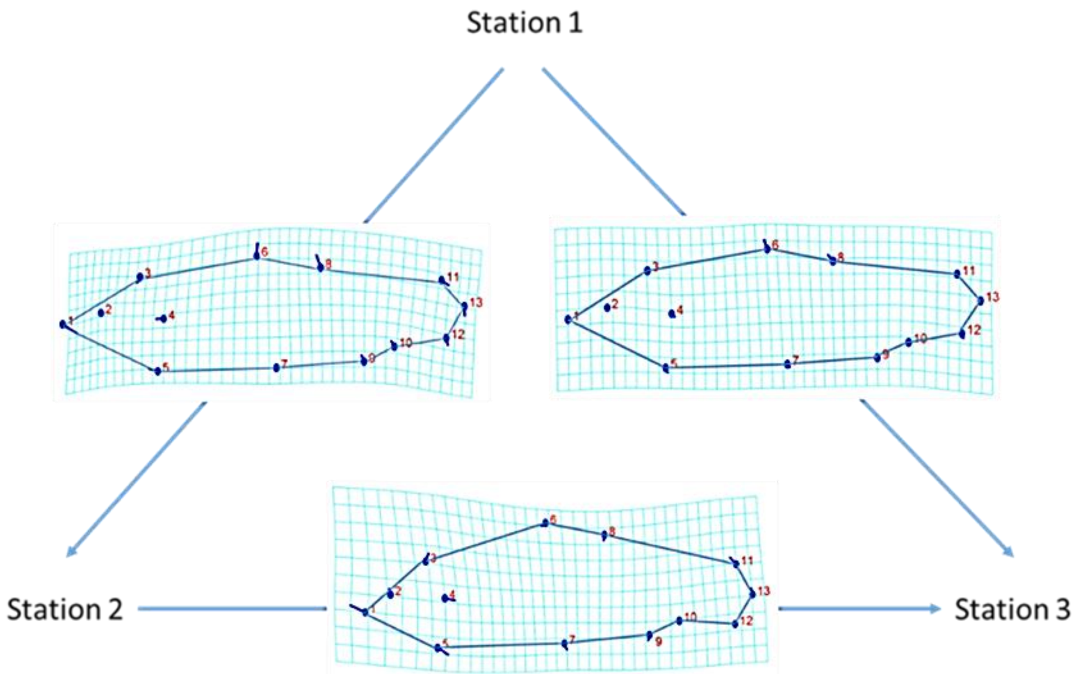

Figure 5. Comparison of the body shape between three studied populations (Deformation grids show differences of body shape from consensus shape of a station to another one).

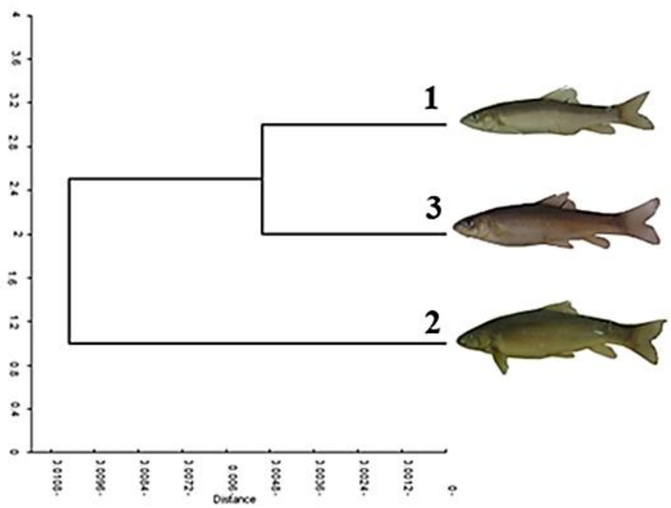

Figure 6. The UPGMA graph for the three studied populations of *C. gracilis*.

The UPMGA analysis divided the studied populations into two major distinct groups. The first branch was the upstream Manjil dam (station 1) and downstream Tarik dam (station 3) and the second branch was comprised of downstream Manjil dam (station 2; Fig. 6). The mahalanobis distance among the three studied groups of *C. gracilic* is shown in Table 2.

Discussion

Morphometric analysis has been significantly enhanced using image processing techniques and in this regard, the geometric morphometrics (GM) approach is a powerful tool that can complement other methods for stock identification (Cadrin, 1999). In the present study, landmark-based GM technique was applied to study the body shape changes among *C. gracilis* populations as a result of the Manjil and Tarik dams in the Sefidrud River. The present study detected morphological differences in body shape of the studied populations. Effects of dams on fish populations have extensively been documented in the recent years (Yamamoto et al., 2006; Dakin et al., 2007). Dakin et al. (2007) showed that the Morgan-Falls dam on the Chattahoochee River caused morphological differences between two populations of shoal bass, *Micropterus cataractae*, especially in the upstream population compared to the downstream one. Yamamoto et al. (2006) also noted habitat fragmentation caused by damming resulted in different body shape in white-spotted Charr, *Salvelinus leucomaenis* populations 20 years after the construction of the dam. Anvarifar et al. (2011) found two distinct populations of

Table 1. Classification matrix showing the number and percentage of individuals that were correctly classified. (Bold values indicate correct classifications).

Area	Upstream Manjil dam	Dawnstream Manjil dam (upstream Tarik dam)	DawnstreamTarik dam
Original			
Upstream Manjil dam	**100**	0	0
Dawnstream Manjil dam (upstream Tarik dam)	0	**93.3**	6.7
Dawnstream Tarik dam	3.3	0	**96.7**
Cross-validated			
Upstream Manjil dam	**94.6**	2.7	2.7
Dawnstream Manjil dam (upstream Tarik dam)	0	**93.3**	6.7
Dawnstream Tarik dam	6.7	0	**93.3**

Table 2. Mahalanobis distances among the three studied groups of *Capoeta gracilic*.

	Station 1	Station 2
Station 2	5.1774	
Station 3	3.8369	4.3906

Capoeta capoeta gracilis at the upstream and downstream of the Shahid-Rajaei dam on the Tajan River. The long-term isolation of populations and interbreeding may lead to morphometric variations between populations, and provides a basis for population differentiation.

The body shape variations of *C. gracilis* populations in upstream and downstream of the dam may be caused by limitation of downstream dispersal of fish, and elimination of upstream migration (Dakin et al., 2007). The dams obstruct the upward migration of fish, especially the migratory species resulting in an ecological trap for migratory fish that ascend the fish passages (Pelicice and Agostinho, 2008). Many fish species shows morphological differences between different habitats (Robinson and Wilson, 1994; Smith and Skulason, 1996; Taylor, 1999; Jonsson and Jonsson, 2001) and intraspecific polymorphism is commonly believed to arise from divergent selection pressures between various environments (Robinson and Wilson, 1994; Smith and Skulason, 1996; Schluter, 2000).

We have found almost similar body shape pattern in the specimens of stations 1 and 3 i.e. they differ significantly from the specimens which were collected between these two dams. Differentiation between the samples from adjacent stations may be due to the geographic isolation of stations by artificial obstacles that allow morphological differentiation to proceed independently at each station (Samaee et al., 2006). Different body shape pattern of the second station suggests that this population may have a smaller population size (founder effect) or procured these morphological traits in responses to different environmental conditions (compared to two others). Our results suggest that characteristics of created habitats (as result of dam construction) may determine evolutionary and ecological conditions driving alternations in the body shape of its resident fishes (Langerhans et al., 2003).

The main differences among the studied populations were found in the head region, the caudal peduncle and the body depth. It is common that morphological characteristics can show high plasticity in response to different environmental conditions (Wimberger, 1992). The new environmental conditions of the upstream and downstream regions as result of the anthropogenic transformation of river may underline the shape differentiation among these three sites (Haas et al., 2011). Hence, the differences in body shape may be related to morphological adaptation to new habitats. For example, deeper body and caudal peduncle of the third station’s specimens can be translated to be an adaptation for the rapid acceleration and maneuverability, whereas, the more fusiform body (a more streamlined body) of the population of second station may lower the drag force (Nacua et al., 2010). Also, differences in the head region may indirectly be related to changes in food seeking habits reflecting the difference between feeding habits and availability of food resources (Langerhans et al., 2003). Dams can alter the feeding habits, availability of food items, growth pattern and reproductive strategy of fish species living upstream and downstream of a river which these factors can influence the morphological differentiation in fishes (Akbarzadeh et al., 2009).

In conclusion, the present study found differences in the body shape of *C. gracilis* populations fragmented by the Manjil and Tarik dams on the Sefidroud River probably as a result of dam construction showing that anthropogenic transformation of rivers influences the body shape in an aquatic organism. In addition, this study indicated that dam play an effective role in body shape of fishes and can be considered as main evolutionary drivers acting on aquatic biodiversity.

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