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Morphometric variation of *Periophthalmus waltoni* Koumans, 1941(Teleostei: Gobiidae) in the Persian Gulf and Gulf of Oman

Ghanbarifardi, M.[a*],Aliabadian, M.,[a,b]Esmaeili, H.R.[c]

[a]*Department of Biology, Faculty of Sciences, Ferdowsi University of Mashhad, Mashhad, Iran*
[b] *Research Department of Zoological Innovations (RDZI), Institute of Applied Zoology, Faculty of Sciences, Ferdowsi University of Mashhad, Mashhad, Iran*
[c] *Department of Biology, College of Sciences, Shiraz University, Shiraz, Iran*

Morphometric variation of 154 specimens of *Periophthalmus waltoni* from seven different sites in the Persian Gulf and Makran Sea (Gulf of Oman) were analyzed based on ten morphometric characters. Canonical Variate Analysis of the sampling sites suggested a partial separation between the north-western sites and the central plus south-eastern sites. Moving larvae were probably the main factor connecting *P. waltoni* populations from different sites and keeping them similar, morphologically and probably genetically. We concluded that environmental factors could be the main explanation for morphological differences between *P. waltoni* specimens from different stations.

Key words: Gulf of Oman, morphometric variables, mudskippers, Persian Gulf

INTRODUCTION

The Walton's mudskipper, *Periophthalmus waltoni* Koumans, 1941 is one of the three species of oxudercine gobies (Gobiidae sensu Agorreta et al., 2013) living in the Persian Gulf and Gulf of Oman (Carpenter et al., 1997; Murdy, 1989). This species has been recorded in a wide range of intertidal habitats, including tidal mudflats and mangrove forests (Clayton, 1985; Rahimian & Pehpuri, 2006; Ghanbarifardi & Malek, 2007), and ecosystems characterized by different physico-chemical regimes (Yao, 2008).

Being a partially closed sea basin, the Persian Gulf presents rather unique characteristics. Its entrance is the narrow Strait of Hormuz, and water circulation with the Makran Sea (Gulf of Oman) is limited. It is very shallow compared to other seas of comparable size, the average depth being only 35 m, and huge expanses are only a few meters deep; its greatest depth, at a few km from the Strait of Hormuz, is only 100 m. As a result of this physiography, the Persian Gulf experiences large seasonal fluctuations of surface water temperature. Temperature varies in surface coastal waters from as low as 10ºC in winter to 35ºC in summer, reaching higher values in shallow lagoons and tidal flats (Randall, 1995). Salinity is high, due to low rainfall and high evaporation rates, except in the north nearthe Arvandrud (Arvand River) where it is moderated by the discharge of the Tigris and Euphrates Rivers. Salinity can reach 40 ppt in open waters and up to 50 ppt in shallow lagoons (Randall, 1995). The marine biodiversity of the Persian Gulf is relatively low (Swift & Bower, 2003).

By contrast, the Gulf of Oman is broadly open, and 3/4 of its area is ≥ 1000 m deep, being up to 3000m deep in its outer portion (Randall, 1995). Because of its better circulation, closer contact with the Indian Ocean, and limited extension of shallow areas, the physical and chemical parameters of the Gulf of Oman are much more stable than in the Persian Gulf (Thoppil & Hogan, 2010).

Phenotypic plasticity of fishes is often observed as an ontogenetic response to environmental change in the form of physiological, behavioural and morphological modifications (Fitzgerald et al., 2002; Langerhans et al., 2003; Helland et al., 2009; Nacua et al., 2010).

*Corresponding Author: *Meghfardi@gmail.com*
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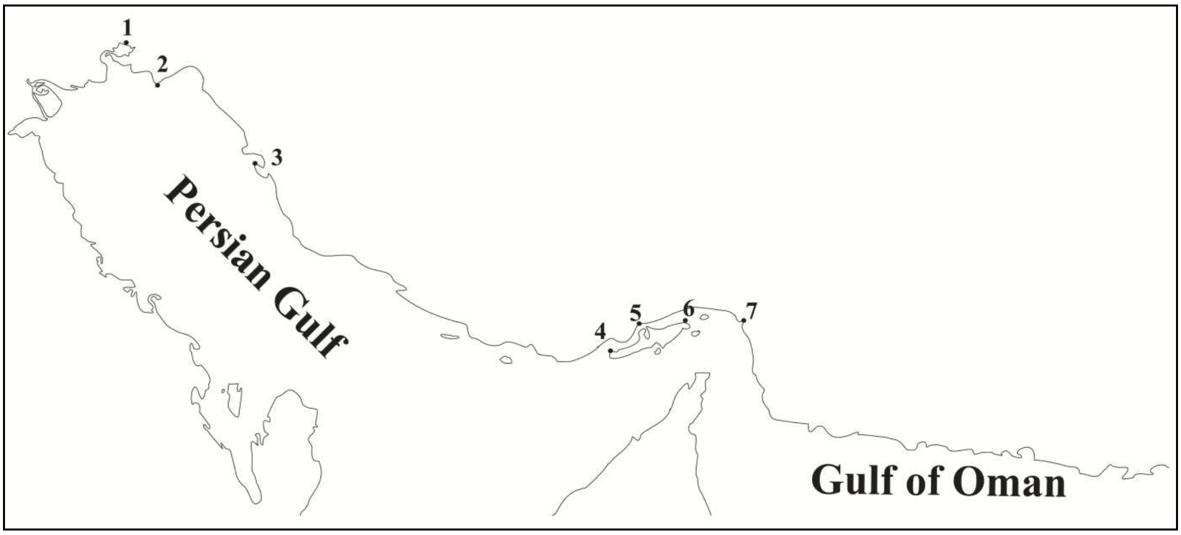

FIGURE1. Sampling sites: 1.Mahshahr, 2. Hendijan, 3. Bushehr, 4. Qeshm1, 5. Khamir, 6. Qeshm 2, 7. Minab.

The objective of this study is to compare the morphometrics of *P. waltoni* samples collected in different sites throughout the Persian Gulf and Makran Sea, and to test for differences among geographic populations.

MATERIAL AND METHODS

Specimens of *P. waltoni* (n= 154) were collected in seven sites of the Persian Gulf and Gulf of Oman (Tab.1, Fig. 1). Ten morphometric variables were measured (Table 2): ED, HD, HL, LD_1, LD_2, GD_1D_2, LA, DAC, LPc, DPl (Tab. 2; Fig. 2).Fishes were collected during low tide by hand net, preserved in 5% formalin, and deposited in the Zoological Museum, University of Tehran (ZUTC).Three of mentioned morphometric variables are used in this study for the first time, including distance between terminus of anal fin to ventral point of insertion of caudal fin (DAC), Least height of the pectoral fin base (LPc) and Distance between the base of the pelvic spines (DPl). Distance between terminus of anal fin to ventral point of insertion of caudal fin (DAC) was measured as the linear horizontal distance from the terminus of anal fin to ventral point insertion of caudal fin. Least height of the pectoral fin base (LPc) was measured as the linear vertical distance where the pectoral fin has the least width. Distance between the bases of the pelvic spines (DPl) was measured as the linear horizontal distance from the first spine of the pelvic fin to the last one at the ventral side. Standard length (SL) and total length (TL) were also measured, but not included in the analyses, since they do not convey information about shape. Linear distances between morphological landmarks were measured with a digital calliper, to the nearest 0.1 mm. To explore the distribution of the measured specimens in a multivariate morphometric space, Canonical Variate Analysis was conducted on the morphometric datasets and descriptive statistics of morphometric variables were computed; moreover, descriptive statistics of all characters in every station were calculated (SPSS 16.0, SPSS Inc., Chicago). CVA results were summarized in a cluster analysis using PAST (Paleontological Statistics) (Hammer et al., 2001). To suppress the size factor, defined as the geometric mean of all morphometric variables, and create scale-free variables, we followed the method of Darroch & Mosimann (Darroch & Mosimann, 1985; Jungers et al., 1995); the morphometric matrix was first logarithmically transformed, and the arithmetic mean of all variables was subtracted from each variable (Polgar et al., 2013).

TABLE 1. Sampling sites, types of habitat and numbers (N) of collected specimens of *P. waltoni*.

Site	Coordinates	Habitat	N
Mahshahr	30°28'N 49°11'E	tidal mudflat and mangrove forest	11
Hendijan	30°6'N 49°46'E	tidal mudflat	32
Bushehr	28° N 51°20'E	tidal mudflat	19
Qeshm1	26°43' N 55°18'E	tidal mudflat	24
Khamir	26°54' N 55°35'E	mangrove forest	23
Qeshm2	26°58' N 56°4'E	tidal mudflat and mangrove forest	20
Minab	27°3'N 56°51'E	tidal mudflat	25

TABLE 2. Morphometric variablesof *P. waltoni* used in this study.

Morphometric variable	Abbreviation	Reference
Eye diameter	ED	Lawson, 2010
Head depth	HD	Coad,2013
Head length: linear distance from the anteriormost tip of the head, to the posteriormost margin of the opercular bones	HL	Polgar et al., 2013
Length of first dorsal fin base	LD_1	Jaafar and Larson, 2008
Length of second dorsal fin base	LD_2	Jaafar and Larson, 2008
Gap between D_1 and D_2	GD_1D_2	Jaafar and Larson, 2008
Length of anal fin base	LA	Jaafar and Larson, 2008
Distance between terminus of anal fin to ventral point of insertion of caudal fin	DAC	This study
Least height of the pectoral fin base	LPc	This study
Distance between the base of the pelvic spines	DPl	This study

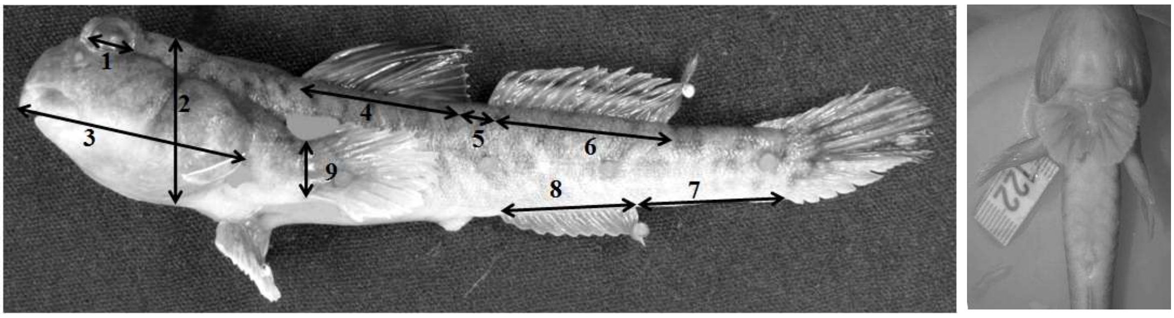

FIGURE 2. Morphometric characters of *P. waltoni* used in the present study. 1= Eye diameter (ED); 2=Head depth (HD); 3= Head length(HL); 4= Length of first dorsal fin base (LD_1); 5= Gap between D_1 and D_2(GD_1D_2); 6= Length of second dorsal fin base (LD_2); 7= Distance between terminus of anal fin to ventral point of insertion of caudal fin (DAC); 8= Length of anal fin base (LA); 9= Least height of the pectoral fin base(LPc); 10=Distance between the base of the pelvic spines (DPl).

TABLE3. Descriptive statistics of collected *P. waltoni* in each site. Abbreviations are explained in table 2.

	Stations	ED	HL	HD	LD1	LD2	GD1.D2	LA	DAC	LPc	DPl	TL	SL
Mahshahr	Mean	5.19± 0.90	24.40± 4.03	13.47± 2.39	20.22± 4.59	20.74± 3.14	2.91± 1.57	15.94± 2.84	18.84± 2.92	6.16± 1.30	5.49± 1.11	108.47± 18.61	87.44± 14.59
	Minimum	4.31	19.48	10.83	14.88	16.75	0.02	12.72	15.28	4.58	4.11	87.49	71.02
	Maximum	6.75	30.55	17.59	27.92	26.98	6.36	20.30	22.95	8.39	7.35	138.46	109.96
Hendijan	Mean	4.72± 0.67	25.67± 3.88	14.36± 1.84	20.00± 3.52	21.77± 2.83	3.24± 0.92	16.37± 2.19	18.04± 2.40	6.56± 0.98	5.93± 0.97	108.68± 14.41	88.04± 11.14
	Minimum	3.77	19.61	10.38	13.81	16.56	0.99	13.35	13.43	4.93	4.24	87.85	71.14
	Maximum	6.65	33.52	17.90	26.02	27.26	6.20	19.98	24.36	8.51	8.37	137.90	112.60
Bushehr	Mean	4.38± 0.93	23.04± 6.75	14.10± 4.30	16.69± 5.70	19.06± 5.70	4.15± 1.02	14.36± 4.26	16.69± 4.19	5.70± 1.80	5.61± 1.86	96.98± 12.12	78.69± 12.45
	Minimum	3.02	13.88	8.80	9.09	12.35	2.50	9.24	11.02	3.31	3.32	62.63	51.06
	Maximum	6.04	41.19	26.19	29.77	35.15	6.61	26.26	26.38	10.92	11.14	168.59	136.30
Qeshm1	Mean	4.66± 0.49	24.79± 3.48	15.60± 2.17	18.63± 3.32	20.92± 2.71	3.69± 1.20	15.37± 1.98	18.08± 2.28	6.34± 0.91	5.90± 0.93	104.73± 12.82	84.97± 10.11
	Minimum	3.90	20.00	12.61	14.04	16.49	0.98	11.78	14.42	4.94	4.56	86.32	69.97
	Maximum	5.66	31.06	20.27	26.33	26.10	5.28	18.38	22.13	8.02	7.67	126.09	100.75
Khamir	Mean	4.60± 0.72	23.68± 4.55	14.58± 3.07	17.12± 5.12	19.66± 4.02	4.22± 1.62	14.51± 3.27	16.47± 3.13	5.83± 1.37	5.53± 1.25	97.01± 18.92	79.02± 14.97
	Minimum	3.39	16.60	9.31	9.36	13.71	1.70	9.98	11.30	3.24	3.55	69.56	55.95
	Maximum	5.90	33.40	20.50	27.86	27.50	7.61	20.84	22.86	8.66	8.09	138.66	110.04
Qeshm2	Mean	4.25± 0.54	22.07± 3.58	13.64± 2.11	15.94± 3.30	18.32± 2.57	3.36± 1.08	13.97± 1.77	16.53± 2.55	5.50± 0.90	5.11± 0.76	95.34± 13.57	77.57± 11.24
	Minimum	3.24	16.73	9.96	10.01	13.79	1.42	11.12	12.39	4.11	3.85	73.47	59.61
	Maximum	5.42	30.57	18.91	21.79	24.14	5.43	17.79	21.57	7.63	6.48	125.97	103.05
Minab	Mean	4.00± 0.52	18.66± 3.09	11.46± 2.07	13.11± 3.29	15.57± 2.63	3.81± 1.04	12.00± 1.90	14.23± 2.37	4.58± 0.95	4.47± 0.92	79.43± 13.08	64.75± 10.44
	Minimum	3.31	14.56	9.16	7.45	11.24	1.64	8.74	11.11	3.26	3.38	61.59	50.82
	Maximum	5.39	25.26	16.12	19.65	20.72	6.11	15.43	19.89	6.91	7.03	108.63	87.89
Total	Mean	4.51± 0.73	23.22± 4.77	13.93± 2.85	17.32± 4.67	19.46± 3.96	3.66± 1.24	14.64± 2.96	16.89± 3.10	5.82± 1.32	5.45± 1.23	98.38± 19.31	79.88± 15.35
	Minimum	3.02	13.88	8.80	7.45	11.24	0.02	8.74	11.02	3.24	3.32	61.59	50.82
	Maximum	6.75	41.19	26.19	29.77	35.15	7.61	26.26	26.38	10.92	11.14	168.59	136.30

TABLE 4.*P*-values for Mahalanobis distances among fishes of the seven sites. *P*-values are bold where they are >0.05.

Stations	Mahshahr	Hendijan	Bushehr	Qeshm1	Khamir	Qeshm2	Minab
Mahshahr	*	0.000	0.000	0.000	0.000	0.000	0.000
Hendijan	0.000	*	0.000	0.000	0.000	0.000	0.000
Bushehr	0.000	0.000	*	0.028	**0.095**	**0.081**	**0.105**
Qeshm1	0.000	0.000	0.028	*	0.028	**0.104**	0.000
Khamir	0.000	0.000	**0.095**	0.028	*	0.001	0.000
Qeshm2	0.000	0.000	**0.081**	**0.104**	0.001	*	0.020
Minab	0.000	0.000	**0.105**	0.000	0.000	0.020	*

RESULTS

Morphometric parameters did not show significant differences between sexes, therefore; females and males samples were subsequently treated as one group in each station.Descriptive statistics of all characters in every stationare presented in Table 3. CVA conducted on the Mahalanobis distances obtained from morphometric data showed significant pairwise differences among Mahshahr and Hendijan with other five stations (p-value<0.05, Table 4). The first four canonical variates (CVs) accounted for 51.7%, 34.5%, 7.3%, and 4.7% of total variance, respectively, with a cumulative proportion of 98.2%. CV1 separates the two western stations in the Persian Gulf (stations 1–2; Table 1) from the rest five stations in the Gulf of Oman (3-7) (Fig. 3). CVA correctly classified 56.5% of the grouped specimens of *P. waltoni* from different stations, illustrating the percentage of overlap among them. Dendrogram summarized the results of CVA (Fig. 4).

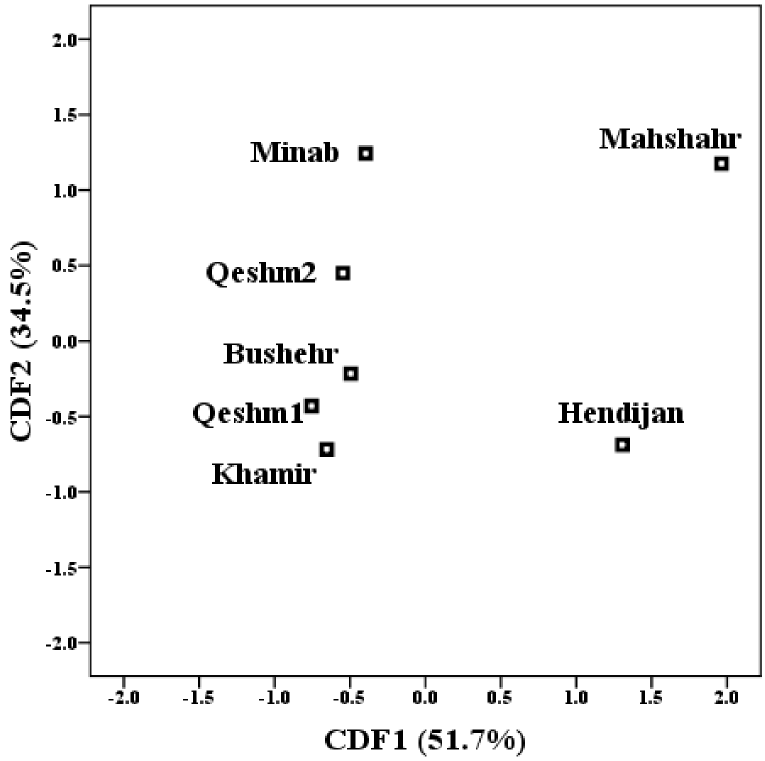

FIGURE3. Multivariate morphometric analyses of *P. waltoni* collected from seven sites. Axes indicate the two canonical discriminant functions that explained the highest percentage of total variance (in parentheses).

DISCUSSION

According to CVA scatter plot (Fig. 3), there is not a great morphometric difference among *P. waltoni* specimens from different sites. The main factor to connect *P. waltoni* populations from different sites and keep them similar, morphologically and probably genetically, is likey due to the movement of larvae between sites. Mudskipper larvae move within anticlockwise currents that flow from Gulf of Oman toward the Persian Gulf (Jones, 1986; Yao, 2008). Fish larval surveys in the coastal waters of the Persian Gulf demonstrated that Gobiidae larvae are abundant (Rabbaniha et al., 2013). It seems that *P. waltoni* specimens living in the Persian Gulf originated from *P. waltoni* population of the Gulf of Oman, just 20,000 years ago after last ice age (Bishop, 2003).

CV1 separated two western stations from other stations (Fig. 3) and these two western stations were nested in one cluster (Fig. 4). In addition, two main clusters in the dendrogarm separated two western stations from others. In the other words, cluster A is composed of Mahshahr and Hendijan (the two most western stations) while cluster B including the rest of five stations. Results of dendrogram were in congruence with CVA. Environmental factors like temperature and salinity were different in the western part of the Persian Gulf than other parts. These differences are caused mainly by the discharge of major rivers (Heleh, Zohrehand Arvand) into the west part of the Persian Gulf. Ghanbarifardi et al. (2014) have surveyed seven populations of *P. waltoni* from Persian Gulf and Gulf of Oman and concluded that differences in physicochemical parameters were the main potential factors to discriminate four populations of Persian Gulf from two populations of Gulf of Oman. The results of this study are compatible with the present survey.

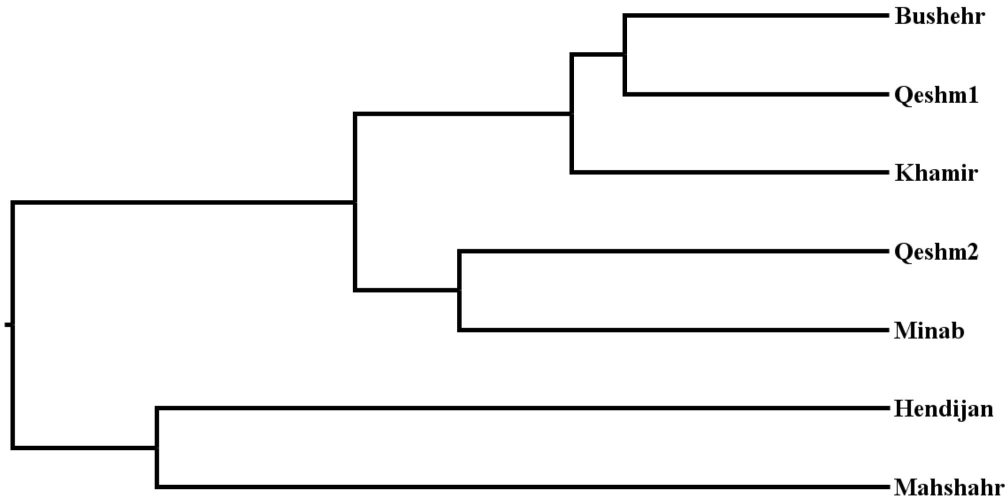

FIGURE 4. Dendrogram constructed from CVs at group centroids in specimens of *P. waltoni* collected from seven sites.

Phenotypic plasticity of fishes is often caused by an ontogenetic response to environmental conditions in the form of physiological, behavioral and morphological modifications (Fitzgerald, et al., 2002; Langerhans, et al., 2003; Helland, et al., 2009; Nacua, et al., 2010). In particular, changes of fish morphology have repeatedly been shown to correlate with or be caused by changes of environmental and ecological factors such as temperature (Loy, et al., 1996; Chen, et al., 2008),salinity (Chen et al., 2008), water velocity (Pakkasmaa & Piironen, 2000),feeding regimes (Chen et al., 2008) and predation risk (Eklov & Svanback, 2006).Therefore, we conclude that environmental factors are the main factors for morphological differences between *P. waltoni* specimens from different stations.

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