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FISHERY MANAGEMENT IN THE LOWER MESOPOTAMIAN REGIONS: POPULATION STRUCTURE OF *HYPORHAMPHUS LIMBATUS* (VALENCIENNES, 1847)

SUMMARY

Continuing isolation of populations and interbreeding can direct to morphometric dissimilarities among fish populations. The present study was performed with the aim to define the stock structure of *Hyporhamphus limbatus* on the basis of morphometric and meristic characters. In total, 300 *H. limbatus* specimens were collected from the three sampling locations of the lower reaches of Mesopotamia and its coastal area. In total, 9 morphometric and 4 meristic traits were examined. Canonical discriminant analysis showed significant differences in each of the morphometric measurements and meristic characters among the fish from different sampling locations. The results of this study can be employed in expressing stock-specific management policies for *H. limbatus* from areas studied in the south of Iraq.

INTRODUCTION

Morphometric changes between stocks of a species are known as vital for assessing the population structure and as a foundation for recognizing stocks (Turan *et al*., 2004). Morphometric and meristic characters are those common features that are measurable and countable to all fishes. Morphometric characters are continuous characters describing aspects of body shape. Meristic characters are the number of distinct and countable structures that are determined in embryos or larvae. Studies of morphologic variation between populations endure to act as an important task in stock identification while constant differences in shape between groups of fish may rendering different growth, mortality or reproductive rates that are applicable for the designation of stocks (Swain and Foote, 1999; Cadrin, 2000). Therefore, Morphological and meristic studies can be useful in a range of research settings of fish biology such as phylogeny (Clabaut *et al*., 2007), stock and hybrid identification (Murta *et al*., 2008), analysis of life history (Letcher, 2003) and ecomorphological studies (Andersson *et al*., 2006).

Evidence on the biology and population structure of any species is a requirement for emerging management and protection strategies (Turan *et al*., 2006) and could be appropriate for studying short-term and environmentally prompted variations. Morphometric differences among stocks of a species are recognized as important for evaluating the population structure and as a basis for identifying stocks (Turan *et al*., 2004). Many natural populations of fish species have decreased drastically in number, mainly because of the effects of over-exploitation, habitat alterations, including physiography, abiotic, and biotic features, the release and introduction of exotic fish species, etc. Over harvesting or fishing, especially when directed against a specific size or class age, can reduce the size of the population to a level where inbreeding and loss of genetic diversity may be a serious problem or may lead to extinction of local populations or segments of the population (Rasool *et al*., 2013).

Finally, the fish morphometrics should be ultimately determined by some environmental selective forces that impose certain constraints on the life history of the population. Therefore, an environmental explanation of morphometric differences would contribute to our understanding of life models followed by different local populations, thus helping to develop a sound conservation strategy.

In this study, we use morphometric and meristic analyses to investigate the stock differences of the halfbeak species *Hyporhamphus limbatus* populations from the marine coasts of Iraq, Shatt al-Arab River, Basrah and Al-Hammar Marsh, South of Iraq. Nevertheless the populations from both the freshwater and marine locations have historically created from the same genotype, differences in morphology may indicate the existence of multiple fish stocks, particularly given the hydrological conditions and limited intermixing of individuals for spawning reasons. The present investigation on stock identification *H*. *limbatus* is a step towards the successful development and management of this species in the lower Mesopotamian region and to provide basic information to support the management of sustainable fisheries.

MATERIAL AND METHODS

Sampling and data collection

A total of 300 specimens of *Hyporhamphus limbatus* collected from the catch landed by commercial artisanal fishing vessels in the Khor al-Zubair area and from the local fishermen operating in both Shat al-Arab River, Basrah, Iraq and the Al-Hammar Marsh, South of Iraq. One hundred specimens were obtained from each locality in June 2016 (Fig. 1). According to Reist's suggestion (Reist, 1985), at least 25 animals should be used for morphological analysis and therefore the number of samples was presumed to be adequate to investigate the dissimilarities between these populations. Gill net was used to catch the fish specimens at a depth range 5-6 m from Khor al-Zubair area and 2-2.5 m from both Shatt al-Arab River and the Al-Hammar Marsh areas. Subsequent to capture, the specimens were positioned individually into plastic bags were kept deep-frozen (-20°C) until further analysis.

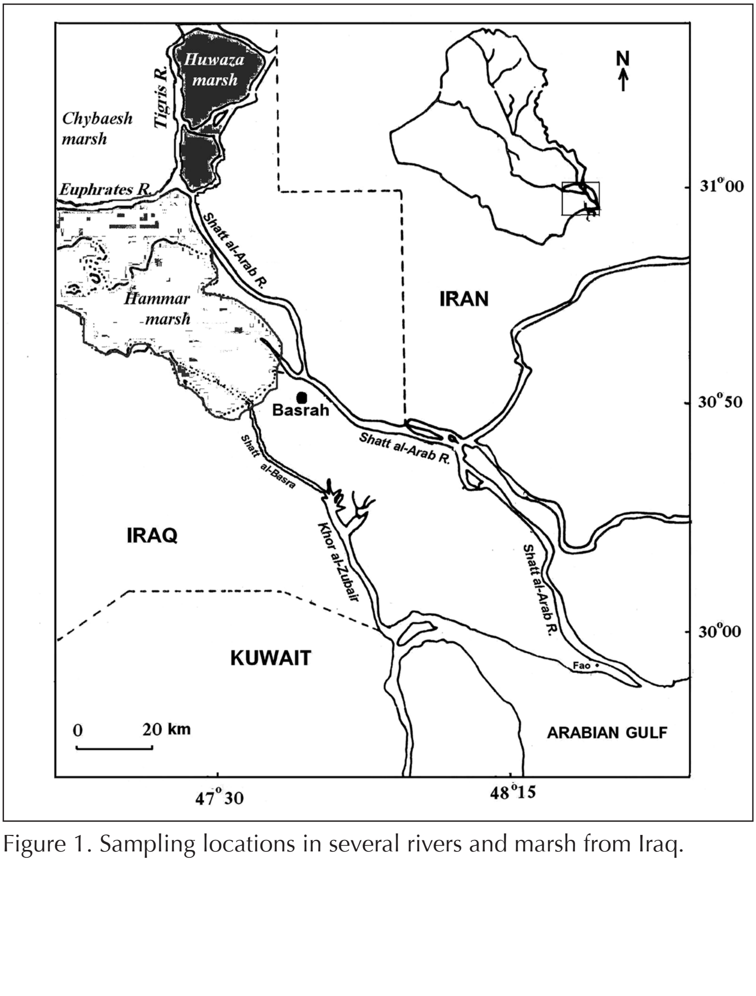


Figure 1. Sampling locations in several rivers and marsh from Iraq.

The identification of the species was based on FISCHER and BIANCHI (1984). In the laboratory, the specimens were allowed to thaw and the morphometric measurements were measured using a digital caliper to the nearest 1 mm. A total of 9 morphometric distances were measured and 4 meristic traits were counted from each specimen (Fig. 2) i.e., total length (TL), from tip of lower jaw to tip of longest caudal fin; standard length (SL), from tip of lower jaw to caudal base (hypural bone junction); fork length (FL); from tip of lower jaw to the fork of caudal fin; head depth (HD); vertical length from the highest point of the head to the ventral side of the head; eye diameter (ED), the horizontal distance between the anterior and posterior edges of the eye; interorbital distance (IO), the horizontal distance between the dorsal edges of the eye; lower jaw length (LJL), from anterior part of lower jaw to the intersection of upper and lower jaw; body depth (BD), distance between dorsal and ventral surface at the deepest point; caudal peduncle depth (CPD), the vertical distance at the base of the caudal fin; number of dorsal fin rays (DFR); number of anal fin rays (AFR); total number of vertebrae (TNV); total number of gill rakers (TNGR). The specimens were dissected to decide the sex of the individual and this was built on the shape and appearance of gonads (BOWERS, 1954). All the specimens collected were with well-developed gonads and the data collected are from mature individuals of the parent stock. There was no problem in the determination of the sex of the specimens.

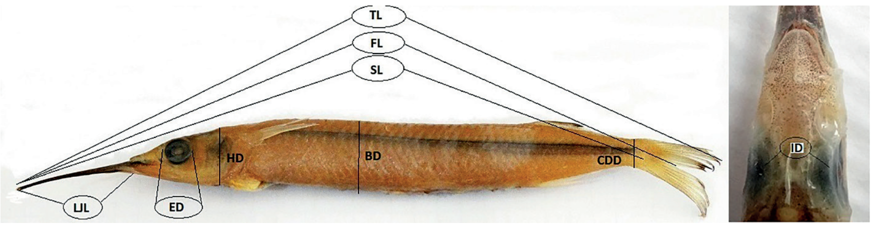


Figure 2. Morphometric measurements taken to *Hyporhamphus limbatus*. TL=Total length; SL= Standard length; FL= Fork length; HD= Head depth; IJL= Length of lower jaw; ED= Eye diameter; ID= Interorbital distance; BD= Body depth; CDD= Caudal peduncle depth.

1.2. Statistical analysis

The 9 morphometric variables and 4 meristic traits obtained from three locations were subjected to the statistical analyses. The measurements were organized by location each with 7 columns by variable (TL, HD, LJ, ED, ID, BD, CP) and 100 cases by each location (only TL were use as size variable since SL and FL are heavily correlated with TL). The resultant matrix was submitted to canonical discriminant analysis to compute generalized Mahalanobis distances to discriminate functions and to assess the efficacy in their classification. Cross-validated discriminant analysis (DA) was used to assess and compare the efficacy of fish shape in classification by location. Meristic variables: DF= Dorsal fin ray count; AF= Anal fin ray count, NV= Number of vertebrae and total gill rakers were reviewed through box plot diagrams. All statistical tests were carried out by SPSS version 23.

RESULTS

The morphological characters of the fish are shown in Table 1. Even though size is very similar among locations the four morphometric variables (Eye diameter, Interorbital distance, Body depth and Caudal peduncle depth) are different between locations. Also the meristic variables (dorsal and anal fin ray count, number of vertebrae and total number of gill rakers) are significant different among the three locations (Figs. 3-5)

Fish shape data (accounted by seven morphometric variables) showed significant differences among locations (Wilks' lambda < 0.001; P<0.001). The cross-validated discriminant analysis s from the 300 specimens correctly classified 100.0 % by location (Table 2). All classification between locations was of 100 %. The first function explained 84.9 % of the total variance while the second accounted for 15.1 % for the classification analysis of the 300 fish examined. Three groups are clearly visible in the DA plot (Fig. 6).

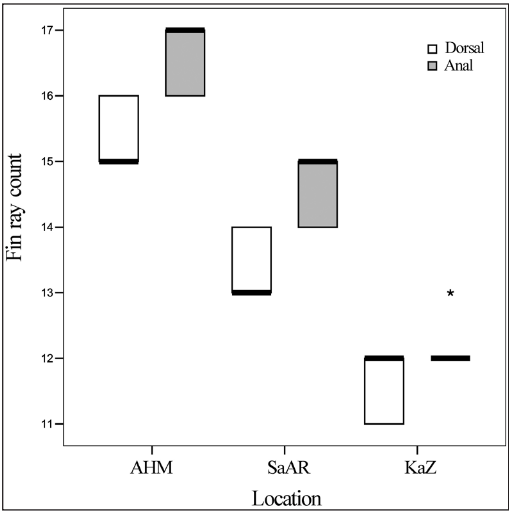


Figure 3. Boxplot depicting dorsal (white) and anal (grey) fin ray count for the three locations: Al-Hammar Marsh (AHM); Shatt al-Arab River (SaAR) and Khor al-Zubair (KaZ).

Table 1 - Mean, standard deviation and range (minimum–maximum) of morphological characters of *Hyporhamphus limbatus* from three different locations: Al-Hammar Marsh; Shatt al-Arab River and Khor al-Zubair.

	Al-Hammar Marsh		Shatt al-Arab River		Khor al-Zubair	
	Mean ± Std	Min-Max	Mean ± Std	Min-Max	Mean ± Std	Min-Max
TL	156.08±4.43	143.70-171.30	156.69±4.85	143.70-171.30	156.69±4.85	143.70-171.30
SL	137.14±4.88	126.10-159.80	137.18±4.88	126.10-159.80	137.18±4.88	126.10-159.80
FL	149.46±4.70	135.80-163.60	149.02±4.87	135.80-163.60	149.02±4.87	135.80-163.60
HD	11.36±0.53	10.29-12.60	11.36±0.53	10.29-12.60	11.36±0.53	10.29-12.60
LJ	24.46±1.43	21.01-27.01	24.43±1.46	21.01-27.01	24.43±1.43	21.01-27.01
ED	6.40±0.10	6.10-6.50	5.10±0.07	5.00-5.20	4.69±0.13	4.50-4.90
ID	7.74±0.31	7.10-8.00	5.58±0.44	5.00-6.00	4.03±0.05	4.00-4.10
BD	14.41±0.25	14.10-14.80	16.42±0.34	15.90-16.80	13.00±0.07	12.90-13.10
CP	6.92±0.46	6.30-7.50	5.89±0.08	5.80-6.00	5.25±0.16	5.00-5.40
DF	15.42±0.50	15-16	13.48±0.50	13-14	11.59±0.49	11-12
AF	16.54±0.50	16-17	14.54±0.50	14-15	12.10±0.30	12-13
NV	50.87±0.84	50-52	48.66±0.47	48-49	45.12±0.74	44-46

TL= Total length; SL= Standard length; FL= Fork length; HD= Head depth; LJ= Length of lower jaw; ED= Eye diameter; ID= Interorbital distance; BD= Body depth; CP= Caudal peduncle depth; DF= Dorsal fin ray count; AF= Anal fin ray count and NV= Number of vertebrae.

Table 2 - Classification results (%) for the cross-validated testing procedure for three locations of the species *Hyporhamphus limbatus*.

	Predicted group membership			
Location	Al-Hammar Marsh	Shatt al-Arab River	Khor al-Zubair	Total
Al-Hammar Marsh	100.0	0	0	100.0
Shatt al-Arab River	0	100.0	0	100.0
Khor al-Zubair	0	0	100.0	100.0

100.0% of cross-validated grouped cases correctly classified.

Figure 4. Boxplot depicting the number of vertebrate for the three locations: Al-Hammar Marsh (AHM); Shatt al-Arab River (SaAR) and Khor al-Zubair (KaZ).

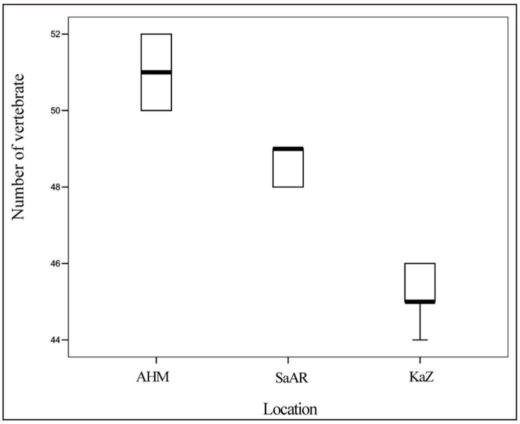


Figure 5. Boxplot depicting the total of gill rakers for the three locations: Al-Hammar Marsh (AHM); Shatt al-Arab River (SaAR) and Khor al-Zubair (KaZ).

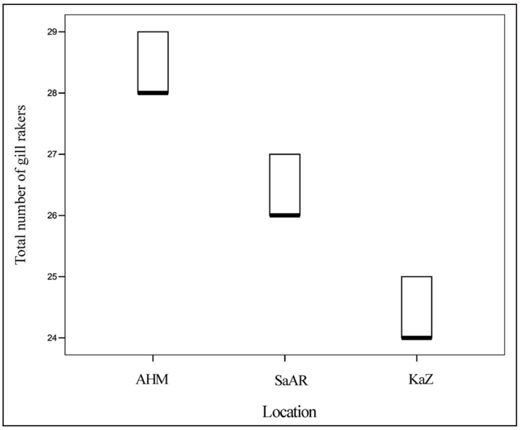
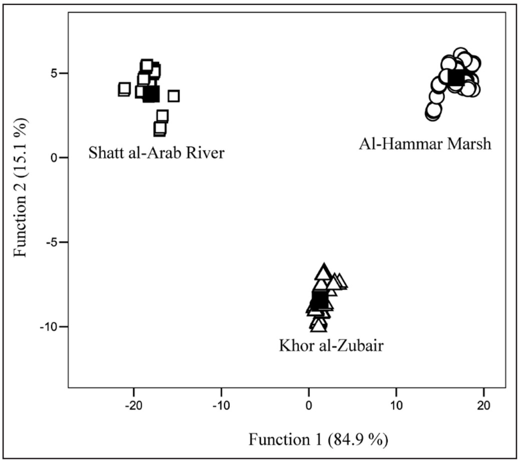


Figure 6. Scatter plot of the discriminant functions scores from the analysis of locations of *Hyporhamphus limbatus* from three different locations: Al-Hammar Marsh; Shatt al-Arab River and Khor al-Zubair.



DISCUSSION

The ability in changing the shape of the fish body involves the ability of a genotype to react to unusual environmental conditions to produce a selection of phenotypes (Thompson, 1991). Such changes are considered the basis for separation and management of distinct population (Turan, 2004). This isolation occurs through reproduction between stocks and stoppage of migration between areas. Inability to recognize or record the stock complexity leads to decline of spawning components results loss of genetic diversity and unknown ecological outcomes (Turan, 2004).

Morphometric analysis can be an influential device for stock identification, although difficulties with interpreting phenotypic characters. Waldman *et al*. (1997) determined that the morphometric methods achieved best among phenotypic methods, and future mixed-stock analyses should be based on morphometrics or mitochondrial DNA.

The morphometric study of *H. limbatus* evidently portrayed the variation of fishes from the three localities studied in the present, though in small magnitude, but absolutely enough to be considered as subpopulations which can be considered as separate management units. However, the three populations in question had similar average lengths. The similarity in the average fish size might reveal the use of similar fishing gear at the three collection sites because all of them were made from commercial catches.

There is a clear morphological distinction between specific characters in the populations studied. It is often challenging to clarify the causes of morphological alterations between populations (Cadrin, 2000). These changes may be genetically related differences or they might be related with phenotypic plasticity in reaction to different environmental factors in each area (Murta, 2000). Thus, morphological variation can manifest genetic differences between stock and/or environmental differences between localities.

Significant differences between the three populations were found using eye diameter (ED), interorbital distance (IO), body depth (BD) and caudal peduncle depth (CPD). Morphological and genetic methods have been used to characterize different populations of fishes (Agnese *et al*., 1997). Therefore, the likelihood exists that the detected morphological variations in the present study might be have a genetic bases. In the present study, the genetic basis of morphometric differences is not investigated. However, the application of molecular markers would be a very useful method (Agnese *et al*., 1997) for approving the perceived phenotypic changes among different localities and for facilitating the development of management strategies and future exploitation of this species.

Water temperature can cause discrepancy in the morphometric characters (Sfakianakis *et al*., 2011), which may disturb fish metabolism through variations in dissolved Oxygen (Wimberger, 1992). The results attained in the present study have shown that individuals of the population of *H. limbatus* at the marsh and Shatt al-Arab River localities have larger eye diameter and interorbital distance, deeper caudal peduncle area and body than the individuals of the southern population located at Khor al-Zubair. In the latter area (coastal marine), water temperature is higher than that in Shatt al-Arab River and the marsh localities. In Khor al-Zubair area, water temperature reaches 37°C, which is far higher than that found in waters of the other two localities studied further north (Al-Hassan and Muhsin, 1986). Analogous effects were acquired by Atkinson (1994) and Pazhayamadom *et al*. (2017). Water viscosity and density will increase with low water temperature and, therefore, variations of body shape will be beneficial to lessening drag (Wimberger, 1992). Consequently, physicochemical traits of aquatic ecosystems convert with water temperature and, hence, fish will respond with new body shapes (Sfakianakis *et al*., 2011).

The eye diameter is greater for specimens collected from the marsh and Shatt al-Arab River areas is likely due to the effect of light intensity at the respective environments because fishes may decrease or dedicate more resources to eye if they grow in environments with low visibility (Remington, 2008). Studies indicate that the turbidity of the Khor al-Zubair area (9.4 m Secchi Disc depth) is relatively higher when compared to the other two freshwater localities (Al-Yamani, 2008). The small eye size of the individuals of *H. limbatus* from Khor al-Zubair area is possibly due to the reduction in light intensity and therefore obstructing the vision of fish populations. Behaviour and biology of the fish in a new environment has shown to have effect on the allometry of eye diameter (positive or negative) (Remington, 2008). For example, the eyes may decrease or degenerate if they are no more useful for survival of the population (Jeffery, 2005). Width of the transmission spectrum elucidates the largest part of the eye length in the marsh and Shatt al-Arab River areas. When the transmission spectrum is broader (i.e. in clear water) the eyes are larger and the dorsal oral length (snout length) is shorter. This may be interpreted as an architectonic interaction: eye size is influenced by the width of the transmission spectrum and eyes get larger at the expense of dorsal oral length (Bouton *et al*., 2002). Thus, the cause of the growth in the eye diameter requires more insight into the behaviour of *H. limbatus*, how they adapt in a turbid environment of Khor al-Zubair for growth, feeding and reproductive purposes so their life cycle can be completed.

The individuals of the marsh and Shatt al-Arab River populations of *H. limbatus* are characterized by a deeper body and caudal peduncle area which is more operative through surge swimming (Webb, 1984) and may be linked with higher swimming efforts but also with a higher ability to gather energy reserves (Boily and Magnan, 2002). Consequently, its deep body appears to be more fitting for a resident life model and should also infer continued competition and more aggressive behaviour (Holtby *et al.*, 1993). The Marsh and Shatt al-Arab River have a distinct eco-hydrological profile different from that of the coastal area of Khor al-Zubair due to their nearly constant discharge throughout the year. Perhaps due to this fact, the marsh and the river can withstand a very rich and plentiful invertebrate community. Such a constant environment with densely distributed and rich food sources must indeed favour the resident life model with strong territorial behavior and can explain the morphological pattern of the populations of both the marsh and Shatt al-Arab River areas.

The *H. limbatus* populations from the marine coastal area of Khor al-Zubair, and the two freshwater localities, marsh and Shatt al-Arab River are quite different from each other mostly regarding interorbital variable (IO), which seem to be somehow related to the capture and/or processing of prey. The freshwater area (the marsh and Shatt al-Arab River) are very rich in food items other than Khor al-Zubair area and in fact, the diet of *H. limbatus* may contain a large portion of prey associated with the water column, such as aquatic insects and their developmental stages (Rainboth 1996). A broad head apparently favours the ingestion of hard prey such as most of the adult aquatic insects present in the freshwater system of Iraq (Jawad, 2003). Variations in interorbital width may directly derive from variations in head width. However, closeness of the eyes could be an indication that these organs are closer to the head dorsal profile, which is a clear benefit for detection of prey associated with the water column, like aquatic insects and their developmental stages, which are the preferred food of *H. limbatus*.

Meristic counts are regulated during a relatively short length of time during early development and the characteristics that are last to appear during ontogeny are the most labile (Barlow, 1961). According to Taning (1952), the denoted cline looks to be related to temperature since there is a good association between cooler environmental temperatures and higher meristic numbers. Seemingly the number of meristic elements is settled by developmental rate, with larger developmental periods usually producing higher counts in meristic structures (Barlow, 1961). This therefore is the means of action of lower temperatures since developmental rate differs directly with temperature (Taning, 1952). Since during reproduction and early development of *H. limbatus* (late spring and early summer) the water temperature reaches much higher values in marine coastal water than in the freshwater areas (Yaseen *et al.*, 2016).

The noteworthy variation in meristic characters obtained between the three populations studied might represent reproductive isolation among the three populations of *H. limbatus* examined. Statistical analysis showed that at the freshwater localities, marsh and Shatt al-Arab River, populations are distinguished in having the highest meristic values for all four characters examined. There is a decreasing trend in the values of the four meristic characters examined from north to south (marsh area to the marine coastal area). This trend concurs with the increasing in water temperature and salinity from north to the south (Moyel, 2014).

Differences in the mean number of gill rakers may also be related to the food and feeding habits of fish (Quilang *et al*., 2007). Fewer rakers are noted in fish that lives in the marine coastal waters and higher values are represented in individuals from the marsh and Shatt al-Arab River areas. In the three areas studied that individuals of *H. limbatus* living, the feeding habits of those individuals was different in respect to the food contents. Decadal results have shown that fish species feeding on large food particles usually required small numbers of gill rakers, while those feed on small food items need large gill rakers (Amundsen *et al*., 2004). The populations of the marine coastal water of Khor al-Zubair usually feed on larger food items such as fish larvae, thus they have less number of gill rakers. On the other hand, those individuals inhabiting the marsh and Shatt al-Arab River areas feed on smaller items such as larvae of other aquatic invertebrates. Therefore, they have larger number of gill rakers.

This study of the morphometrics and meristic of the species shows that the *H. limbatus* populations in the lower reaches of Mesopotamia and its marine coastal area are distinct from each other. Further research will be required in order to conclude either environmental plasticity or genetic manifestation through common field experiments which will offer much greater understanding into the biological dynamics of the species for speciation. Such future researches will enhance the management of the fish stocks and their assessment especially if the factors driving the stock separation are known and fully understood.

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