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Morphometric characterization of four cichlid species from River Nile and Lake Burullus populations, Egypt

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ABSTRACT

The present study was conducted to determine morphometric characteristics of two populations (Lake Burullus and Nile) of four Tilapia species (*Oreochromis aureus, Oreochromis niloticus, Sarotheodon galilaeus, and Tilapia zillii)* to establish whether populations could be differentiated based on morphometric variability which may result from different habitat ecology. Thirteen morphometric characters were used to test the hypothesis differentiation. Data obtained were analyzed statistically using analysis of variance (ANOVA). The obtained results revealed a significant intra-specific variability ($P < 0.05$) between different collection sites in some traits, while no variability was found in other traits. In *O. aureus*, SL, BD, PAL and HL showed distinctive variations between collection sites. In *S. galilaeus*, there was variability in BD, PPL and CPL between collection sites. While in *O. niloticus*, SL, BD, PAL, HL and ED showed significant variations between collection sites. In *T. zillii*, BD, PDL, PAL, CPL, CPD, SnL were the traits that have significant variability between collection sites. Morphological variations within a species may be associated to different habitat characteristics such as water turbidity and food availability.

INTRODUCTION

Studying morphological characteristics of fishes has a vital role in various perspectives such as evolution, ecology, behavior, conservation, water resource management, stock assessment, and study of short-term and environmentally induced variations (**Kalhoro *et al*., 2015; Özcan & Altun, 2015)**. Morphological characters have also been widely used effectively for the determination of morphological relationships between the population of a species and for identifying fish stocks and describing their spatial distributions (**Mustač & Sinovčić, 2010; Ivanković *et al.*, 2011)**. Due to the combined effects of genetics, environmental factors, and development stages, fish morphological characteristics, mainly morphometric traits, can vary among populations (**Cadrin, 2000; Yen *et al*., 2019).**

Morphometrics may be defined as a more or less interwoven set of largely statistical procedures for analyzing variability in the size and shape of organs and organisms. Morphometric differences among stocks of a species are recognized as necessary for evaluating the population structure and as a basis for identifying stocks **(Turan, 2004; Cadrin & Friedland, 1999).**

The environmental factors have an influential role in that a conspecific population of the same species tends to exhibit phenotypic differentiation at geographically different habitats **(Skúlason & Smith, 1995)**; in such cases, the phenotypic differentiation is the divergence of two or more populations for a given observable trait. Such differentiation typically results from one or more processes: natural selection, phenotypic plasticity, or genetic drift **(Lang, 2016).**

There are more than 100 sites recorded along the Nile branches and major irrigation channels at which freshwater fish are collected for marketing. The typical fish caught from these channels are tilapia species (*O. aureus, O. niloticus, S. galilaeus,* and *T. zilli*) and *Clarias spp.* Although these fishing sites are sparsely distributed, and reliable statistics are in short supply, it has been estimated that 34% of the total Egyptian freshwater fish catch is slated to the two main Nile branches (Rosetta and Damietta) and the major irrigation channels **(GAFRD, 1995-2002).**

The four lakes (Mariut, Edku, Burullus, and Manzalah) are the final reservoirs of Nile river water before it flows into the Mediterranean. One of the most vulnerable areas along the delta's coastline is Burullus Lake. This is the second largest of the northern Egyptian lakes along the Mediterranean coast. It is located in the central part of the northern shoreline of the Nile Delta between longitudes 30° 30'–31° 10'E and latitudes 31° 35'–31° 21' N. (**El-Adawy *et al.*, 2013**). Cichlids are represented in Lake Burullus by the same four primary species: *Tilapia zillii, Sarotherodon galilaeus, Oreochromis niloticus,* and *Oreochromis aureus* found in the Nile.

For a better understanding of the processes that influence phenotypic differentiation, our study investigated morphological divergence between Nile and Burullus populations of the four most common cichlids species *O. aureus, O. niloticus, S. galilaeus,* and *T. zillii*

MATERIALS AND METHODS

1. Study area

Sampling stations are shown in **Table (1)**. Three collection sites were covered to collect the investigated most common cichlids species **(Fig. 1)**. Balteem and El-Borg are two major cities on Lake Burullus with many inhabitants. ElTebeen is a site on the River Nile near Great Cairo with a vast population and high industrial activity.

Table (1): Sampling sites of the present study

Site	Latitude	Longitude	Type of pollution
Balteem	31°30'56"N	31°00'24" E	Agricultural and urban activities
El-Borg	31°34'10"N	30°59'52" E	Agricultural and urban activities
Nile (near ElTebeen)	29°47'33"N	31°17'37" E	Industrial and urban activities

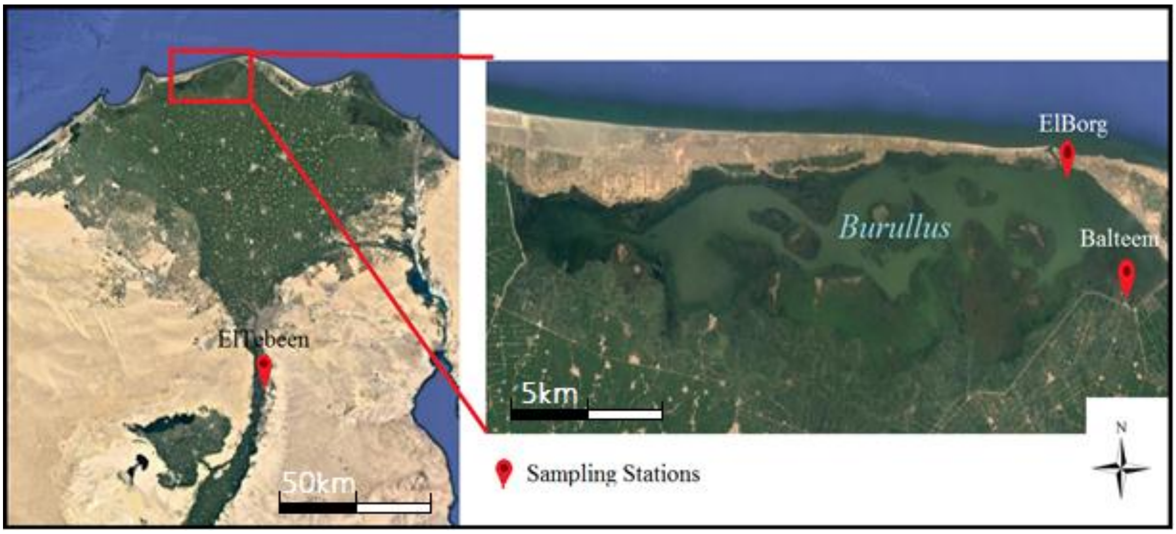

Fig. (1). Map of sampling locations Nile (near ElTebeen), Balteem and El-Borg

2. Sampling of studied cichlid fish species

A total of 278 specimens of each cichlid fish species **(Fig. 2)** were used in the present study. The fish species were blue tilapia (*Oreochromis aureus*),Nile tilapia (*Oreochromis niloticus*), mango tilapia (*Sarotherodon galilaeus*) and redbelly tilapia (*Tilapia zillii*). Fish specimens were obtained from the different sites using gill nets from October to December 2020. The total length of each fish was measured to the nearest mm, and its weight was weighed to the nearest gram using a digital electric balance.

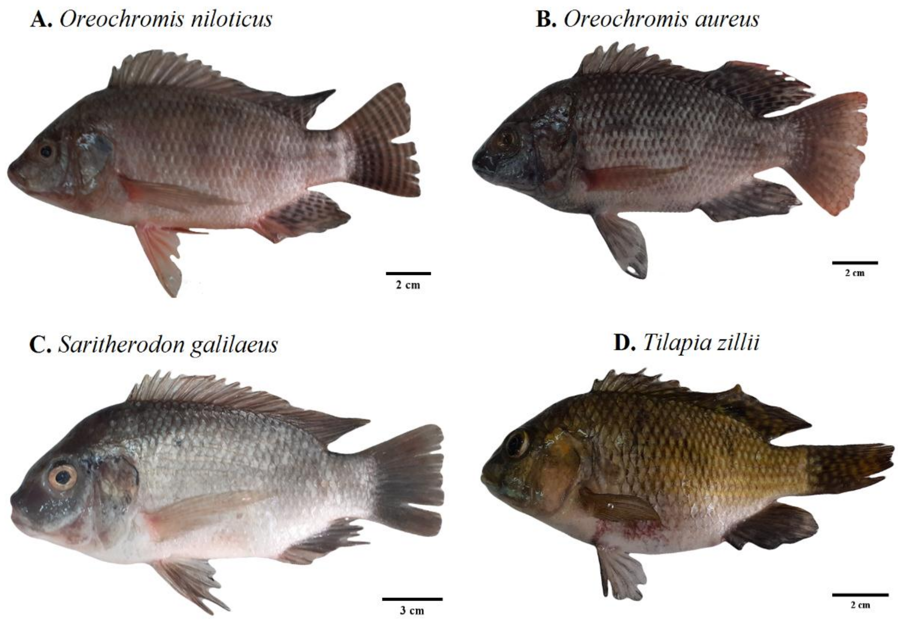

Fig. (2). The four studied species: (A) *O. niloticus*; **(B)** *O. aureus*; **(C)** *S. galilaeus*; **(D)** *T. zillii*

3. Biometric measurements

The total length (TL) was used as a reference for: standard length (SL), predorsal length (PDL), dorsal fin length (DFL), pre pectoral length (PPL), pre pelvic length (PPvL), pre ventral length (PAL), anal fin length (AFL), body depth (BD), head length (HL), caudal peduncle length (CPL) and caudal peduncle depth (CPD). While, the head length (H.L) was used as a reference for snout length (SnL) and eye diameter (ED). Then, the ratio index for each characteristic (morphometric measurement / relevant reference X 100) was calculated, and the different length groups were pooled to calculate the mean values of these indices and their standard deviation (**Fig. 3)**.

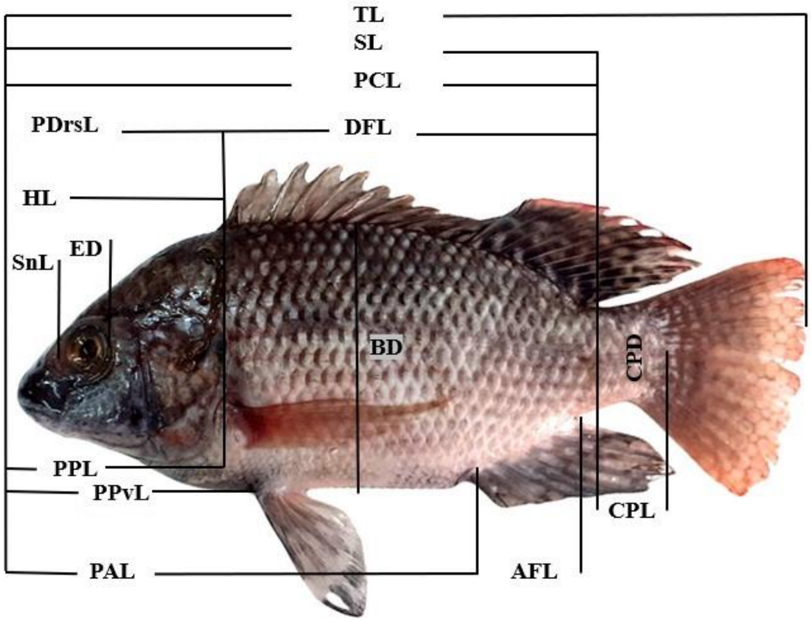

Fig. (3) outline drawing of a cichlid fish to show different morphometric measurements

Data were analyzed using Statistical Package for the Social Sciences (SPSS) software (version 22)(IBM Corp., Armonk, NY). Differences in morphometric measurements were determined using analysis of variance (ANOVA). A significant level was determined at $P \leq 0.05$.

RESULTS

Fish morphometric variations in different sites

In ***Oreochromis aureus,*** the comparison of morphometric characteristics of examined specimens from each collection site (Nile, Balteem, El-Borg) is presented in **Table (2)**. Standard length ratio (SL%) showed a significant variation between collection sites ($P < 0.05$). The highest mean ratio was found in the Nile population, while the lowest one was in the Balteem population, the same situation was found in both BD and PAL. Head length ratio (HL%) showed a significant difference between collection sites ($P < 0.05$) highest mean ratio was found in the Balteem population, while the lowest one was found in the Nile. Ratios of PDL, DFL, AFL, PPL, PPvL, CPL, CPD and ED showed no significant variation between collection sites ($P > 0.05$).

The comparison of morphometric characteristics of examined specimens of ***Oreochromis niloticus*** from each collection site are presented in **Table (3)**. Standard length ratio (SL%) showed a significant difference ($P \leq 0.05$) between collection sites; the highest mean ratio was found in the El-Borg population, and the lowest one was found in the Balteem population. A different situation was observed in BD and PAL, Nile and Balteem populations were significantly higher than El-Borg one at $P \leq 0.05$. The significant variation ($P < 0.05$) in the mean ratio of HL followed the order: El-Borg > Nile > Balteem. While in ED, the significantly highest mean ratio was found in the El-Borg population, and the lowest was found in Balteem population. Ratios of PDL, DFL, AFL, PPL, PPvL, CPL and CPD showed no significant variation (P > 0.05) between collection sites.

Table (2): Morphometric measurements comparison of the *Oreochromis aureus* specimens captured seasonally from the three collection sites

Morphometric ratios	Nile		Balteem (Burullus)		El-Borg (Burullus)	
	Range	Mean± SD	Range	Mean± SD	Range	Mean± SD
TL (cm)	14.6 -19.5	16.7±1.41	13.0 - 20.3	16.8 ± 2.11	10.5 - 20.1	14.7 ± 2.33
SL%	81.4 - 84.8	83.3^{b} ± 1.09	78.2 - 83.4	81.8^{a} ± 1.55	80.4 - 84.5	$82.6^{a,b}$ ± 1.35
BD%	32.2 - 35.9	33.9^{b} ± 1.26	29.1 - 34.8	31.9^{a} ± 1.75	30.9 - 35.5	$33.1^{a,b}$ ± 1.37
PDL%	21.4 - 29.1	26.6^{a} ± 2.29	22.9 - 29.8	26.5^{a} ± 2.07	22.6 - 28	25.2^{a} ± 1.39
PAL%	54.8 - 62.3	59.1^{b} ± 2.23	52.1 - 59.7	56.5^{a} ± 2.16	53.9 - 60.9	$57.6^{a,b}$ ± 1.8
DFL%	44.7 - 52.9	47.4^{b} ± 2.38	43.2 - 48.5	45.8^{a} ± 1.75	43.6 - 48.4	45.8^{a} ± 1.46
AFL%	12.9 - 15.9	14.3^{a} ± 1.11	12.3 - 17.1	15.1^{a} ± 1.26	12.2 - 18.7	14.8^{a} ± 1.79
PPL%	23.9 - 29.4	27.0^{a} ± 1.6	25.4 - 30	27.7^{a} ± 1.49	25.1 - 29.7	27.6^{a} ± 1.26
PPvL%	28.8 - 34.4	31.3^{a} ± 1.92	27.7 - 33.9	30.3^{a} ± 1.65	27.1 - 33.8	31.2^{a} ± 1.91
CPL%	9.1 - 12.4	11.2^{a} ± 1.01	9.7 - 30.9	11.1^{a} ± 1.02	9.4 - 13	11.4^{a} ± 1.11
CPD%	11 - 12.4	11.7^{a} ± 0.4	11.1 - 13.1	12.0^{a} ± 0.52	10.2 - 13.1	11.8^{a} ± 0.75
HL%	21.9 - 30.3	26.3^{a} ± 2.52	25 - 30.9	28.0^{b} ± 1.82	24.9 - 29.9	$27.3^{a,b}$ ± 1.6
ED%	18.5 - 29.4	22.4^{a} ± 3.52	18.7 - 24.4	20.7^{a} ± 1.53	17.6 - 24.6	20.7^{a} ± 2.03
SnL%	26.5 - 32.1	29.3^{a} ± 2.16	24.5 - 32.7	28.7^{a} ± 2.67	21.5 - 33.3	27.0^{a} ± 3.38

SD= Standard Deviation. Means with different letters in the same rows are significantly different (Duncan test, P ≤ 0.05); a < b < c < d; abbreviations of morphometric ratios were previously recorded in materials & methods.

Table (3): Morphometric measurements comparison of *Oreochromis niloticus* specimens Captured seasonally from the three collection sites

Morphometric ratios	Nile		Balteem (Burullus)		El-Borg (Burullus)	
	Range	Mean± SD	Range	Mean± SD	Range	Mean± SD
TL (cm)	15.4 – 25.4	18.3 ± 2.75	14.5 - 22	17.3 ±1.75	10.4 - 17.5	14.4 ± 2.42
SL%	81.2 - 85.4	$83.0^{a,b}$ ± 1.11	81.0 - 84.3	82.6^{a} ± 0.84	81.7 - 84.9	83.6^{b} ± 1.12
BD%	31.0 - 36.6	33.8^{b} ± 1.59	31.8 - 34.8	33.5^{b} ± 0.85	31.4 - 34.3	32.4^{a} ± 1.05
PDL%	22.9 - 30.2	26.0^{a} ± 2.17	24.1 - 29.5	26.8^{a} ± 1.56	23.9 - 28.8	26.0^{a} ± 1.78
PAL%	57.1 - 62.3	59.4^{b} ± 1.66	57.1 - 61.9	59.5_{b} ± 1.25	56.6 - 59.6	58.2^{a} ± 1.09
DFL%	45.1 – 52.0	48.3^{a} ± 1.8	45.0 - 48.8	47.0^{a} ± 1.22	45.7 - 50.7	48.2^{a} ± 1.79
AFL%	13.5 - 16.9	14.8^{a} ± 0.87	13.1 - 17.3	14.8^{a} ± 1.05	14.4 - 17.1	15.2^{a} ± 0.93
PPL%	24.7 - 31.6	28.7^{a} ± 1.91	27.0 - 32.1	30.4^{b} ± 1.71	26.3 - 29.6	27.6^{a} ± 1.2
PPvL%	29.3 - 34.8	31.9^{a} ± 1.62	31.0 - 35.6	32.9^{a} ± 1.33	28.6 - 34.6	31.6^{a} ± 1.99
CPL%	9.8 - 12.5	10.7^{a} ± 0.79	9.2 - 11.8	10.4^{a} ± 0.86	10.3 - 13.2	11.6^{b} ± 1.09
CPD%	10.7 - 15.8	11.9^{a} ± 1.32	10.9 - 12.3	11.6^{a} ± 0.4	11.1-12.0	11.5^{a} ± 0.31
HL%	25.9 - 31.2	27.9^{b} ± 1.56	27.0 - 32.4	29.6^{c} ± 1.55	24.8 - 27.9	26.6^{a} ± 0.99
ED%	19.0 - 25.6	$21.7^{a,b}$ ± 1.67	16.3-25.0	20.8^{a} ± 2.7	19.8 - 25.9	22.9^{c} ± 2.03
SnL%	24.4 – 32.0	28.2^{a} ± 2.32	25.0-37.0	27.9^{a} ± 3.15	24.1 - 28.6	26.7^{a} ± 1.45

SD= Standard deviation. Means that different letters in the same rows are significantly different (Duncan test, P ≤ 0.05); a < b < c < d; abbreviations of morphometric ratios were previously recorded in materials & methods.

In ***Sarotherodon galilaeus,*** the comparison of morphometric characteristics of examined specimens from the collection sites is presented in **Table (4)**. The mean ratio of BD in the Nile population was significantly higher (P < 0.05) than Balteem and El-Borg, which no significant difference between them. The ratio of PPL the significant variation (P < 0.05) between collection sites followed the pattern: Balteem > El-Borg > Nile. While the significant variation (P < 0.05) in CPL followed the pattern: Nile > Balteem > El-Borg. On the other hand, SL, PDL, PAL, DFL, AFL, PPvL, CPD, HL, ED, and SnL showed no significant variation (P > 0.05) between collection sites.

Table (4): Morphometric measurements comparison of the *Sarotherodon galilaeus* specimens captured seasonally from the three collection sites

Morphometric ratios	Nile		Balteem (Burullus)		El-Borg (Burullus)	
	Range	Mean± SD	Range	Mean± SD	Range	Mean± SD
TL (cm)	13.5 – 19.1	16.4 ± 1.47	12.5 – 24.2	17.6 ±3.59	11.2 -18.8	14.8 ± 2.51
SL%	81.7 - 85.8	84.3^{a} ± 1.16	81 - 86	83.9^{a} ± 1.36	80.6 - 86.6	83.3^{a} ± 1.71
BD%	34.3 - 41.4	37.5^{b} ± 2.26	33.3 - 38.2	35.7^{a} ± 1.55	33 - 39.8	35.3^{a} ± 2.05
PDL%	25.6 - 28.3	26.8^{a} ± 0.96	24.2 - 28.6	26.3^{a} ± 0.94	23.1 - 29.3	26.4^{a} ± 1.63
PAL%	57.1 - 63.7	60.3^{a} ± 2.02	55.8 - 61.8	59.3^{a} ± 2.09	56 - 61.8	59.7^{a} ± 2.06
DFL%	45.6 - 49	47.1^{a} ± 0.98	43.2 - 51.1	47.1^{a} ± 1.66	43.2 - 50	46.5^{a} ± 2.1
AFL%	13.1 - 17	15.2^{a} ± 1.09	13.7 - 17.4	15.4^{a} ± 0.87	13 - 17.1	15.2^{a} ± 1.1
PPL%	25.5 - 30.8	27.5^{a} ± 1.48	26.3 - 33	29.0^{b} ± 1.74	26.5 - 30.1	$28.5^{a,b}$ ± 1.1
PPvL%	28.3 - 35.7	31.5^{a} ± 1.93	29.5 - 35.7	32.4^{a} ± 1.77	30.3 - 34.5	31.9^{a} ± 1.26
CPL%	11.1 - 13.6	12.1^{b} ± 0.71	9.7 - 29.1	$11.8^{a,b}$ ± 1.3	9.3 - 12.9	11.1^{a} ± 1.19
CPD%	11.9 - 13.6	12.9^{a} ± 0.47	12 - 14.1	12.8^{a} ± 0.62	11.4 - 13.7	12.6^{a} ± 0.61
HL%	26.6 - 30.4	28.5^{a} ± 1.25	25.8 - 33.5	29.0^{a} ± 1.68	25.1 - 31.5	29.1^{a} ± 2.21
ED%	20 - 25	22.7^{a} ± 1.61	19.6 - 27.8	22.7^{a} ± 2.29	19.1 - 28.1	23.3^{a} ± 2.47
SnL%	24.1 - 37.8	30.5^{a} ± 4.14	25 - 41.1	31.7^{a} ± 4.21	27.3 - 35.7	30.3^{a} ± 2.3

SD= Standard Deviation; Means that different letters in the same rows are significantly different (Duncan test, P ≤ 0.05); a < b < c < d; abbreviations of morphometric ratios were previously recorded in materials & methods.

In *Tilapia zillii*, the comparison of morphometric characteristics of examined specimens from each collection site is presented in **Table (5)**. There was a significant variation (P < 0.05) between collection sites in the mean ratio of BD, PDL and PAL, showing the highest value in the Nile and the lowest value in Balteem **(Table 5).** Similarly, there was a significant variation (P < 0.05) between collection sites in the mean ratio of CPD and CPL, in which the difference followed the order: El-Borg > Nile = Blateem. There was also a significant variation (P < 0.05) between collection sites in SnL, showing the highest value in Nile population and the lowest in El-Borg. The ratios of SL, DFL, AFL, PPL, PPvL, HL, and ED showed no significant variation (P > 0.05) between collection sites.

Table (5): Morphometric measurements comparison of the *Tilapia zillii* specimens Captured seasonally from the three collection sites

Morphometric ratios	Nile		Balteem (Burullus)		El-Borg (Burullus)	
	Range	Mean± SD	Range	Mean± SD	Range	Mean± SD
TL (cm)	9.45 – 20.6	15.3 ± 2.50	9.9 – 15.8	12.1 ± 1.92	9.8 – 18.23	14.1 ± 2.89
SL%	80.7 – 85	82.0^{a} ± 1.21	78.6 - 86.4	81.2^{a} ± 2.24	80 - 84.8	82.4^{a} ± 1.41
BD%	31.9 - 37.3	34.4^{b} ± 1.92	29.9 - 35.5	32.6^{a} ± 1.88	30.5 - 37.3	$33^{a,b}$ ± 1.95
PDL%	24.6 - 29.6	26.8^{b} ± 1.69	22.2 - 27.3	24.5^{a} ± 1.45	21.9 - 26.9	25.1^{a} ± 1.32
PAL%	55.8- 63.7	59.5^{b} ± 2.19	50.9 - 62	56.3^{a} ± 3.04	53.6 - 60	56.8^{a} ± 2.01
DFL%	42.6 - 48.7	45.6^{a} ± 1.93	42.5 - 49.5	45.2^{a} ± 2.29	42.3 - 48.9	45.8^{a} ± 2.01
AFL%	11.7 - 15.9	13.5^{a} ± 1.3	12.7 - 15.3	14.2^{a} ± 0.73	11.9 - 18.8	14.6^{a} ± 1.89
PPL%	23.7 - 28.7	27.0^{a} ± 1.55	25.2 - 29.4	27.1^{a} ± 1.27	25.2 - 29.2	27.4^{a} ± 1.2
PPvL%	26.9 - 33.3	30.0^{a} ± 1.86	29 - 33	30.4^{a} ± 1.37	26.3 - 33.7	30.0^{a} ± 2.11
CPL%	10.1 – 13	11.4^{a} ± 1	9.3 - 14.4	11.7^{a} ± 1.72	10.3 - 13.8	12.8^{b} ± 1.09
CPD%	10.6 - 12.7	12.0^{a} ± 0.58	11.5 - 13	12.0^{a} ± 0.38	11.5 - 13.8	12.8^{b} ± 0.64
HL%	22.5 – 28	26.1^{a} ± 1.43	23.6 - 29.3	25.6^{a} ± 1.59	24.1 ± 28.6	26.5^{a} ± 1.29
ED%	20 - 30.6	24.0^{a} ± 3.46	22.9 - 30.5	25.0^{a} ± 2.22	20 - 25.9	23.2^{a} ± 1.98
SnL%	28.6 - 37.5	34.7^{b} ± 2.52	29.2 - 38.6	$33.5^{a,b}$± 2.95	26.7 - 38.6	32.0^{a} ± 3.13

SD= Standard Deviation. Means that different letters in the same rows are significantly different (Duncan test, P ≤ 0.05); a < b < c < d; abbreviations of morphometric ratios were previously recorded in materials & methods.

Fish morphometric variations between different cichlid species

The comparison of morphometric characteristics between the four studied cichlid species (*O. aureus, O. niloticus, S. galilaeus* and *T. zillii*) is presented in **Table (6).** SL, BD, PDL, PAL, DFL, AFL, PPL, PPvL, CPL, CPD, HL and ED showed significant variations (P < 0.05) between at least two of these four species, although two species may show no significant variation (P > 0.05) in some characteristics.

The highest significant difference (P ≤ 0.05) in mean ratio of SL was found in *S. galilaeus,* followed by *O. niloticus, O. aureus,* and *T. zillii.* The mean ratio of BD in *S. galilaeus* was significantly higher (P < 0.05) than both *O. niloticus*, *O. aureus*, and *T. zillii*. The highest significant difference (P < 0.05) in mean ratio of PDL was found in *S. galilaeus,* while the lowest one was found in *T. zillii*, with no significant difference (P > 0.05) in mean ratio of PDL between *O. aureus* and *O. niloticus*. Morphometric ratios of PPvL and HL were significantly varied (P < 0.05) as follows: *S. galilaeus = O. niloticus> O. aureus> T. zillii*. PAL and PPL showed significant variation between different species by the order: of *S. galilaeus = O. niloticus > O. aureus = T. zillii* **(Table, 6).**

DFL showed the highest mean ratio in *O. niloticus*, followed by *S. galilaeus*, followed by *O. aureus*, and the lowest in *T. zillii* (P < 0.05). AFL showed no significant variation between *O. niloticus, O. aureus,* and *S. galilaeus,* while *T. zillii* showed a significantly lower mean ratio than them. The significantly (P < 0.05) highest mean ratio of CPL was found in *T. zillii* and *S. galilaeus*, and the lowest was in *O. niloticus* and *O. aureus*. The significant difference (P < 0.05) in CPD was found to follow the order: *S. galilaeus > T. zillii > O. niloticus = O. aureus*. E.D. and SNL, the significant variation showed the following order: *T. zillii > S. galilaeus > O. aureus = O. niloticus* **(Table, 6).**

Table (6): Morphometric measurements comparison between *O. aureus, O. niloticus, S. galilaeus,* and *T. zillii* specimens seasonally captured from three collection sites

Morphometric ratios	*O. aureus*		*O. niloticus*		*S. galilaeus*		*T. zillii*	
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
TL (cm)	10.5-20.3	15.93±2.25	10.4-25.4	17.0±2.76	11.16-24.2	16.3±2.93	9.45-20.6	13.9±2.76
SL%	78.2-84.8	82.5[a,b] ±1.46	81 - 85.4	83.0[b] ±1.05	80.6-86.6	83.8[c] ±1.46	78.6-86.4	81.9[a] ±1.67
BD%	29.1-35.9	32.9[a] ±1.66	31 - 36.6	33.3[a] ±1.31	33.0-41.4	36.1[b] ±2.11	29.9-37.3	33.3[a] ±2.02
PDL%	21.4-29.8	26.0[a,b] ±1.96	22.9-30.2	26.3[a,b] ±1.85	23.1-29.3	26.5[b] ±1.21	21.9-29.6	25.5[a] ±1.73
PAL%	52.1-62.3	55.1[a] ±2.33	56.6-62.3	59.2[b] ±1.46	55.8-63.7	59.8[b] ±2.05	50.9-63.7	57.55[a] ±2.7
DFL%	43.2-52.9	46.2[a,b] ±1.91	45.0-52.0	47.8[c] ±1.68	43.2-51.1	46.9[b] ±1.66	42.3-49.5	45.6[a] ±2.03
AFL%	12.2-18.7	14.8[b] ±1.46	13.1-17.3	14.9[b] ±0.95	13.0-17.4	15.3[b] ±1.0	11.7-18.8	14.1[a] ±1.47
PPL%	23.9-30	27.5[a] ±1.42	24.7-32.1	29.1[b] ±2.0	25.5-33.0	28.4[b] ±1.57	23.7-29.4	27.1[a] ±1.33
PPvL%	27.1-34.4	30.9[b] ±1.83	28.6-35.6	32.2[c] ±1.67	28.3-35.7	32.0[c] ±1.66	26.3-33.7	30.1[a] ±1.8
CPL%	9.1-13.8	11.3[a,b] ±1.03	9.26-13,2	10.8[a] ±1.0	9.3-13.7	11.7[b,c] ±1.2	9.3-14.4	12.0[c] ±1.38
CPD%	10.2-13.1	11.8[a] ±0.6	10.7-15.8	11.7[a] ±0.86	11.4-14.1	12.8[c] ±0.57	10.6-13.8	12.3[b] ±0.67
HL%	21.9-30.9	27.3[b] ±2.0	24.8-32.4	28.2[c] ±1.85	25.1-33.5	28.9[c] ±1.75	22.5-29.3	26.1[a] ±1.43
ED%	17.6-29.4	21.1[a] ±2.41	16.3-25.9	21.7[a] ±2.29	19.1-28.1	22.9[b] ±2.15	20.0-30.6	24.0[c] ±2.68
SnL%	21.5-33.3	28.2[a] ±2.98	24.1-37.0	27.7[a] ±2.53	24.1-41.1	30.9[b] ±3.61	26.7-38.6	33.4[c] ±3.02

SD= Standard deviation. Means that different letters in the same rows are significantly different (Duncan test, P ≤ 0.05); a < b < c < d; abbreviations of morphometric ratios were previously recorded in materials & methods.

Similarly, there was a significant variation ($P \leq 0.05$) between collection sites in the mean ratio of CPD and CPL, in which the difference followed the order: El-Borg> Nile = Blateem. There was also a significant variation ($P \leq 0.05$) between collection sites in SnL, showing the highest value in Nile population and the lowest in El-Borg. SL, DFL, AFL, PPL, PPvL, HL, and ED showed no significant variation ($P \leq 0.05$) between collection sites **(Tables, 2-5).**

Heat maping and ordination of ciclid fishes in different collection sites

Two-way cluster (Heat map) showed color-graded variables on which the collection sites for each species have been clustered, showing the similarities and the differentiations between contributed variables, and organizing the investigated collection sites for each species population into one cluster showing the close and far relation between them.

For *O. aureus*, *S. galilaeus,* and *T. zillii,* the cluster showed a close relationship between El-Borg and Balteem populations having a common node, while the cluster showed a distant relationship between the Nile population on the one hand and both El-Borg and Balteem populations in the other hand **(Figs. 4- 6)**.

In *O. niloticus,* the situation was different as a close relationship between Nile and Balteem populations was shown in the cluster due to having a common node, while a far relationship was found between El-Borg population on one hand and both Nile and Balteem populations in the other hand **(Fig. 7)**.

In ordination graph collection, sites are represented as symbols, while different variables are represented as arrows with direction toward its positive correlated species within ordination, and the variable length reveals its more or less correlation value. On the other hand, 3D ordination explains that species is localized in 3D dimensional space with the effecting variables adding more clarification on the understanding of the simplified 2D dimensional ordination.

Each population for every ciclid fish species (*O. aureus, O. niloticus, S. galilaeus,* and *T. zillii*) is represented in different collection sites with specific morphometric features.

Fish population of *O. aureus* collected from El-Borg was positively correlated with specific morphometric features in the following order: PPvL> SL> CPL. While its Balteem population mainly represents a positive correlation with PDL > CPD. Finally, the Nile population positively correlates with ED> PAL > DFL **(Fig. 8)**.

O. niloticus specimens of El-Borg population were positively correlated with morphometric features in the following order: ED> CPL >AFL While the Balteem population mainly represents a positive correlation with PPL > HL> PPvL. Finally, the Nile population positively correlates with Snl > BD> CPD **(Fig. 9)**.

El-Borg population of *S. galilaeus* showed a positive correlation with specific morphometric features in the following order ED> HL, while Balteem population mainly represents a positive correlation with SnL > AFL. Finally, the Nile population positively correlates with BD> SL >CPD **(Fig. 10)**.

El-Borg population of *T. zillii* revealed a positive correlation with the following morphometric features in the presented order CPL > StL > CPD > HL, While the Balteem population mainly represents a positive correlation with ED> PPvL. Finally, the Nile population positively correlates with PAL> PDL > B.D **(Fig. 11)**.

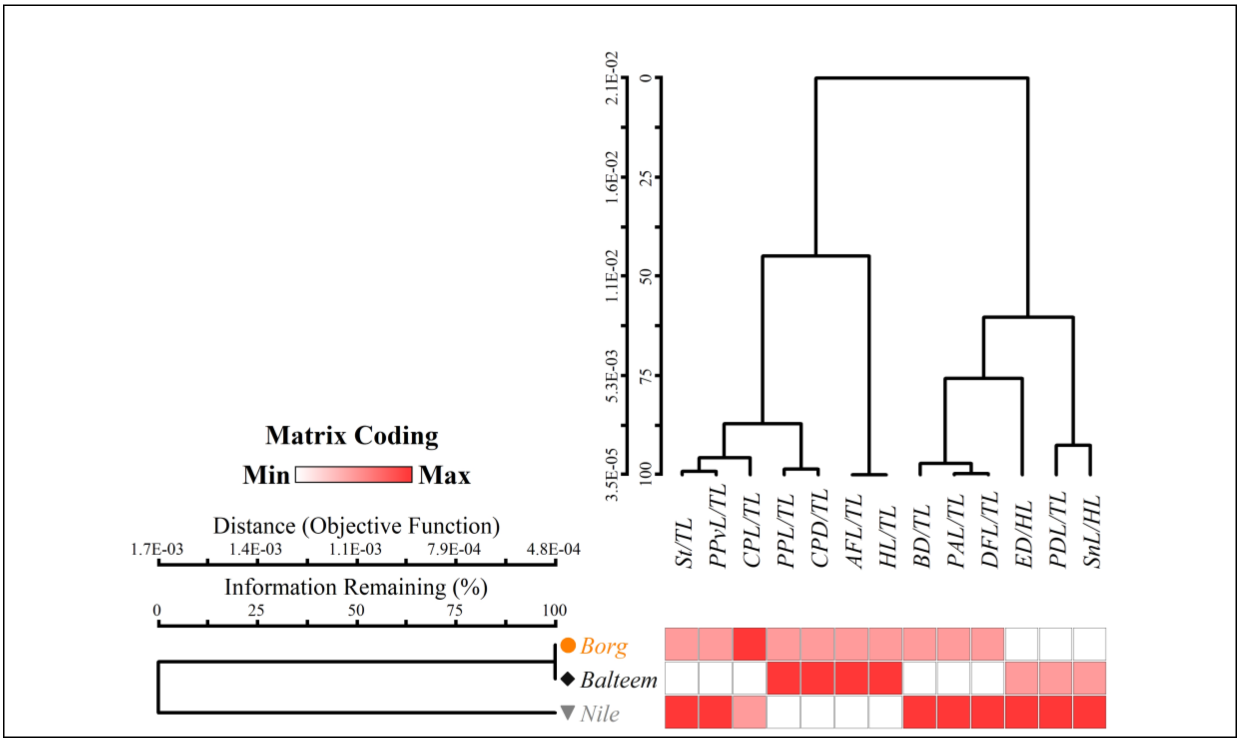

Fig (4): Two-way cluster (Heat map) of color graded variables represents relationship between the collection sites for *O. aureus*

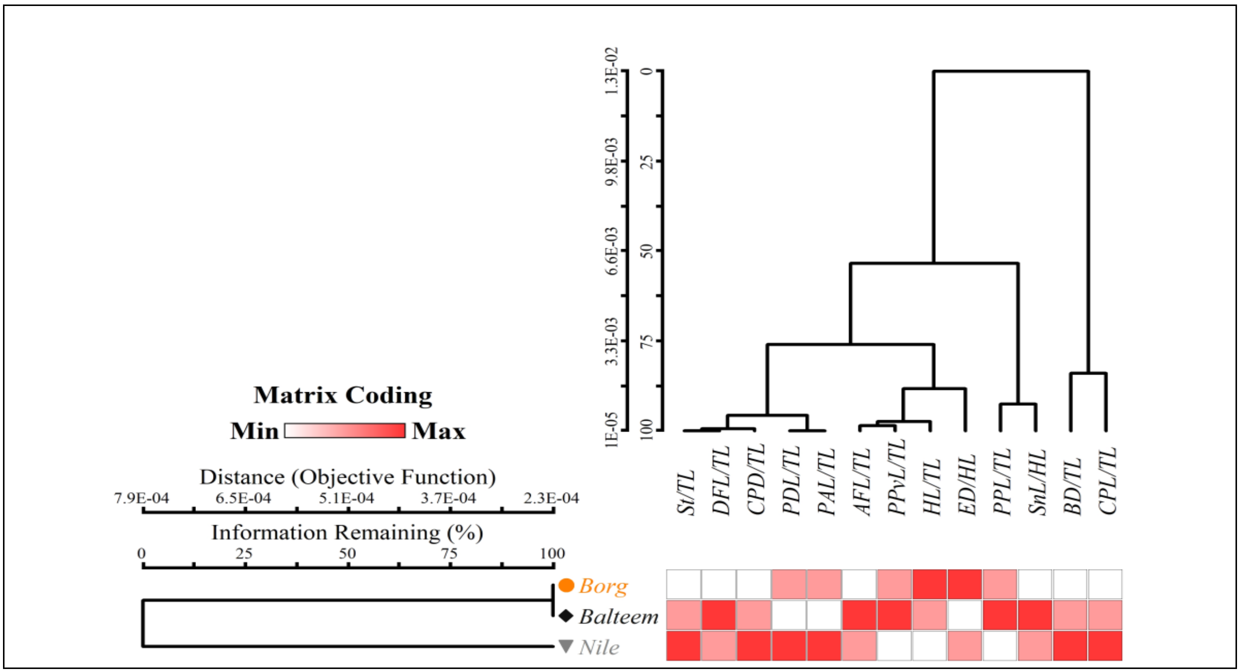

Fig (5): Two-way cluster (Heat map) of color graded variables represents relationship between the Collection sites for *S. galilaeus*

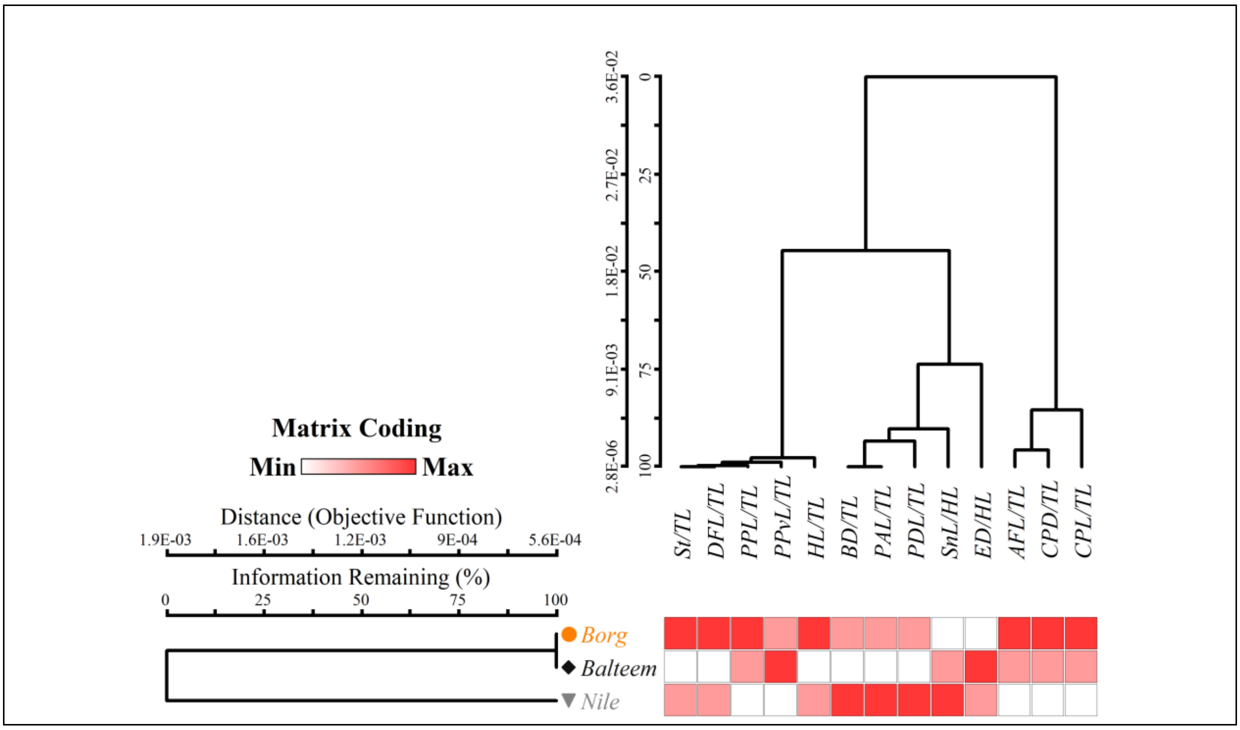

Fig (6): Two-way cluster (Heat map) of color graded variables represents relationship between the Collection sites for *T. zillii*

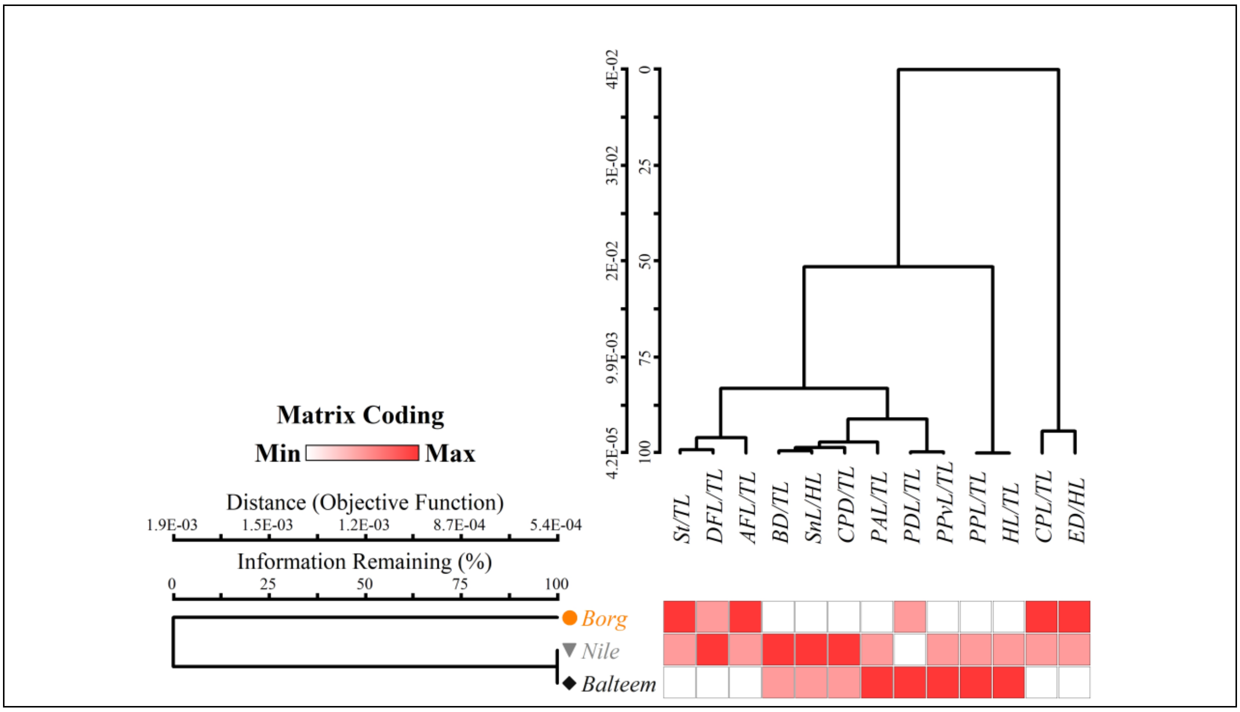

Fig (7): Two-way cluster (Heat map) of color graded variables represents relationship between the Collection sites for *O. niloticus*

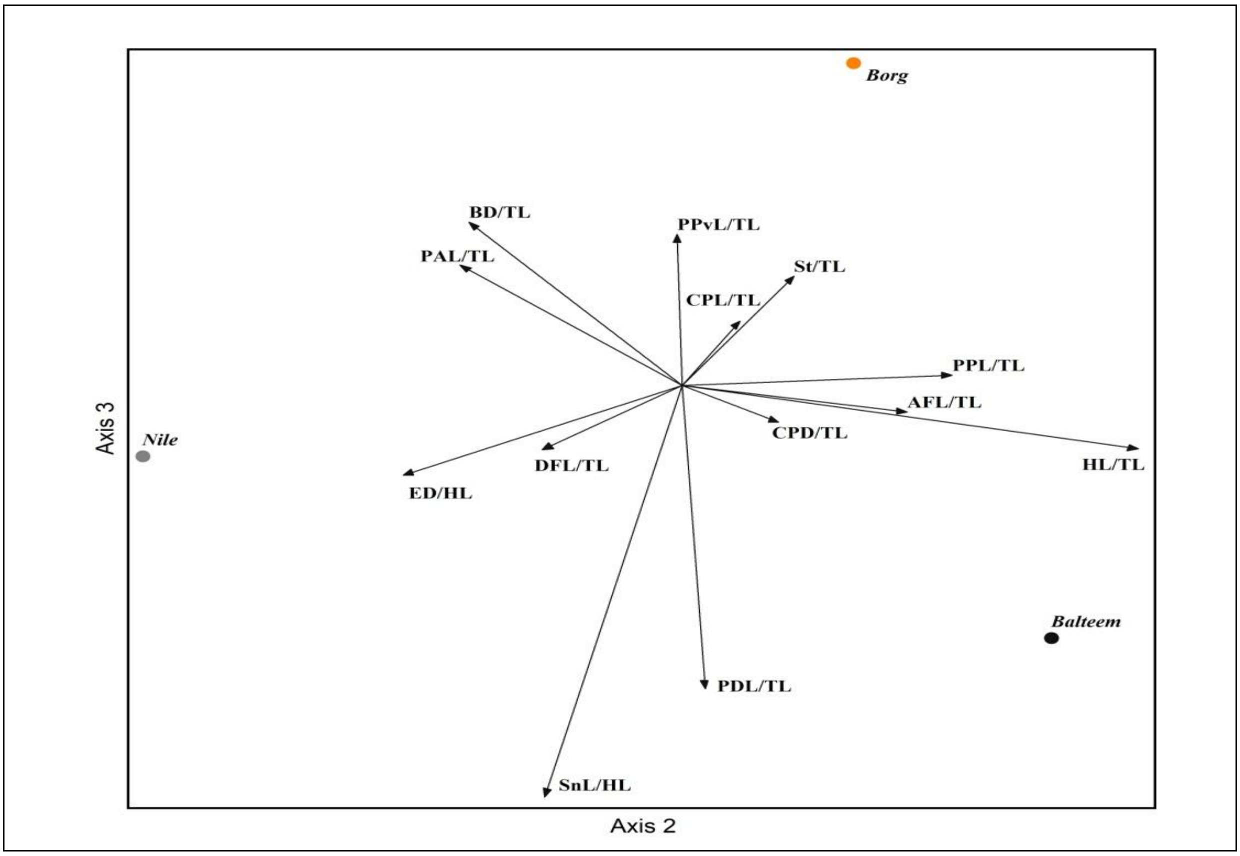

Fig. (8): 2D ordination represent Borg, Nile and Balteem population of *O. Aureus*

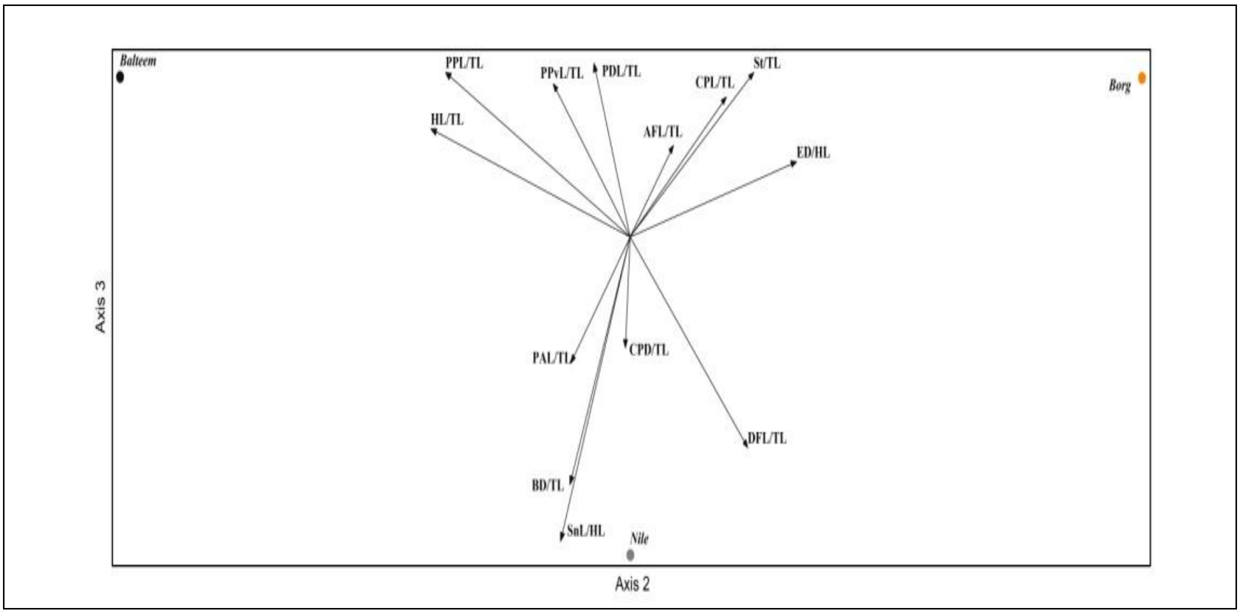

Fig. (9): 2D ordination represent Borg, Nile and Balteem population of *O. niloticus*

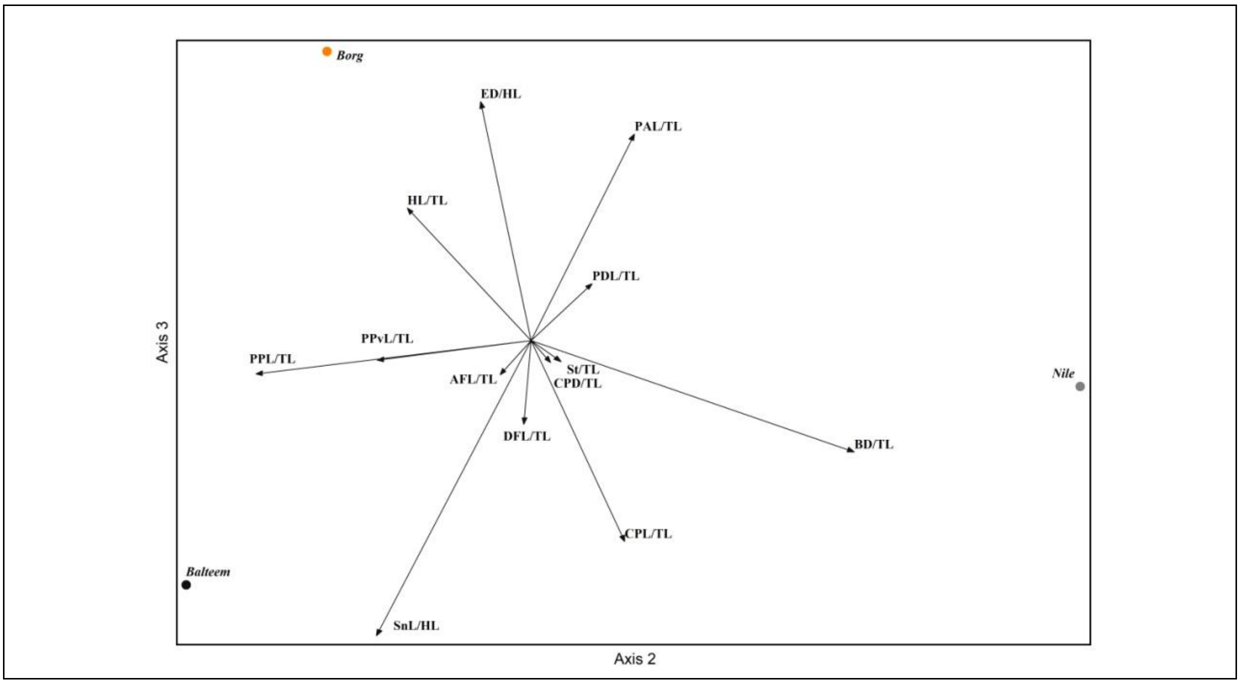

Fig. (10): 2D ordination represent Borg, Nile and Balteem population of *S. galilaeus*

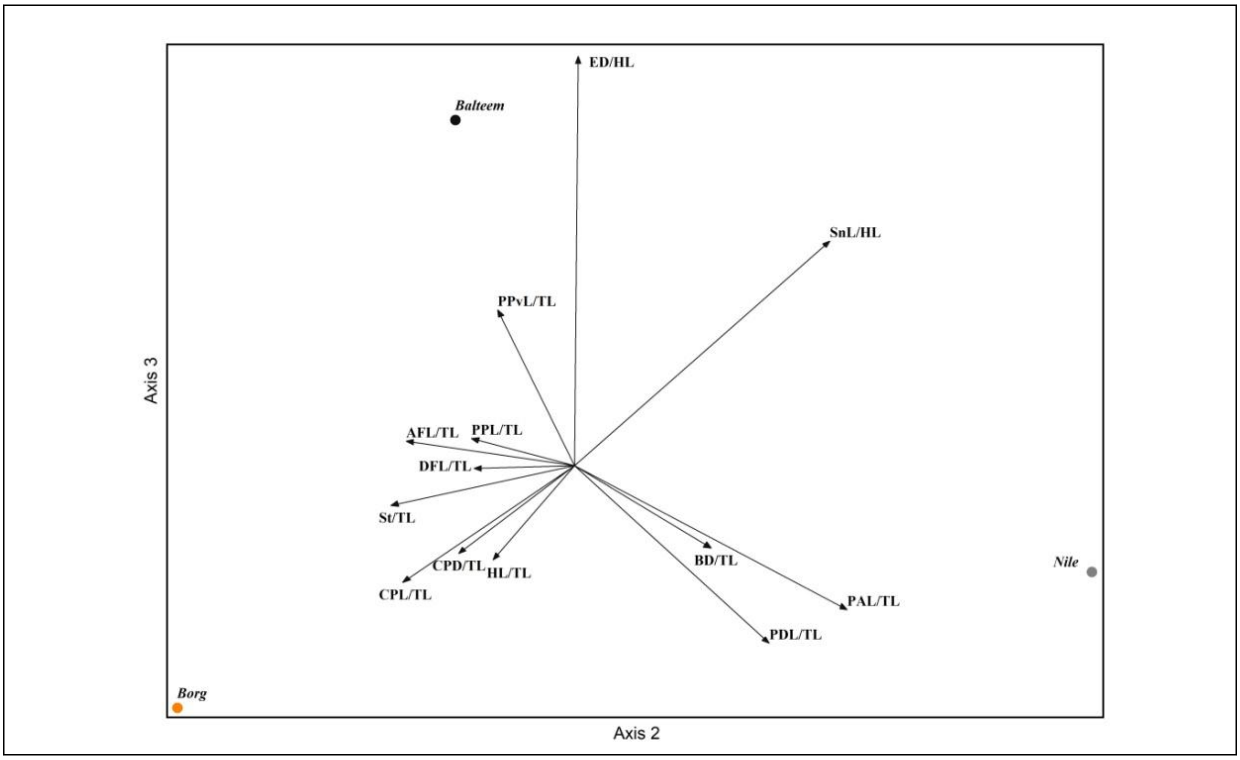

Fig. (11): 2D ordination represent Borg, Nile and Balteem population of *T. zillii*

DISCUSSION

Morphometric variations within the same species are generally associated with geographic isolation due to the effects of interaction with the environment, selection, and genetics on individual ontogenies **(Poulet *et al.*, 2005** and **Astuti *et al.*, 2022).** Morphological parameters and biometrical characteristics, including morphometric measurement and meristic count, have been used to identify fish stocks and remain the simplest and most direct way among methods of species identification **(Turan *et al.,* 2004; Naeem *et al.,* 2012** and **Umaru *et al.,* 2015).**

Stock identification is a multidisciplinary field of fisheries science involving genetics, biometrics, and life history studies (**ICES, 1996; Pawson & Jennings, 1996** and **Begg *et al.,* 1999).** A general definition of "fish stock" involves a group of individuals that sustains itself over time, but precise definitions vary among disciplines **(Booke, 1981).** For example, morphometric variation can discriminate "phenotypic stocks," defined as groups with similar growth, mortality, and reproductive rates. Variability in growth, development, and maturation creates a variety of body shapes within a species.

As a vertebrate animal, fish shows the most significant phenotypic variability within the same population compared to other vertebrates **(Carvalho, 1993** and **Sajina *et al.,* 2011).** Such a high-reliability level comes from fish's phenotypic plasticity in response to the effects of environmental factors **(Wimberger, 1992).** These partial modifications of the aquatic environment are continuously happening as a result of either natural or anthropogenic factors. These modifications may alter fish morphology **(Stearns, 1983** and **Chaklader, 2016).**

Actual results of the current study reveal a degree of variation between the population in morphometric characteristics within the same species Comparison between the mean value of 14 traits, i.e., Total Length (TL), standard length (SL), Body depth (BD), predorsal length (PDL), preanal length (PAL), Dorsal fin length (DFL), anal fin length (AFL), prepectoral length (PPL), prepelvic length (PPvL), caudal peduncle length (CPL), caudal peduncle depth (CPD), Head length (HL), eye diameter (ED) and snout length (SnL) reported morphological variability of studied fish (*O. aureus, O. niloticus, S. galilaeus,* and *T. zillii*) from different geographic distributions which represent two different habitats, riverine habitat (Nile) and lake habitat (Balteem and El-Borg).

The present results showed a significant intra-specific variability ($P \leq 0.05$) between different collection sites in some traits, while no variability was found in other traits. in *O. aureus*. SL, BD, PAL and HL showed distinctive variation between collection sites. In *S. galilaeus,* there was variability in BD, PPL, and CPL between collection sites. While in *O. niloticus,* SL, BD, PAL, HL, and ED were significantly varied between collection sites. In *T. zillii,* BD, PDL, PAL, CPL, CPD, and SnL were the traits that significantly varied between collection sites.

Morphological variations within a species are majorly associated with geographic isolation and different habitat characteristics, such as water turbidity and fish diets. The diversification of fish in habitat had been recorded in different studies like light intensity **(Witte *et al.,* 2008)**; water flow **(Langerhans, 2008),** and predator densities (**Hendry *et al.,* 2006, Langerhans *&* Makowicz 2009).** Intraspecific variation may be seen as a balance between gene flow and local adaptation **(Hendry *et al.,* 2002).**

Whether the observed morphological patterns were produced through genetic differences or phenotypic plasticity is unknown. Populations could diverge via an alternative, genetically based morphologies or environmentally induced phenotypes **(Langerhans *et al.,* 2003** and **Wagle *et al.,* 2008).** Morphometric characteristics usually indicate the ontogenetic changes associated with allometric growth **(Robinson & Parsons, 2002).** These ontogenetic changes in body shape can occur rapidly at major life-history stages, such as metamorphosis from larvae to juvenile body shape and sexual maturation **(Swain *et al.,* 2005)**. Differences in morphological and morphometric variations cannot be separated from habitat conditions, including intraspecific differences **(Hendry *et al.,* 2002** and **McKinnon *et al.,* 2004)**. Similar studies on different fish species have proved the morphological differences between populations occupying different habitats **(Lutterschmidt *et al.*, 2016; Cabuga *et al.*, 2017** and **Astuti *et al.*, 2022)**

Environmental conditions and anthropogenic stressors can have a negative impact on the environmental quality of aquatic ecosystems **(Seixas *et al.*, 2016).** The results showed that the highest fluctuation in morphometric characters was found in the ratio between standard length and total length. Morphometric variations in individual shapes may occur due to habitat conditions and river flows that provide adaptation patterns to survive in these aquatic conditions.

Water regimes generally have the most substantial effect on body shape **(Franssen *et al.*, 2013)**. This is also supported by research showing that morphological differences between fish populations in reservoirs and rivers can directly impact their growth **(Langerhans & Reznick, 2010).** This adaptive response in different selections may be related to genetic differentiation within the population **(Langerhans 2008).**

The present study by the two-way cluster (heat map) analysis showed a clear overlap between *O. aureus, S. galilaeus* , and *T. zillii* samples from El-Borg and Balteem and distinct separation of Nile samples**.** This is due to differences in habitats being typical riverine in the Nile and lake conditions in the case of El-Borg and Balteem. While *O. niloticus* showed a different situation, the similarity occurred between Nile and Balteem samples, which are distinct from El-Borg samples. This may be because *O. niloticus* favors the freshwater nature of both Nile and Balteem while can not resist the saltwater nature of El-Borg site. The brackish lake salinity levels range from 2.1‰ in the west to 17.2‰ in the north. The flushing rate is 61 days, i.e., lake water is renewed six times a year (**El-Adawy *et al.*, 2013**).

Generally, the adaptation of the river populations reflects their body morphology: they are relatively robust with long pectoral fins, which are related to slow and precise movement **(Ehlinger, 1990);** large fins are also have advantage in maintaining one's position in the river **(Riddell & Leggett, 1981).** The river populations are more streamlined. That body shape allows for efficient cruising, foraging for patchily distributed prey in large volumes of torrential open water **(Baumgartner *et al.*, 1988** and **Robinson & Witson, 1996).**

Moreover, environmental factors that elicit the plasticity of traits can result in canalization **(Debit & David, 2001)** and may facilitate the evolution of resident populations **(Pfennig *et al.*, 2010).** Morphological measures provide insight into the bio-geographical elements of fish habitats, as concluded from the results of **Agnese & Teugels (2005)** and **Gatson *et al.* (2012).** The morphometric measurements could be useful in preliminary population characterization before genetic characterizations.

REFERENCES

Agnese, J.F. and **Teugels, G.G. (2005):** Insight into the phylogeny of African Clarisdar (Teleostei: Sturformes) implications for their body shape evolution, biogeography, and taxonomy Molecular phylogenetics and evolution, **36** (3): 546-553

Astuti, S.S.; Hariati, A.M.;. Kusuma, W.E. and **Wiadnya, D.G.R. (2022):** Morphometric Variation among 28 Sub-populations of *Barbodes binotatus* in Indonesia. Sains Malaysiana **51**(1): 15-26.

Baumgartner, J.V.; Bell, M.A. and **Weinberg, P.H. (1988):** Body form differences between the Enos Lake species pair of threespine sticklebacks (*Gasterosteus aculeatus)* complex. Canadian Journal of Zoology, **66**: 467-474.

Begg, G.; Friedland, K.D. and **Pearce, J.B. (1999):** Stock Identification – its role in stock assessment and fisheries management. Fish. Res., **43**: 1–8.

Booke, H. E. (1981): The conundrum of the stock concept – are nature and nurture definable in fishery science? Can. J. Fish. Aquat. Sci., **38**: 1479–1480.

Cabuga, C.C.; Apostado, R.R.Q.; Abelada, J.J.Z.; Calagui, L.B.; Presilda, C.J.R.; Angco, M.K.A.; Bual, J.L.; Lador, J.E.O.; Jumawan, J.H.; Jumawan, J.C.; Havana, H.C.; Requieron, E.A. and **Torres, M.A.J. (2017):** Comparative fluctuating asymmetry of spotted barb (*Puntius binotatus*) sampled from Rivers of Wawa and Tubay, Mindanao, Philippines. Computational Ecology and Software, **7**(1): 8-27.

Cadrin, S.X. (2000): Advances in morphometric identification of fishery stocks. Reviews in Fish Biology and Fisheries, **10**: 91–112.

Cadrin, S.X. and **Friedland, K.D. (1999):** The utility of image processing techniques formorphometric analysis and stock identification. Fisheries Research, **43**: 129-139.

Carvalho, G. R. (1993): Evolutionary aspects of fish distribution: genetic variability and adaptation. J. Fish Biol., **43**: 53-73.

Chaklader, M.R.; Siddik, M.A.B.; Hanif, M.A.; Nahar, A.; Mahmud, S. and **Piria, M. (2016):** Morphometric and Meristic Variation of Endangered Pabda Catfish, Ompok pabda (Hamilton-Buchanan, 1822) from Southern Coastal Waters of Bangladesh. Pakistan J. Zool., **48**(3): 681-687

Debit, V. and **David, P. (2001):** Mapping phenotypes canalization, plasticity and developmental stability Trends in Ecology & Evolution, **16**(10): 555-561.

Ehlinger, T.J. (1990): Habitat choice and phenotype-limited feeding efficiency in bluegill: individual differences and trophic polymorphism. Ecology, **71**: 886-896.

El-Adawy, A.; Negm, A.M.; Elzeir, M.A.; Saavedra, O.C.; El-Shinnawy, I.A. and **Nadaoka, K. (2013):** Modeling the Hydrodynamics and Salinity of El-Burullus Lake (Nile Delta, Northern Egypt). Journal of Clean Energy Technologies, **Vol. 1**, No. 2.

Franssen, N.R.; Stewart, L.K. and **Schaefer, J.F. (2013): Morphological** divergence and now indiced phenotypic plamicity in a native fish teen anthropogenically altered stream habmats Ecology and evolution, **14**: 4648-4657

GAFRD (1995-2002): Annual fishery statistics reports (General Authority for Fish Resources Development), Cairo-Egypt.

Gatson, K.A., Ent, J.A. and **Lauer, T.E. (2012):** Morphology and its effect on habitat selection of stream fishes. In Proceedings of the Indiana Academy of Science, **12**(11): 71-78.

Hendry, A.P.; Noul, P. and **Rieseberg. L.H. (2006):** The speed of ecological speciation. Functional Ecology, **21**(3): 455-464

Hendry, A.P.; Taylor, E.B. and **McPhail, J.D. (2002):** Adaptive divergence and the balance between selection and gene flow: Lake and stream stickleback in the Misty system. Evolution, **56**: 1199-1216.

ICES (International Council for the Exploration of the Sea) (1996): Report of the study group on stock identification protocols for finfish and shellfish stocks. *ICES C.M.* M1.

Ivanković, P.; Piria, M.; Treer, T. and **Knezović, Z. (2011):** Meristic and morphometric characteristics of endemic Neretva chub, *Squalius svallize* from the Neretva River area, Bosnia and Herzegovina. J. appl. Ichthyol.; **27**: 1031–1032.

Kalhoro, M.A.; Liu, Q.; Valinassab, T.; Waryani, B.; Abbasi, R. and **Memon, K.H. (2015):** Population Dynamic of greater Lizardfish, *Saurida tumbil* from Pakistani waters. Pakistan J. Zool.; **47**: 921-931.

Lang, J.J.V. (2016): An Analysis of Morphometric Differentiation in Lake and River Populations of the Emerald Shiner, *Notropis Atherinoides* An analysis of morphometric differentiation. Biology Theses. 28. http://digitalcommons.buffalostate.edu/biology_theses/28

Langerhans, R.B. (2008): Predictability of phenotypic differentiation across flow regimes in fishes. Integrative and Comparave Biology, **48**(6), 750-768.

Langerhans, R.B. and **Makowicz, A.M. (2009):** Shared and unique features of morphological differentiation between predator regsmes in Cambusta caymanesisis. Journal of evolutionary biology, **22**(11) 2231-2242

Langerhans, R.B. and **Reznick, D. (2010):** Ecology and evolution of swimming performance in fishes: Predicting evolution with biomechanics. Fish Locomotion an Etho-Ecological Perspect, **200**: 200-248.

Langerhans, R.B.; Layman, C.A.; Langerhans A.K. and **Dewitt, T.J. (2003):** Habitat-associated morphological divergence in two neotropical fish species. Biological Journal of the Linnean Society, **80**: 689-698

Lutterschmidt, W.I.; Martin, S.L. and **Schaefer, J.F. (2016):** Fluctuating asymmetry in two common freshwater fishes as a biological indicator of urbanization and environmental stress within the Middle Chattahoochee Watershed. Symmetry, **8**(11): 1-17.

McKinnon, J.S.; Mori, S.; Blackman, B.K.; David, L.; Kingsley, D.M.; Jamieson, L.; Chou, J. and **Schluter, D. (2004):** Evidence for ecology's role in speciation. Nature**, 429**: 294-298.

Mustač, B. and **Sinovčić, G. (2010):** Morphometric and meristic parameters of Sardine (*Sardina pilchardus*, walbaum, 1792) in the Zadar fishing area. Croatian J. Fish, **68**: 43- 48.

Naeem, M.; Zuberi, A; Khan, N.A.; Rasool, S.A.; Ismail, H.F. and **Qamar, A. (2012):** Some morphometric relationship traits of *Labeo bata* (Hamilton,1822) from Head Panjnad, Pakistan. African Journal of Biotechnology, **11**(88): 15465-15468.

Özcan, G. and **Altun, A. (2015**): Length-weight relationship and condition factor of three endemic and threatened freshwater fishes from Orontes River. Pakistan J. Zool., **47**: 1637-1643.

Pawson, M.G. and **Jennings, S. (1996):** A critique of methods for stock identification in marine capture fisheries. Fish. Res., **25**: 203–217.

Pfennig, D.W.; Wund, M.A.; Snell Rood, E.C.; Cruickshank, T.; Schlichting, C.D. and **Meczek, A.P. (2010):** Phenotypic plasticity's impacts on diversification and speciation. Trends in ecology & evolution, **23**(5): 459-467

Poulet, N.; Reyjol, Y.; Collier, H. and **Lek, S. (2005):** Does fish scale morphology allow the identification of populations at a local scale? A case study for rostrum dace *Leuciscus leuciscus burdigalensis* in River Viaur (SW France). Aquatic Sciences, **67**: 122-127.

Riddell, B.E. and **Leggett, W.C. (1981):** Evidence of an adaptive basis for geographic variation in body morphology and time of downstream migration of juvenile At-lantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Science, **38**: 321-333.

Robinson, B. W. and **Parsons, K. J. (2002):** Changing times, spaces, and faces: Tests and implications of adaptive morphological plasticity in the fishes of northern postglacial lakes. *Canadian Journal of Fisheries and Aquatic Sciences* **59**(11): 1819-1833.

Robinson, B.W. and **Witson, D. S. (1996):** Genetic variation and phenotypic plasticity in a trophically polymorphic population of pumpkinseed sunfish (*Lepomis gibbosus*). Evolutionary Ecology, **10**: 631-652.

Sajina, A.M.; Chakraborty, Jaiswar, S.K.; Pazhayamadam, A.K. and **Sudheesan, D.G. (2011):** Stock structure analysis of *Megalaspis cordyla* (Linnaeus, 1758) along the Indian coast based on truss network analysis. Fish. Res., **108**: 100-105.

Seixas, L.B.; Santos, A.F.G.N. and **Santos, L.N. (2016):** Fluctuating asymmetry: A tool for impact assessment on fish populations in a tropical polluted bay. Ecological Indicators, **71**: 522-532.

Skúlason, S. and **Smith, T.B (1995):** Resource polymorphism in vertebrates. Trends in Ecology & Evolution, **10**: 366-370.

Stearns, S.C. (1983): A natural experiment in life-history evolution: field data on the introduction of mosquitofish (*Gambusia affinis*) to Hawaii. Evolution, **37**: 601-617.

Swain, D.P.; Hutchings, J.A. and **Foote, C.J. (2005):** Environmental and genetic influences on stock identification characters. In: Stock Identification Methods, edited by Cadrin, S.X.; Friedland, K.D. & Waldman, J.R. Massachusetts: Academic Press, 45-85.

Turan, C. (2004): Stock identification of Mediterranean horse mackerel (Trachurusmediterraneus) using morphometric and meristic characters. Journal of Marine Science, **61**: 774-781.

Turan, C.; Erguden, D.; Turan, F. and **Gurlek, M. (2004):** Genetic and morphologic structure of Liza abu (Heckel, 1843) populations from the Rivers Orontes, Euphrates and Tigris. Turkish Journal of Veterinary and Animal Science, **28**: 729-734

Umaru, J.A.; Annune P.A.; Cheikyula J.O. and **Okomoda V.T. (2015):** Some biometric parameters of four selected fish species in Doma Dam, Nasarawa State, Nigeria. International Journal of Aquaculture, **5**(31): 1-7

Wagle, S.K.; Pradhan, N. and **Rai, A.K. (2008):** A morphometric study on mahseer (*Tor putitora*) from a Mid-Hill Lake and rivers of Nepal. Asian Fisheries Science, **21**: 113-125

Wimberger, P.H. (1992): Plasticity of fish body shape. The effects of diet, development, family and age in two species of *Geophagus* (Pisces: Cichlidae). Biol. J. Linn. Soc., **45**: 197-218.

Witte, F.; Welten, M.; Heemskerk, M.; van der Stap, I.; Ham, L.; Rutjes, H. and **Wanink, J. (2008):** Major morphological changes in a Lake Victoria cichlid fish within two decades. Biological Journal of the Linnean Society, **941**: 41-32.

Yen, D.T.; Duyen, V.N.; Hien, T.T.; Pomeroy, R. and **Hillary, E. (2019):** Variation in morphometric characteristics between cultured and wild striped snakehead (*Channa striata*) populations in the Mekong Delta. Can Tho University Journal of Science, **11**(1): 70-77