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RESEARCH ARTICLE

Morphometric and meristic character variability and relationships among populations of *Boops boops* (L.) from four marine stations along the Tunisian coast

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Abstract. The variability of 14 morphometric and seven meristic characters of *Boops boops* (L.) collected at four stations along the Tunisian coast was examined in 518 samples ranging from 126 to 206 mm in total length and 37 to 78 g in total weight. Statistical analysis of both sets of characters showed significant variation among the four populations in 13 (92.9%) morphometric and four (57.1%) meristic characters. CVA and cluster analysis of the morphometric characters revealed four groups corresponding to four populations, with 95.36% correct classifications of individuals to their populations of origin. However, CVA and cluster analysis of the meristic characters showed a reticulate relationship among the four populations, as there was clear differentiation between those in Monastir and Zarzis and an overlap between those in Bizerte and Kelibia, with only 51.75% of individuals correctly classified to their respective populations. This morphological differentiation among the populations from the four stations was attributed to the differences in the physico-chemical water properties at these stations. However, further studies are needed on the impact of environmental factors and diet at these stations on the morphological population structure of *B. boops* to better understand the contribution of environmental conditions to morphological variation.

Keywords: *Boops boops*, populations, relationship, morphometric characters, meristic characters, Tunisian marine stations

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Introduction

Morphological or phenotypic variations among fish populations are controlled by a combination of environmental factors that include but are not limited to temperature, salinity, radiation, dissolved oxygen, water depth, and current flow (Lindsey 1988, Turan 2000). Phenotypic variations can include variation in morphometric and meristic characters that are

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dynamic characters commonly used to measure differences among populations of the same fish species (Ihssen et al. 1981, Cadrin 2000, Doherty and McCarthy 2004, Jayasankar et al. 2004) and have been used repeatedly to identify stocks of a variety of exploited fish species (Murta 2000, Silva 2003, O'Reilly and Horn 2004, Turan 2004). These phenotypic variations in morphometric and meristic characters among fish of the same species stem from differences in sex, food availability, predator-prey interactions, physical parameters, and environmental conditions (Dasgupta 1991). Morphometric relationships are used to determine minimum legal sizes in many developed countries for fisheries management (Thomas 1973).

Morphometric characters are continuous, quantifiable characters that describe features of body shape and size (Turan 1999). However, several morphometric characters reflect ecophenotypic variation and are commonly used not only in biometric studies as is common in field studies (Waldman 2005), but also in studies of species health and reproduction in the environment (Fagbuaro et al. 2015). On the other hand, meristic characters are several discrete, serially repeated, countable structures that are controlled in unknown proportions by genetic and environmental factors (Swain and Foote 1999, Liasko et al. 2012) and have also long been used for identifying fish stocks (Jawad et al. 2017, 2018) and providing information for subsequent studies on stock improvement (Jawad and Al-Janabi 2016). These characters are established during larval ontogenetic development and remain stable throughout the lives of fishes, i.e., they reflect environmental influences over a relatively short period of larval development (Jawad et al. 2017). As a result of these criteria, significant variations can occur within stocks among year populations or geographic subgroups exposed to changing environmental conditions (Silva 2003, Jayasankar et al. 2004). However, regular environmental influences have the potential to provide stock discrimination as there is little genetic variation among actual stocks (Begg and Waldman 1999, Ünlü et al. 2012, Coad 2014). Studies of morphological variation among populations still play an important role in stock identification because stable differences in shape among fish groups can reveal different growth, mortality, or reproduction rates relevant to the definition of the stocks (Swain and Foote 1999, Cadrin 2000).

Geographically, the Tunisian shore is a border region between the basins of the eastern and western Mediterranean that contain many lagoons, including the Bizerte, Kelibia, Monastir, and Zarzis. Their geographical location means they are important ecological niches that provide more potential biodiversity to the Tunisian coast (Kaoučche et al. 2017). Previous ecological studies at stations in the Bizerte, Kelibia, Monastir, and Zarzis lagoons showed that environmental characteristics such as temperature, salinity, and currents differed in these locations (Béjaoui et al. 2008, 2010, 2019, Martins et al. 2015, Jamila et al. 2016, Kaoučche et al. 2017, Zaafrane et al. 2019). Anthropogenic pressures including urbanization, industrial activities, naval and commercial shipping harbors, and organic chemical and heavy metal pollution also differed among the sites (Barhoumi 2014). These environmental changes among the four stations were expected to induce variation in fish phenology to permit adaptations to environmental changes by adjusting fish physiology and behavior to the effects of environmental variation, which would lead to changes in morphology, reproduction, and survival (Stearns 1983, Meyer 1987). Variation in morphological characters resulting from changes in environmental factors could be useful for stock identification, especially when time scales are inadequate for important genetic differentiation in populations, which can occur in partially isolated stocks.

The bogue, *Boops boops* (L.), is one of the most widespread commercial seabream species in the Mediterranean, including in Tunisian waters, the Eastern Atlantic, and the Black Sea (Khemiri et al. 2005, Amira et al. 2019). It is a gregarious, demersal, semi-pelagic species that is found at a depth of 350 m above a variety of substrata, including sand, mud, rocks, and seaweeds (Ceyhan et al. 2018, Şimşek et al. 2018). However, it is more common at depths of less than 150 m and is sometimes found in coastal waters. This species moves in aggregations and

mainly ascends to the surface at night (Ider et al. 2017). *B. boops* grows rapidly in length during the first year of life, where it reaches 53.49% of its final length, and it can live up to seven years (Pollard et al. 2014). In Egypt, Azab et al. (2019) reported that its total length ranged from 9.3 to 23 cm and its total weight ranged from 7.4 to 133.1 g, while the length-weight relationship revealed a tendency toward isometric growth. These researchers also determined that its longevity is four years, and the lengths at first capture and first maturity were 12.5 and 13.2 cm, respectively, while the total mortality rate was 2.26 y^{-1}. Conversely, Kara and Bayhan (2008) reported that the length-weight relationship showed allometric growth and the length-length relationships were highly correlated ($P < 0.001$) in Izmir Bay (Aegean Sea of Turkey). Similarly, Soykan et al. (2015) described length-weight relations as positively allometric with lengths at first maturity of 12.96 cm for females and 9.35 cm for males from the waters of the Turkish coast of the Aegean Sea. Additionally, Özvarol (2016) reported no statistically significant differences between the length groups of escapees and catches in the Gulf of Antalya (northeastern Mediterranean Sea). Moreover, Monteiro et al. (2006) reported that sexual maturity was reached between ages one and three at a length of about 15.22 cm for both sexes in the Algarve (southern Portugal). Along the Benghazi Mediterranean coast, *B. boops* feeds on a wide variety of prey species, including Crustacea (49.0%), Porifera (22.7%), Coelenterata (10.2%), seagrasses (9.2%), Mollusca (8.1%), and Protozoa (0.9%) (El-Maremie and El-Mor 2015), while along the Algerian coast it is omnivorous and feeds on benthic (Crustacea, Mollusca, Annelida, Sipuncula, Plantae) and pelagic (Siphonophorae, Copepoda, eggs) prey (Derbal and Kara 2008).

In Tunisian waters, however, Anato and Ktari (1986) studied the age and growth of *B. boops* with otolith and scale readings and found that the first sexual maturity age was between the thirteenth and fifteenth months after birth and female linear growth and weight increased slightly over males during the first four years of life. Khemiri et al. (2005) also determined the age and growth in fish from four areas along the Tunisian coast by studying growth in cross-sections of otoliths; they reported that hyaline zones were deposited annually from November to April and that the increases in length and age fit Von Bertalanffy equations. Additionally, Cherif et al. (2008) analyzed the length-weight relationship of individuals in the Gulf of Tunis and found a high degree of positive correlation between total length and total weight. Moreover, the infection of the *B. boops* gallbladder with *Ceratomyxa ghannouchensis* and *C. pallida* parasites in the Gulf of Gabes was confirmed by Thabet et al. (2019). Furthermore, Ben Labidi et al. (2020a, b) found that there was asymmetry in otolith shape within and among stocks of *B. boops* from the stations studied.

Thus, there is currently no knowledge of the *B. boops* stock structure in Tunisia. Thus, the aim of this study was to investigate the morphological population structure of *B. boops* in four different stations along the Tunisia coast based on an examination of 14 morphometric and seven meristic characters to determine whether they constitute one demographic unit or independent management groups. There is also a brief discussion of their relationships and the impact of environmental factors on their morphological structure.

Material and Methods

Study area and sampling

A total of 518 samples of *B. boops* were collected between May 2018 and July 2019 from four sampling stations located in the Bizerte, Kelibia, Monastir, and Zarzis lagoons, which cover most of the geographical distribution of this species along the Tunisian coast (Fig. 1). The sampling size, total weight, and geographical coordinates of these stations are given in Table 1. Fish samples were caught alive with gillnets from coastal boats ranging from 5 to 13 m in length. Immediately after they were caught, the total weight of each fish specimen was recorded and the values were rounded to the nearest 0.1 g (Table 1).

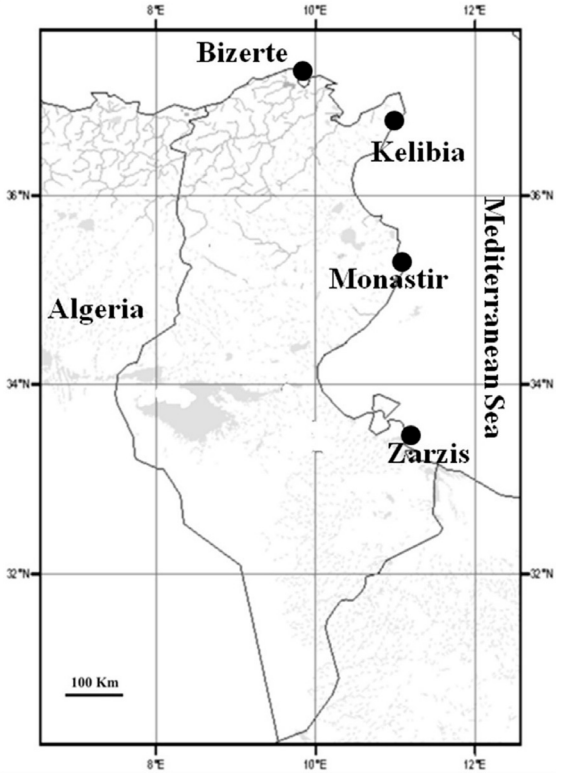

Figure 1. Map showing collection sites of *B. boops* at the Bizerte, Kelibia, Monastir, and Zarzis stations, Tunisia.

Table 1

Sampling sites with coordinates, sample size, and total weight (range and mean ± standard deviation (SD) values) of *B. boops* samples collected at the four stations in Tunisia

Sampling site	Sample size	Total weight (in g)		Geographic coordinates
		Range	Mean ± SD	
Bizerte	118	37 - 60	46.16 ± 7.63	(37°16'27"N 9°52'26"E)
Kelibia	147	39 - 70	49.93 ± 9.12	(36°50'51"N 11°05'37"E)
Monastir	103	42 - 72	54.04 ± 9.42	(35°46'40"N 10°49'34"E)
Zarzis	150	45 - 78	58.43 ± 9.57	(33°30'14"N 11°06'43"E)
All	518	37 - 78	52.14 ± 9.11	-

Morphometric and meristic characters

A total of 14 morphometric and seven meristic characters were used for the present study. These characters and their corresponding abbreviations are shown in Fig. 2. The morphometric characters were measured from the left side of the fish using digital calipers and values were rounded to the nearest 0.01 mm (Table 2). Meristic characters were counted for all the samples from the left side of the fish following the method of Hubbs and Lagler (1958). Details and abbreviations of these characters are given in Table 3. The gill rakers of the first gill arch were counted under a dissecting microscope after the removal of the anterior gill arch. Sex was determined macroscopically, and the effect of sex on truss measurements was tested using univariate statistics (ANOVA). However, to eliminate the biased effect of large measurements related to the large size of fish on the statistical analysis, the values of the morphometric characters measured were first transformed into size-independent shape variables. Size-dependent variation for morphometric and meristic characters was removed using the Reist (1985) equation, where the base-10 logarithm was used for all variables. This equation is proven to be effective in removing such size-dependent variation (Hauser et al. 1995, Turan 2000).

Statistical analyses

All statistical analyses were performed using Past v.1.81 (Hammer et al. 2001) and Statistica v.12.5 (StatSoft, Inc.). Univariate analysis of variance (ANOVA) was performed on standardized data for both types of characters to compare variation among samples for size-adjusted truss measurements. The number of significantly different measurements among the populations of the four stations was an additional indication of the degree of population separation. A posteriori Scheffé's (1959) post-hoc multiple comparison tests were also performed to determine the number of significant characters between pairs of samples. A non-parametric multiple analysis of variance (MANOVA) was conducted to test the significance of each character difference among populations using Shapiro-Wilks' λ test

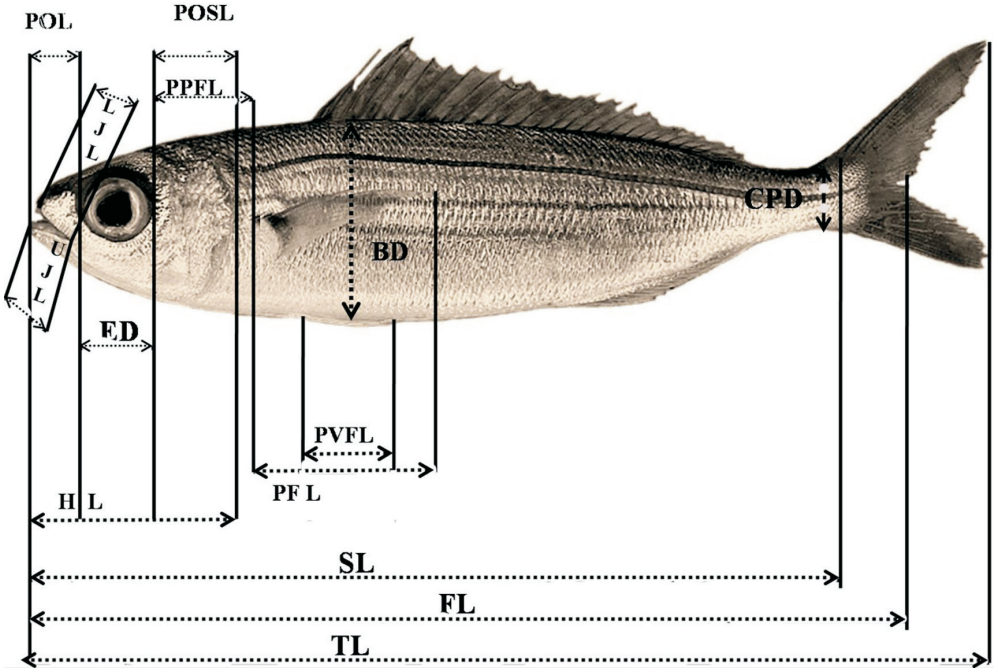

Figure 2. Morphometric measurements of the bogue, *B. boops*. ED - Eye diameter; BD - Body depth; CPD - Caudal peduncle depth; HL - Head length; TL - Total length; SL - Standard length; FL - Fork length; POL - Preorbital length; POSL - Postorbital length; UJL - Upper jaw length; LJL - Lower jaw length; PFL - Pectoral fin length; PVFL - Pelvic fin length; PPFL - Prepectoral fin length.

Table 2

Range and mean ± standard deviation (SD) values of the 14 morphometric characters of *B. boops* samples collected at the four stations in Tunisia

	Sampling site							
	Bizerte		Kelibia		Monastir		Zarzis	
Character	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
TL	152 - 188	168.30 ± 8.50	126 - 193	162.06 ± 14.44	152 - 198	172.35 ± 9.98	148 - 206	172.79 ± 10.46
SL	129 - 155	140.30 ± 6.20	114 - 172	139.94 ± 10.86	128 - 166	143.93 ± 8.88	125 - 170	144.11 ± 8.86
FL	139 - 174	156.89 ± 8.41	125 - 188	154.93 ± 11.48	140 - 178	158.84 ± 8.79	140 - 188	159.27 ± 9.37
BD	21.4 - 39	27.93 ± 2.10	22.04 - 24.97	23.52 ± 0.85	22.44 - 44.71	31.85 ± 6.72	22.66 - 44.86	33.69 ± 6.51
CPD	8.35 - 12.2	10.48 ± 0.84	8.03 - 12.43	10.24 ± 1.28	8.62 - 11.92	10.44 ± 0.90	8.95 - 11.94	10.45 ± 0.87
HL	29.9 - 42.50	33.53 ± 1.82	29.61 - 31.82	30.72 ± 0.64	29.91 - 34.53	31.48 ± 0.10	30.08 - 33.05	31.56 ± 0.87
ED	10.01 - 14.02	12.06 ± 0.83	11.34 - 14.87	13.11 ± 1.02	11.20 - 15.34	13.59 ± 0.97	12.08 - 15.36	13.72 ± 0.96
POL	7.22 - 11.47	9.45 ± 1.15	8.30 - 37.99	23.24 ± 8.60	7.25 - 12.52	9.91 ± 1.25	14.56 - 19.20	16.96 ± 1.31
POSL	11.45 - 16.51	13.86 ± 1.25	11.26 - 13.17	12.22 ± 0.55	11.52 - 14.01	12.60 ± 0.58	11.66 - 13.60	12.63 ± 0.56
UJL	6.75 - 13.10	9.19 ± 1.68	6.92 - 11.19	9.07 ± 1.23	6.75 - 12.56	9.99 ± 1.40	7.82 - 12.59	10.21 ± 1.39
LJL	7.89 - 14.60	10.58 ± 1.93	7.08 - 11.48	9.29 ± 1.28	7.68 - 13.59	10.23 ± 1.39	8.01 - 12.77	13.72 ± 1.39
PFL	24.34 - 31.20	27.61 ± 1.59	24.63 - 26.10	25.37 ± 0.43	24.83 - 28.45	25.18 ± 0.45	24.94 - 25.17	25.06 ± 0.07
PVFL	16.85 - 22.70	19.56 ± 1.48	17.66 - 41.17	29.50 ± 6.81	18.10 - 38.29	24.59 ± 3.82	22.62 - 24.58	23.66 ± 0.52
PPFL	14.15 - 36.18	17.89 ± 3.73	14.25 - 35.10	24.42 ± 5.90	15.57 - 35.99	20.44 ± 3.69	18.24 - 21.54	19.82 ± 1.15

Table 3
Range, mode, and mean ± standard deviation (SD) counts of the 7 meristic characters of *B. boops* samples collected at the four stations in Tunisia

Character	Sampling site	Sample size	Range	Mode	Mean ± SD
Number of anal fin rays (NAFR)	Bizerte	118	11 - 28	18	18.07 ± 4.93
	Kelibia	147	11 - 28	17	17.66 ± 4.69
	Monastir	103	11 - 30	21	20.38 ± 4.17
	Zarzis	150	11 - 28	22	20.67 ± 3.52
Number of vertebrae (NV)	Bizerte	118	22 - 23	22	22.00 ± 0.09
	Kelibia	147	22 - 23	22	22.02 ± 0.14
	Monastir	103	22 - 22	22	22.00 ± 0.00
	Zarzis	150	22 - 22	22	22.00 ± 0.00
Number of left pelvic fin rays (NPFRleft)	Bizerte	118	14 - 24	17	17.82 ± 2.73
	Kelibia	147	11 - 24	18	17.15 ± 2.54
	Monastir	103	13 - 24	18	18.48 ± 2.86
	Zarzis	150	14 - 25	17	17.96 ± 2.99
Number of right pelvic fin rays (NPFRright)	Bizerte	118	12 - 24	18	17.74 ± 2.63
	Kelibia	147	12 - 24	19	17.61 ± 2.25
	Monastir	103	13 - 25	17	18.56 ± 2.84
	Zarzis	150	12 - 25	18	18.10 ± 2.53
Number of gill rakers on left first gill arch (NGRleft)	Bizerte	118	20 - 33	24	25.04±3.567
	Kelibia	147	24 - 31	24	24.59 ± 3.70
	Monastir	103	13 - 32	31	26.21 ± 4.08
	Zarzis	150	20 - 33	24	25.11 ± 4.01
Number of gill rakers on right first gill arch (NGRright)	Bizerte	118	20 - 35	23	24.90 ± 3.70
	Kelibia	147	15 - 33	24	24.78 ± 3.50
	Monastir	103	12 - 33	22	25.72 ± 4.11
	Zarzis	150	19 - 34	22	25.31 ± 3.90
Number of pectoral fin rays (NPER)	Bizerte	118	12 - 22	15	17.29 ± 2.73
	Kelibia	147	11 - 25	16	17.11 ± 2.87
	Monastir	103	14 - 25	18	18.15 ± 2.56
	Zarzis	150	12 - 25	19	18.68 ± 2.69

(Klecka 1980). The transformed variables were submitted to canonical variant analysis (CVA). CVA maximizes the amount of multivariate variation among populations relative to within-population variation and identifies those variables that serve best to discriminate between populations by location and percentages of correct classifications (Bookstein 1982). The dissimilarity matrix of characters among populations was calculated using Euclidean distance (Clifford and Stephenson 1975). Hierarchical cluster analysis was performed based on the Euclidean distance matrix of dissimilarity using unweighted pair-group matrix analysis with the arithmetic average (UPGMA) method (Sneath and Sokal 1973) to assess relationships among populations.

Results

Morphometric characters

Univariate analysis of variance (ANOVA) revealed that 13 (92.9%) of the 14 characters, except CPD (caudal peduncle depth), were significantly different among the populations of the four stations. Likewise, both Scheffé's post-hoc test (Table 4) and MANOVA showed statistically significant differences among the four populations (Wilks' $\lambda = 0.013$, $F = 118.7$, $P = 0.00$). In addition, CVA showed that the scatter plot for CV1 and CV2 generated a clear separation of all samples into four groups, or morphotypes, corresponding to the four populations (Fig. 3a). CV1 accounted for the largest amount of among-group variability (58.32%) and was associated with POL (main loading = 0.7), while CV2 accounted for 34.81% and was also associated with POL (main loading = 0.55). The overall percentage of correct classification of individuals to their populations of origin was 95.36%, while their percentages of correct classification in the populations of Bizerte, Kelibia, Monastir, and Zarzis were 91.52%, 95.23%, 97.08, and 97.33%, respectively. The percentages of morphological differences among the four populations indicated highly significant differences (Wilks' $\lambda = 0.004$; $P < 0.0001$). The dissimilarity matrix computed using Euclidean distance for the morphometric parameters is shown in Table 5. The

Table 4
Summary of the ANOVA results of the 14 morphometric and 7 meristic characters of *B. boops* samples collected at the four stations in Tunisia. Significance levels; * - $P < 0.05$; ** - $P < 0.01$; *** - $P < 0.001$

			Sampling site					
Morphometric characters	F	P	Bizerte - Kelibia	Bizerte - Monastir	Bizerte - Zarzis	Kelibia - Monastir	Kelibia - Zarzis	Monastir - Zarzis
TL	27.250	< 0.001	***		*	***	***	
SL	8.338	< 0.001		*	**	**	**	
FL	5.909	< 0.001				*	**	
BD	123.053	< 0.001	***	***	***	***	***	*
CPD	1.610	0.185						
HL	144.456	< 0.001	***	**	***	***	***	
ED	77.107	< 0.001	***	***	***	**	***	
POL	250.876	< 0.001	***		***	***	***	***
POSL	106.272	< 0.001	***	***	***	**	***	
UJL	21.675	< 0.001		***	***	***	***	
LJL	20.299	< 0.001	***			***	***	
PFL	266.656	< 0.001	***	**	***		*	
PVFL	133.309	< 0.001	***	***	***	***	***	
PPFL	63.944	< 0.001	***	***	**	***	***	
NAFR	17.1018	< 0.001		**	***	***	***	
NV	1.691	0.167						
NPFRleft	4.870	< 0.01				**		
NPFRright	3.2841	0.05						
NPER	10.300	< 0.001			***	*	***	
NGRleft	3.668	< 0.05				*		
NGRright	1.500	0.213						

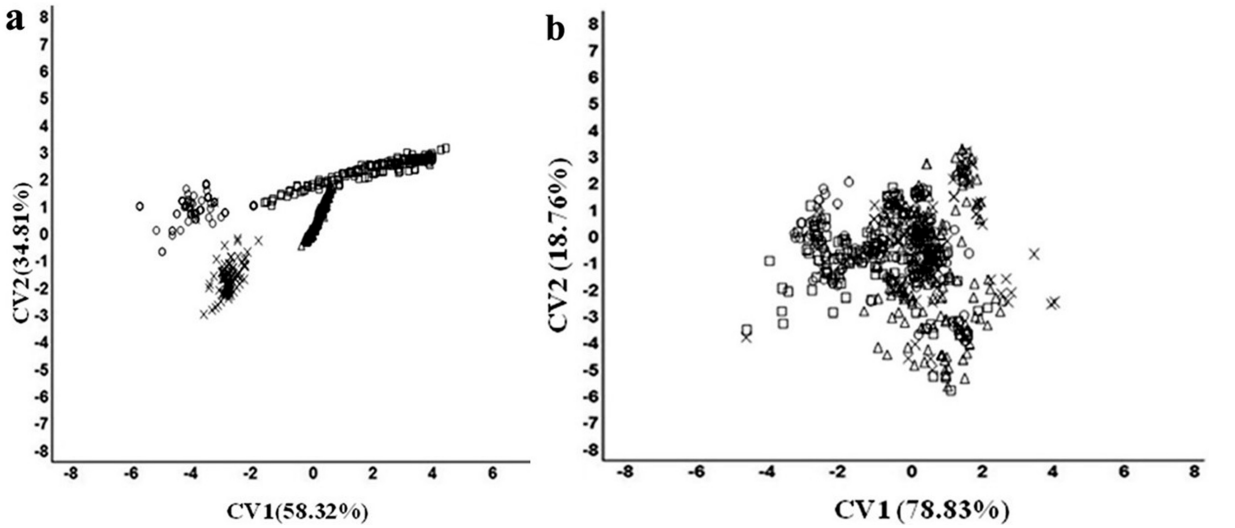

Figure 3. Scatter plot of the CV1 and CV2 axes of the CVA of (a) morphometric characters; (b) meristic characters of *B. boops* samples collected at four stations along the Tunisian coast. □, △, O, and X refer to individuals from the Kelibia, Zarzis, Bizerte, and Monastir stations, respectively.

Table 5
Dissimilarity matrix of morphometric characters (above the diagonal) and meristic characters (below the diagonal) characters using Euclidean distance

	Bizerte	Kelibia	Monastir	Zarzis
Bizerte	-	19.36	22.76	31.54
Kelibia	9.7	-	16.65	24.54
Monastir	11.9	8.2	-	20.17
Zarzis	19.2	13.7	9.84	-

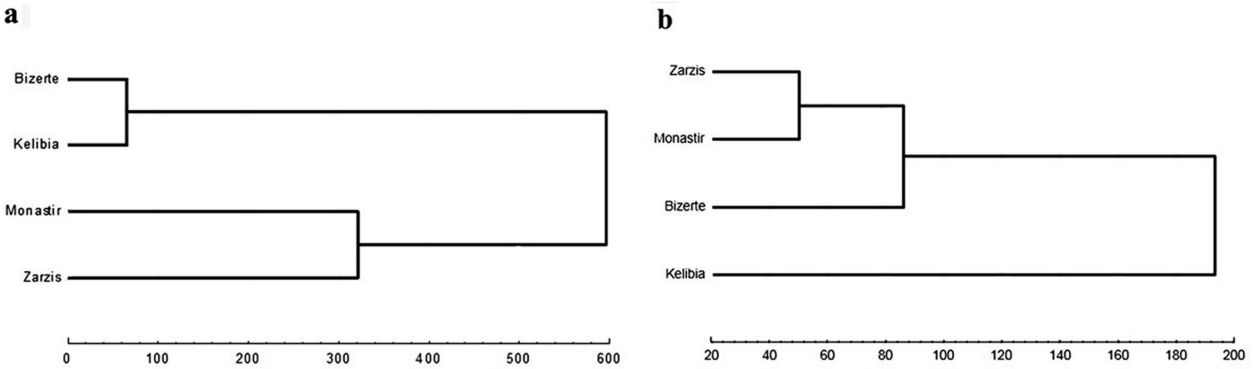

Figure 4. Cluster analysis dendrogram generated based on the Euclidean distance matrix of dissimilarity of the (a) morphometric characters; (b) meristic characters using the UPGMA method showing the relationship among populations of *B. boops* collected at the Bizerte, Kelibia, Monastir, and Zarzis stations, Tunisia.

dendrogram generated by cluster analysis based on Euclidean distances of dissimilarity among the four populations using the UPGMA method showed two main groups, or clusters. The first comprised the populations of Bizerte and Kelibia, while the second included those of Monastir and Zarzis (Fig. 4a).

Meristic characters

Univariate analysis of variance (ANOVA), Scheffé's post-hoc test, and MANOVA revealed statistically significant differences among the four populations in only four (57.1%) of the seven meristic characters. In detail, ANOVA showed significant differential differences between populations, especially in NAFR, NPFRleft, NPER, and NGRleft. Scheffé's post-hoc test, as well as ANOVA and Wilks' λ test, showed significant differences ($P < 0.001$) in both NAFR and NPER between the populations of Bizerte and Monastir, Bizerte and Zarzis, Kelibia and Monastir, and Kelibia and Zarzis. However, both NPFRleft and NGRleft displayed significant differences ($P < 0.001$ and $P < 0.05$, respectively) only between the Kelibia and Monastir populations (Table 4). In addition, the scatter plot for CV1 and CV2 showed clear differentiation only between the populations of Monastir and Zarzis, while there was overlapping differentiation between those of Bizerte and Kelibia (Fig. 3b). CV1 accounted for 78.83% of between-group variability and was correlated with NAFR (main loading = 0.71), while CV2 accounted for 18.76% and was correlated with NGR left (main loading = 0.72). The overall percentage of correct assignment or classification of individuals to their original populations was 51.75%, while their percentages of correct classification to their populations were 57.14% in Monastir, 56.66% in Zarzis, 49.42% in Bizerte, and 46.78% in Kelibia. Hierarchical cluster analysis based on the Euclidean distances of dissimilarity among the four populations (Table 5) resulted in three primary clusters (Fig. 4b). The first cluster contained the Zarzis and Monastir populations. The second comprised the Bizerte population and joined the first, while the third included the Kelibia population and linked it to the Bizerte population.

Discussion

The current TL measurements of 518 *B. boops* samples revealed that TL ranged from 126 to 206 mm. Khemiri et al. (2005) analyzed 3,000 samples of *B. boops* from Tunisian waters and confirmed that the TL ranged from 61 to 320 mm, while Cherif et al. (2008) reported a range of 120 to 260 mm from the examination of 243 samples from the Gulf of Tunis. However, Ceyhan et al. (2018) recorded a TL of 420 mm and a weight of 986 g from different geographical areas in Gull Bay, Turkey, compared to a TL range of 9.3–23 cm and a total weight range of 7.4–133.1 g in Alexandria, Egypt (Azab et al. 2019). Therefore, we suggest that the differences observed in the range of TL could be related to different growth rates under the influence of environmental conditions and food resources specific to each sampling station. Additionally, differences in TL could also reflect the degree of exploitation to which the different populations were exposed and non-exhaustive sampling (Khaldi and Chakroun-Marzouk 2016).

Statistical analyses of morphometric characters showed significant variation among the four populations in only 13 characters (Wilks's $\lambda = 0.004$; $P < 0.0001$). Additionally, CVA and cluster analysis showed a distinct relationship among the four populations. Similar morphological differentiation results were reported recently for the sparid fish *Lithognathus mormyrus* (L.) (Hammami et al. 2011, 2013), *Diplodus vulgaris* (Geoffroy Saint-Hilaire) (Kaoučche et al. 2013), *Diplodus puntazzo* (Walbaum) (Hammami et al. 2016), and *Diplodus sargus* (L.) (Kaoučche et al. 2017) inhabiting different habitats in Tunisia, as well as for *B. boops* collected at seven sampling sites along the Algerian coast (Abla et al. 2018). Prabakaran et al. (2014) found that 10 of 16 morphometric and meristic characters were highly correlated with total length in *Nemipterus japonicus* (Bloch) from the Chennai Coast. Indeed, the morphological differences found among Tunisian *B. boops* populations could reflect differences in the physico-chemical characteristics of water, such as temperature, hydrodynamics, turbidity, salinity, and substrata (Moussa et al. 2005, Hammami et al. 2011). Undoubtedly, environmental influences on fish morphometric characters are well documented. For example, Stearns (1983), Meyer (1987), and Guill et al. (2003) stated that changes in fish body shape allow them to adapt to any changes

in the habitats they live in by modifying their physiology and behavior. Other researchers assumed that morphometric characters changed with water temperature, which could affect fish metabolism through changes in dissolved oxygen (Georgakopoulou et al. 2007, Sfakianakis et al. 2011, Jawad and Al-Janabi 2016). Wimberger (1992) also reported that the viscosity and density of water increased with decreases in water temperature, and, thus, changes in the shape of the body would be advantageous to decrease drag. Additionally, Matthews (1988) found that low light intensity from reduced water turbidity could influence fish eye development. Similarly, salinity clearly affected morphological differentiation in fish species (Akbarzadeh et al. 2009, Siddik et al. 2016). Previous environmental studies at the present four stations showed that at the Bizerte station the water temperature range was 15–16°C, salinity was 37.5‰ (Kaoučche et al. 2017) and the waters were polluted with persistent organic pollutants (POPs), metals, and nutrients that were received through uncontrolled discharges of municipal and industrial wastes, in addition to raw sewage that was back-washed from the sea into the lagoon during high tides and the concentrations of which were generally high at the water surface during the rainy season as was characterized by the abundance and quality of food (Zrafi-Nouira et al. 2008, Barhoumi 2014, Martins et al. 2015, Jamila et al. 2016). However, at Kelibia station, the water temperature ranged from 12.6 to 22.8°C, the salinity was from 35.4‰ in winter to 37.5‰ in summer, and it was mostly polluted with biological and biochemical pollutants that varied throughout the seasons of the year (Boulajfene et al. 2019). Water temperature ranged from 19.6 to 25.8°C at Monastir (Zaafrane et al. 2019) and from 15.6 to 28.3°C at Zarzis (Béjaoui et al. 2019), while the salinity varied from 37‰ in Monastir to 39.5‰ in Zarzis (Kaoučche et al. 2017, Béjaoui et al. 2019), and significant differences in substrates and habitats were determined previously by Mejri et al. (2018). Therefore, we can conclude that the morphological differentiation identified in the present study among the four populations of *B. boops* can be attributed to local changes in physico-chemical water properties at these four stations. Additionally, the availability of food in fish habitats can potentially determine morphometric distinctions among fish (Turan et al. 2006). According to Derbal and Kara (2008) and El-Maremie and El-Mor (2015), *B. boops* is an omnivorous fish that is observed feeding on a wide range of prey species, such as Crustacea, Porifera, Coelenterata, seagrasses, Mollusca, Protozoa, Annelida, Sipuncula, Plantae, Siphonophorae, Copepoda, and eggs along the coasts of Algeria and Benghazi. Depending on the environmental characteristics prevalent at each of these stations, the availability and abundance of potential prey could vary among them. Thus, in light of the lack of data on the *B. boops* diet in Tunisian waters, we can assume that there could be a difference in diet composition that might reflect prey availability with the heterogeneity of target environments along the Tunisian coast, especially at these stations. We can also justify the conclusion that the environmental differences among the four stations can present different intrinsic influences, such as hydrodynamics, turbidity, temperature, salinity, and substrata, and that they offer different ecological niches with different diets that, in turn, lead to morphological adaptations. Therefore, the morphological variation among *B. boops* stock populations at these four stations could be attributed to phenotypic plasticity in response to these environmental parameters. However, some authors have suggested that morphometric divergence in fish species can be attributed either to the impact of habitat differences (Hammami et al. 2011, Kaoučche 2012) or to the interaction of both environmental components and genetic data (Bahri-Sfar and Ben Hassine 2009, Mejri et al. 2012); however, the latter hypothesis cannot be discussed here because of a lack of genetic data on *B. boops* in Tunisia. Moreover, Via et al. (1995) mentioned that when *B. boops* colonizes a range of heterogeneous environments, a single phenotype is unlikely to be associated with high fitness throughout the range. Besides, Jřrgensen et al. (2008) declared that this fish must adapt to succeed, notably by becoming able to match phenotypes to local environments. Such adaptations might involve changes in morphology, survival features, or

reproduction (Stearns 1983). Thus, we can suggest that the four morphometric groups or populations of *B. boops* documented here have thus far adapted to local environments through phenotypic plasticity alone, which is considered an optimal strategy for survival in heterogeneous environments (Kaoučche et al. 2013).

On the other hand, the statistical analysis of meristic characters showed that only four (57.1%) of the seven characters were significantly different among the populations at the four stations ($P < 0.001$, 0.01 or 0.05). CVA and cluster analysis revealed a reticulate relationship among these populations, as there was clear differentiation between those at the Monastir and Zarzis stations and overlap between those at the Bizerte and Kelibia stations. We cited several studies to explain the main causes of variation in meristic characters among fish species. For example, Templeman and Pitt (1961) reported that meristic characters were affected by temperature since the lower the temperature in early life stages, the greater the number of vertebrae. However, Jawad et al. (2017) stated that these variations might result either from environmental or genetic parameters or both. Additionally, Jawad et al. (2018) indicated that the number of vertebrae and the fin ray count could be determined during early larval development and that their number was influenced by environmental parameters, especially temperature, with lower temperatures in early life stages generating greater numbers of vertebrae. Nevertheless, Turan (2000) proposed there was a direct relationship between the extent of phenotypic divergence and the geographical separation of populations and indicated that geographical separation limited migration among populations. Moreover, it has been reported that meristic characters exhibit plasticity under the influence of environmental factors such as temperature, salinity, pH, and oxygen tension, which alter the expression of genes responsible for meristic characters (Dunham et al. 1979, Balon 1980, Todd et al. 1981). Jawad et al. (2017) definitely claimed that warm water temperatures led to shorter incubation periods and lower counts of both fin rays and vertebrae. In the current investigation, the populations at Kelibia and Bizerte, which had the lowest maximum temperature (range = 16–22.8°C), presented the highest number of vertebrae (range = 22–23), while those at Monastir and Zarzis, with the highest maximum temperature range (22.5–38.5°C) had the lowest number of vertebrae (number = 22). Thus, we can assume that each population adapted locally to the environmental parameters of its habitat, in particular water temperature (Kaoučche et al. 2017). Additionally, only four characters—NAFR, NPFRleft, NPER, and NGRleft—showed significant variation among the populations of the four stations relative to their geographic latitudes. For NAFR, the mean numbers decreased among the populations from 20.67 in Zarzis (33°30'14"N) to 17.66 in Kelibia (36°50'51" N), while they decreased from 18.48 in Monastir (35°46'40" N) to 17.15 in Kelibia for NPFRleft. For NPER, they decreased from 18.68 in Zarzis to 17.11 in Kelibia. As for variation in the number of gills rakers, Khalaf-Allah et al. (2016) confirmed that the counts of gill rakers on the first gill arch of *B. boops* collected in the Mediterranean Sea and Gulf of Suez ranged from 23 to 27. In the current study, the mean numbers for the NGRleft decreased from 26.21 in Monastir to 24.59 in Kelibia. As described by Kahilainen et al. (2011), fish that feed on small prey items always have numerous gill rakers. Thus, this difference in the number of gills rakers recorded here appeared to be related to the food type and feeding habits of *B. boops* stemming from variation in the availability and abundance of potential prey among the four stations (El-Maremie and El-Mor 2015). In summary, we can assume here that the differences in meristic characters among the populations of the four stations might be attributed either to the fact that the larvae were exposed to different environmental conditions or to the possibility of the existence of geographically separate spawning populations.

In conclusion, the 13 morphometric and four meristic characters analyzed in this study revealed significant morphological discrimination among populations of *B. boops* collected at four stations located in the lagoons of Bizerte, Kelibia, Monastir, and Zarzis along the Tunisian coast. This phenotypic variability strongly suggests that environmental conditions had an impact

on it. Therefore, further studies are needed to determine the impacts of environmental factors and diet at these four stations on the morphological population structure of *B. boops* and to garner a better understanding of the contribution of environmental conditions to morphological variation. Additionally, the present results recommend the use of morphometric and meristic characters as reliable keys to provide imperative information for discriminating among *B. boops* stocks in Tunisian waters. Moreover, these results provide basic information for stock management and will enable efficient management strategies to differentiate among the structures of populations of the *B. boops* stock to ensure that their fisheries are sustainable and also to develop appropriate conservation plans for Tunisian waters.

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