Oceanologia (2016) xxx, xxx—xxx

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.journals.elsevier.com/oceanologia/

ORIGINAL RESEARCH ARTICLE

Morphometric variations in white seabream *Diplodus sargus* (Linneus, 1758) populations along the Tunisian coast

Myriam Kaouèche *, Lilia Bahri-Sfar, Ibtissem Hammami, Oum Kalthoum Ben Hassine

Département de Biologie, Unité de Recherche Biologie Intégrative et Ecologie Fonctionnelle et Evolutive des milieux Aquatiques, UR11ES08, Faculté des Sciences de Tunis, Université Tunis El Manar, Tunisia

Received 10 March 2016; accepted 24 October 2016

KEYWORDS
Morphometric variation;
Diplodus sargus;
Siculo-Tunisian Strait;
Ecological features

Summary Morphometric characters of the white seabream *Diplodus sargus* (Linnaeus 1758) were compared among samples collected from six marine and lagoon sites along the Tunisian coast to elucidate the impact of the geographical barrier of the Siculo-Tunisian Strait and/or the lagoon environment in the morphological variation among the Tunisian white seabream population. Two morphometric descriptors (twenty-five Truss elements and six traditional measurements) were used to study the pattern of this morphological variation. Univariate analysis of variance revealed significant differences ($P < 0.001$) for both traditional and Truss variables. Multivariate analysis using the two morphometric descriptors detected a clear variation in the body shape between *D. sargus* populations along the Tunisian coast. All these analyses showed the distinctness of the sample from El Biban lagoon compared to the remaining ones. This discrimination was due to the head and the peduncle of the studied fish. Varying degrees of differences were also observed between northern and southern samples, and between the lagoon and the marine samples. The morphological variations of the head explain also the discrimination between the different lagoons samples. Observed morphological heterogeneity seems to be related to the impact of ecological factors.

* Corresponding author.
E-mail addresses: myrka26@gmail.com (M. Kaouèche), lilia.bahri@gmail.com (L. Bahri-Sfar), hammamibtissem@gmail.com (I. Hammami), kalthoum.benhassine@gmail.com (O.K.B. Hassine).
Peer review under the responsibility of Institute of Oceanology of the Polish Academy of Sciences.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.oceano.2016.10.003
0078-3234/

Please cite this article in press as: Kaouèche, M., et al., Morphometric variations in white seabream *Diplodus sargus* (Linneus, 1758) populations along the Tunisian coast. Oceanologia (2016), http://dx.doi.org/10.1016/j.oceano.2016.10.003

1. Introduction

Morphological studies have long been useful to delimit marine fish stocks and describe their spatial distribution (Ihssen et al., 1981; Palma and Andrade, 2002). Such knowledge is important to elaborate management strategies for a better exploitation of fish resources (Bailay, 1997). Morphological variations between fish populations may be induced by several environmental factors. Several works have demonstrated morphological divergence on different regions of the fish body in several marine fish species (Hammami et al., 2013; Mejri et al., 2012; Turan, 2004; Wainwright et al., 2004). Such discrepancy could be explained by intrinsic specificities of each kind of the aquatic environment offering different ecological niches (Hammami et al., 2013).

In fact, such variations may be considered as adaptive responses to environmental variation in order to maintain relative fitness (Thompson, 1991).

Morphometric studies are based on a set of measurements which are continuous data, revealing the size and shape variation (Turan, 1999). The development of image analysis systems has facilitated progress and diversification of morphometric methods (Cadrin and Friedland, 1999). Truss network (Strauss and Bookstein, 1982) has been described as an approach which enables covering the entire fish body in a uniform network and increases the possibility of extracting shape differences among populations (Turan and Basusta, 2001). Numerous works have used Truss approach in order to detect variation among fish populations (Cabral et al., 2003; Erdogan et al., 2009; Hammami et al., 2011, 2013; Palma and Andrade, 2002; Silva, 2003; Turan, 2004; Turan et al., 2004, 2005, 2006).

Sparid fishes are widespread in the Mediterranean Sea. Most of them are overexploited. The white seabream *Diplodus sargus* (Linnaeus, 1758) is one of the most important commercial seabream species in the Mediterranean Sea (Fischer et al., 1987). It lives in coastal rocky reef areas and coastal lagoons. Despite its great ecological and economic importance, and its large geographic distribution (Fischer et al., 1987), a few works have been carried out on Atlantic and Mediterranean white seabream populations focusing on their morphological variations (Palma and Andrade, 2002). Studied populations from the northern Mediterranean shores and the Atlantic ones showed some morphological dissimilarity between them. However, investigations are scarce along the southern Mediterranean shores, which are of a major importance as these shores extend over the two parts of the Siculo-Tunisian Strait.

Table 1 Sample locations of specimens of *Diplodus sargus* and main environmental features of sites. MSL ± SE: mean standard length ± standard error.

Geographic location	North of the Siculo-Tunisien Strait			South of the Siculo-Tunisien Strait		
	Bizertalagoon	Bizerta	Ghar El Melhlagoon	Mahdia	Gabes Gulf	El Bibanlagoon
Sites code	BIZL	BIZM	GEML	MAHM	GABM	BIBL
Environment type	Lagoon	Marine	Lagoon	Marine	Marine	Lagoon
Sample size	28	37	26	28	30	25
MSL [cm] ± SE	13.3 ± 0.7	13.8 ± 0.9	14.9 ± 1.2	14.5 ± 1.3	11.3 ± 0.2	14.8 ± 0.6
Geographic coordinates	37°14′N 9°46′E	37°16′60″ N 9°58′0″ E	37°10′N 10°11′E	35°30′ N 11°04′ E	34°04′48″ N 10°28′36″ E	33°16′ N 11°17′ E
Vegetation	*Cymodoceanodosa* *Zosteranoltii* *Zostera marina*	Posidonia Caulerpa *Janiarubens* (Molinier and Picard, 1954)	*-Ruppiacirrhosa* - *Cladophorasp* (Moussa et al., 2005)	Phanerogams and Algae (Ben Hassine et al., 1999)	- *Cymodocea* - *Posidonia* - *Caulerpa* (Ben Othman, 1971)	- *Zosteranoltii* - *Cymodoceanodosa* - *Caulerpaprolifera* - *Lithothamnium sp* (Guelorget et al., 1982)
Tide	10—12 cm (Harzallah, 2003)	0.40 m (Blanco, 1992)	0.08—0.22 m (Moussa et al., 2005)	≈ 20 cm	2 m (Mensching, 1968)	± 0.5 m (max ≈ 1 m) (Lemoalle and Vidy, 1984)
Currentology	Mediterranean Atlantic Water (Astraldi et al., 1999)	Mediterranean Atlantic Water (Astraldi et al., 1999)	Mediterranean Atlantic Water (Astraldi et al., 1999)	Levantine Intermediate water (Astraldi et al., 1999)	Levantine Intermediate water (Astraldi et al., 1999)	Levantine Intermediate water (Astraldi et al., 1999)
Temperature	13—32.5°C	21—22°C (low depths) 15—16°C (deep)	10.3—29.7°C (Ben Hassine, 1983)	15—25°C (Zakhama et al., 2005)	≈ 21.45°C (Drira; 2009)	13—30°C (Neifar, 2001)
Salinity	32—38.5‰	≈ 37‰	36—51‰ (Moussa et al., 2005)	≈ 37.1%	38—39‰ (Hamza, 2003)	45—50‰ (Neifar, 2001)

Please cite this article in press as: Kaouèche, M., et al., Morphometric variations in white seabream *Diplodus sargus* (Linneus, 1758) populations along the Tunisian coast. Oceanologia (2016), http://dx.doi.org/10.1016/j.oceano.2016.10.003

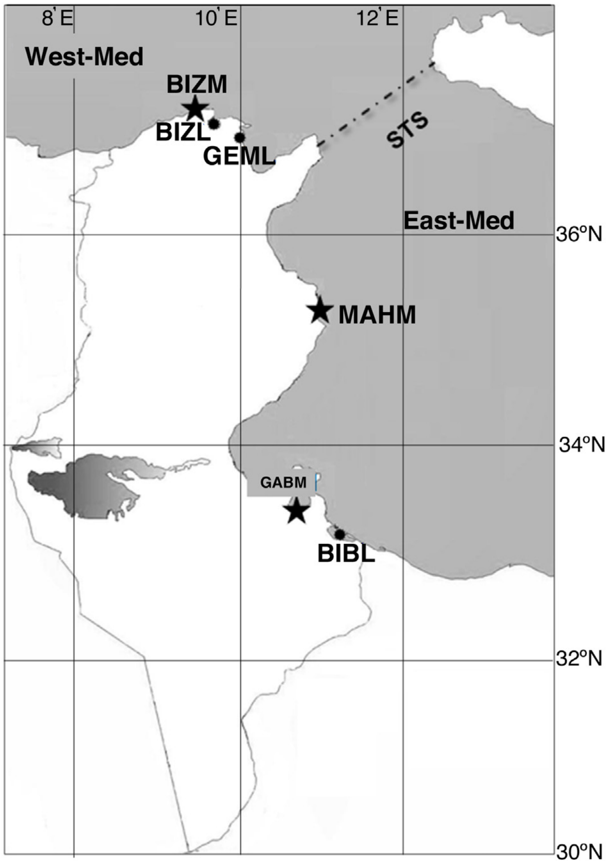

Figure 1 Location of sampling sites along the Tunisian coasts. ★: marine samples. ●: lagoon samples. BIZM: Bizerta, MAHM: Mahdia, GABM: Gabes Gulf, BIZL: Bizerta lagoon, GEML: Ghar El Melh lagoon and BIBL: El Biban lagoon. STS: Siculo-Tunisian Strait. West-Med: Western Mediterranean basin. East-Med: Eastern Mediterranean basin.

Indeed, Tunisian shores are a boundary area between eastern and western Mediterranean basins containing numerous lagoons. Such geographic position gives them a status of important ecological niche, which provides bio-diversity to Tunisian coasts resulting in a correlation with the morphology of fish populations. In this paper, the aim is to investigate the spatial morphological variation of *D. sargus* populations along the Tunisian coastline. Sampling was done among six localities characterised by different environmental features (Table 1, Fig. 1) using Truss network system (Strauss and Bookstein, 1982) and with some traditional measurements.

2. Material and methods

Samples were collected from six localities distributed along the Tunisian coast from June 2006 to January 2008. This sampling covered the north-eastern (Bizerta, Bizerta lagoon and Ghar El Melh lagoon) and the south-eastern (Mahdia, Gabès Gulf and El Biban lagoon) sectors. These localities differ by their environmental features such as temperature, salinity and currents (Fig. 1; Table 1). Fishing gear used included trammel nets, long lines and weir. The sample sizes ranged from 25 to 37 individuals in each locality.

Morphological analysis has been significantly enhanced by image processing techniques, which have become a powerful tool that can complement other approaches to stock identification (Cadrin and Friedland, 1999). In order to describe the shape of fish, the Truss approach was used to create a network of fish body (Strauss and Bookstein, 1982). The left side of each fish, with the fins in the extended position, was photographed with a high quality digital camera mounted on a tripod. The landmark method is based on placing several homologous points called "landmarks" on the most important locations of the body shape image. Morphological landmarks were selected around the outline of the fish form (Turan, 1999). Landmark coordinates were performed on digital images using Visilog 6.480 software. The *x* and *y* coordinates of landmarks were chosen and recorded in agreement with the current literature (Loy et al., 2000; Palma and Andrade, 2002; Sara et al., 1999; Turan, 2004). To test the precision of landmarks placing, we have digitised one specimen from each sample twenty times and calculated the error variance for each variable. Eleven landmarks, which permitted the plotting of 25 measurements, were recorded (Fig. 2, Table 2). Six traditional measurements were added to our data set (Fig. 2; Table 2), which are:

- the eye diameter ($Ø_{eye}$: 13—14),
- the snout length ($leng_{m}$: 1—12),
- the operculum length ($leng_{op}$: 1—15),
- the distance between the operculum and the upper part of the head ($dist_{uh\text{-}op}$: 2—15),
- the distance between the operculum and the lower part of the head ($dist_{lh\text{-}op}$: 11—15),
- the length of the pectoral fin base ($leng_{pec\text{-}b}$: 16—17).

Size-dependent variation of morphometric characters was corrected using the allometric transformation given by Reist (1985): $M_{trans} = \log M - \beta (\log SL - \log SL_{mean})$ where M_{trans} is the transformed measurement, M is the original measurement, β is the within-group slope regressions of log M against log SL, SL is the standard length of the fish and SL_{mean} is the overall mean of the standard length.

Truss and traditional measurements were analysed separately. ANOVA F-test was performed to examine the statistical significance of each measurement variation among the studied samples. In addition, the t-test was established to verify whether the averages of one variable are significantly different between two considered samples.

The discriminant function analysis (DFA) (Ramsay et al., 2009) was used to assess the pattern of morphological variation between samples and to reveal the degree of similarities or differences between the studied samples and the relative importance of each measurement for group separation. Wilks' λ (Everitt and Dunn, 1991) values were estimated to test the significance of observed discrimination for a combination of variables. The classification success rate (PCS) was evaluated based on the percentage of individuals correctly assigned into the original sample. All morphometric measurements and statistical analyses were performed using R 2.11.1 software.

Please cite this article in press as: Kaouèche, M., et al., Morphometric variations in white seabream *Diplodus sargus* (Linneus, 1758) populations along the Tunisian coast. Oceanologia (2016), http://dx.doi.org/10.1016/j.oceano.2016.10.003

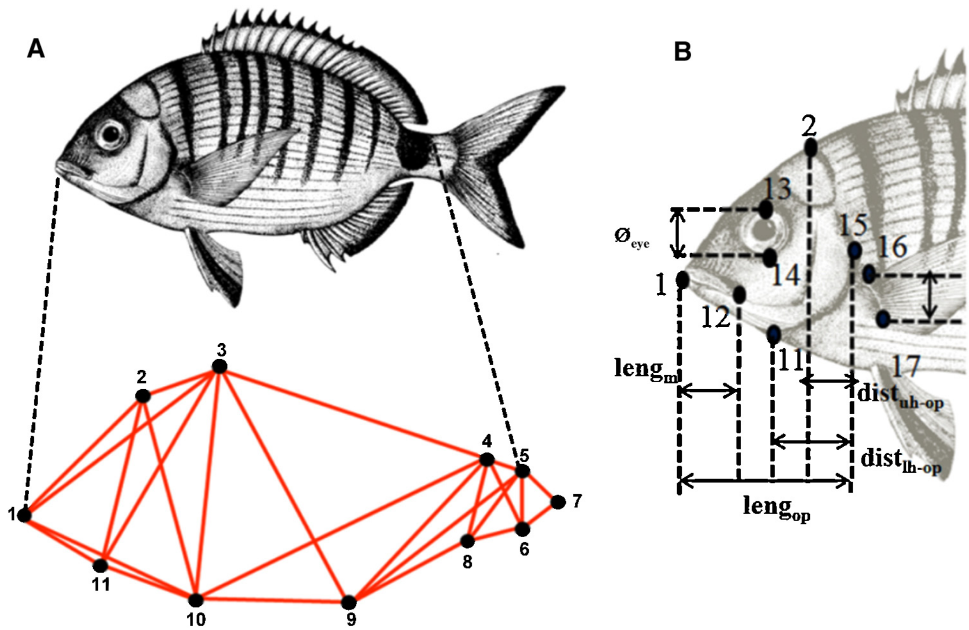

Figure 2 Location of landmarks (1—11) and additional points (12—17). Lines indicate the morphometric measures used for constructing Truss network on *Diplodus sargus*. Landmarks were illustrated as black dots. $Ø_{eye}$: 13—14: the eye diameter; $leng_m$: 1—12: the snout length; $leng_{op}$: 1—15: the operculum length; $dist_{uh\text{-}op}$: 2—15: the distance between the operculum and the upper part of the head; $dist_{lh\text{-}op}$: 11—15: the distance between the operculum and the lower part of the head; $leng_{pec\text{-}b}$: 16—17: the length of the pectoral fin base.

3. Results

3.1. Traditional measurements

The analysis of variance of the 6 traditional measurements revealed significant differences ($P < 0.001$) between samples at all variables (Table 2). The projection of all samples on DF1—DF2 plane showed the discrimination of the two lagoon samples, Bizerta lagoon in the north and El Biban lagoon in the south (Fig. 3). All other samples showed moderate overlapping (Fig. 3).

The significance of this morphological distinction was indicated by Wilk's criterion (Wilk's $\lambda = 0.1263$, $F = 14.491$, $P < 0.001$). The overall assignment of individuals into their original sample (PCS) was 65.5%. These values ranged from 50% for Ghar El Melh lagoon sample to 92% for El Biban one (Table 3). Such discrimination seemed to be defined by two measurements: the operculum length ($leng_{op}$) and the eye diameter ($Ø_{eye}$) (Table 2).

For a better understanding of the observed morphometric variation, we projected separately marine and lagoon samples. The plot obtained with DF1 and DF2 for the three lagoon samples (BIZL, GEML and BIBL) showed a significant discrimination (Wilk's $\lambda = 0.1138$, $F = 22.249$, $P < 0.001$) between northern (BIZL and GEML) and southern (BIBL) samples (Fig. 4a). The overall assignment of individuals into their original sample (PCS) was 90%. These values ranged from 89% for Ghar El Melh and Bizerta lagoons (GEML and BIZL) to 92% for El Biban lagoon sample (BIBL) (Table 4). Such distinction was again related to the operculum length ($leng_{op}$) and the eye diameter ($Ø_{eye}$) (Table 2). The *t*-test calculated between lagoon samples showed that El Biban lagoon has the lowest average of the $Ø_{eye}$ ($t_{GEML\text{-}BIBL} = 18.266$, $P < 0.01$ and $t_{BIZL\text{-}BIBL} = 23.171$, $P < 0.01$).

Across DF2, we observed a moderate discrimination between Ghar El Melh and Bizerta lagoon samples which is related to the variable $dist_{hl\text{-}op}$ (the distance between the operculum and the lower head part: 11—15).

The projection of the marine samples showed a partial overlapping between them with a slight discrimination (Wilk's $\lambda = 0.4193$, $F = 7.8903$, $P < 0.001$) of Bizerta sample (BIZM) highlighted by DF1 (Fig. 4b). The overall assignment of individuals into their original sample (PCS) was 73.36%. These values ranged from 67% to 79% (Table 5). Such distinction seems to be related to two traditional measurements, the snout length ($leng_s$: 1—12) and the distance between the operculum and the lower part of the head ($dist_{hl\text{-}op}$: 11—15).

3.2. Truss measurements

Twenty-five distances which define a network between the 11 homologous points were taken into consideration (Fig. 2). The variance analysis of these measurements revealed significant differences across mean values ($P < 0.001$) between samples for 23 variables (Table 2). The projection of all samples on DF1-DF2 plane showed a clear distinction between three groups (Fig. 5). The first one was formed by El Biban lagoon sample (BIBL) which showed a clear discrimination from all other samples (Wilk's $\lambda = 0.0069$, $F = 9.7553$, $P < 0.001$). The second group gathers the north-eastern samples (BIZM, BIZL and GEML) and the third one is made up of the south-eastern samples (Mahdia and Gabes gulf) across DF1 (Fig. 5). The overall assignment of

Please cite this article in press as: Kaouèche, M., et al., Morphometric variations in white seabream *Diplodus sargus* (Linneus, 1758) populations along the Tunisian coast. Oceanologia (2016), http://dx.doi.org/10.1016/j.oceano.2016.10.003

Table 2 Loadings from discriminant function of the 31 morphometric characters (25 Truss elements and 6 traditional measurements) for *Diplodus sargus*.

Samples	All samples			Lagoon samples			Marine samples		
Variables	DF1	DF2	*F*	DF1	DF2	*F*	DF1	DF2	*F*
Traditional measurements									
	49.78%	21.43%		72.9%	27.1%		60.56%	39.44%	
$leng_s$: 1—12	−0.307	−0.325	10.776***	−0.480	0.349	10.956***	**−0.620**	0.040	8.933***
$leng_{op}$: 1—15	**−0.732**	−0.189	29.193***	**−0.874**	−0.183	67.493***	−0.047	−0.019	0.048^{ns}
$dist_{hu\text{-}op}$:2—15	0.423	0.066	13.701***	0.547	0.015	12.183***	−0.186	**0.798**	10.786***
$dist_{hl\text{-}op}$: 11—15	−0.712	**−0.664**	33.477***	−0.823	**−0.535**	69.415***	**−0.517**	−0.546	11.149***
$Ø_{eye}$:13—14	**−0.702**	0.191	26.026***	**−0.854**	0.139	58.33***	0.263	**0.505**	5.078**
$dist_{base\text{-}pec}$: 16—17	0.059	−0.375	4.390***	0.003	−0.361	1.545***	−0.442	0.279	5.346**
	DF1	DF2	*F*	DF1	DF2	*F*	DF1	DF2	*F*
Truss measurements									
	29.22%	24.48%		54.47%	45.52%		55.49%	44.50%	
V1: 1—2	−0.559	0.318	28.827***	−0.442	−0.483	21.682***	0.686	0.070	36.479***
V2: 2—3	0.651	−0.076	21.901***	0.710	0.011	33.829***	−0.572	−0.005	20.219***
V3: 3—4	−0.526	0.360	18.880***	−0.374	0.002	5.615***	0.661	0.060	32.077***
V4: 4—5	0.705	−0.366	41.543***	0.641	−0.047	23.612***	**−0.792**	−0.091	66.356***
V5: 5—7	−0.368	0.195	14.588***	−0.351	0.410	12.239***	0.331	**0.379**	12.220***
V6: 7—6	**−0.820**	0.297	77.389***	**−0.780**	−0.146	54.082***	**0.892**	0.041	132.95***
V7: 6—8	0.695	−0.177	33.32***	0.634	0.231	27.044***	−0.755	−0.157	56.338***
V8: 8—9	0.091	0.359	4.290**	0.426	0.074	7.87***	0.257	−0.053	3.149*
V9: 9—10	−0.477	−0.398	17.51***	−0.678	0.064	28.89***	0.054	0.331	4.266*
V10:10—11	0.030	−0.299	15.496***	−0.113	−0.428	6.860**	−0.063	−0.321	4.055*
V11: 11—1	−0.233	**0.516**	23.42***	0.075	0.432	6.644**	0.533	0.112	17.439***
V12: 2—11	−0.696	0.344	46.199***	−0.666	−0.179	29.660***	0.775	0.002	58.438***
V13: 11—3	−0.462	0.342	18.089***	−0.284	−0.418	10.062***	0.644	−0.076	29.634***
V14: 3—10	−0.436	0.301	12.457***	−0.303	−0.139	4.181*	0.570	−0.116	20.934***
V15: 10—4	−0.679	−0.181	26.905***	−0.732	0.087	39.056***	0.549	0.132	19.208***
V16: 4—8	−0.521	0.022	12.027***	−0.551	0.066	15.135***	0.436	0.175	11.531***
V17: 8—5	−0.257	−0.002	4.892***	−0.338	0.326	8.766***	0.436	0.175	1.410^{ns}
V18: 5—6	**−0.787**	0.225	57.018***	**−0.776**	−0.104	51.016***	0.119	0.148	80.174***
V19: 6—4	−0.202	−0.064	3.321**	−0.325	−0.194	5.499**	0.794	0.251	1.865^{ns}
V20: 4—9	−0.257	0.516	13.341***	0.143	0.266	3.001^{ns}	0.050	0.221	19.261***
V21: 9—3	−0.461	0.296	15.553***	−0.369	0.029	5.497**	0.558	0.076	19.02***
V22: 5—9	0.284	0.300	6.646***	0.566	0.261	20.520***	0.528	0.207	0.033***
V23: 10—1	−0.183	0.310	4.777***	0.067	−0.090	0.398^{ns}	−0.024	−0.014	10.812***
V24: 2—10	−0.535	0.327	19.741***	−0.462	−0.143	10.292***	0.426	−0.166	26.364***
V25: 1—3	−0.088	0.408	13.812***	0.209	**−0.603**	18.121***	0.621	−0.080	9.464***

F: *F*-test's values, significance levels of *F*-test's *P*-values:
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.
Bold text: variables related to discriminations. $Ø_{eye}$: 13—14: the eye diameter; $leng_m$: 1—12: the snout length; $leng_{op}$: 1—15: the operculum length; $dist_{uh\text{-}op}$: 2—15: the distance between the operculum and the upper part of the head; $dist_{lh\text{-}op}$: 11—15: the distance between the operculum and the lower part of the head; $leng_{pec\text{-}b}$: 16—17: the length of the pectoral fin base.

individuals into their original sample (PCS) was 86.33%. These values ranged from 82% for Bizerta marine sample to 93% for Gabes Gulf sample (Table 3). The discrimination between the north-eastern and the south-eastern samples seems to be mainly related to two Truss measurements, V6 and V18 (Table 2), defining the posterior body part (Fig. 2). The application of *t*-test between all samples showed that El Biban lagoon has the highest average of V6 compared to Bizerta and Ghar El Melh lagoon samples ($t_{BIBL\text{-}BIZL} = 97.790$, $P < 0.001$ and $t_{BIBL\text{-}GEML} = 30.725$, $P < 0.001$) whereas Bizerta marine sample showed a lower average than Mahdia and Gabes Gulf samples ($t_{MAHM\text{-}BIZM} = 27.558$, $P < 0.001$ and $t_{GABM\text{-}BIZM} = 37.221$, $P < 0.001$).

For V18 variable, which is related to peduncle height, Bizerta marine specimens seemed to have the highest average compared to Mahdia marine sample ($t_{BIZM\text{-}MAHM} = 7.906$, $P < 0.01$). The *t*-test was also significant between El Biban and the two northern lagoons and showed that El Biban lagoon specimens have the highest average of V18 ($t_{BIBL\text{-}BIZL} = 44.514$, $P < 0.001$ and $t_{BIBL\text{-}GEML} = 9.178$, $P < 0.01$).

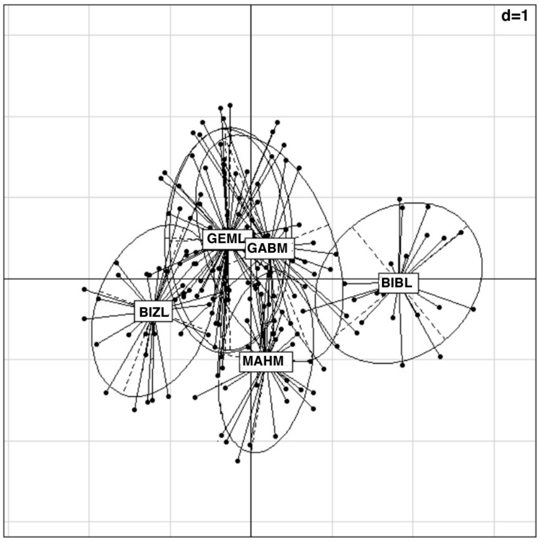

Figure 3 Plot of the first two discriminant functions of DFA scores with all samples using traditional measurements. BIZM: Bizerta, MAHM: Mahdia, GABM: Zarzis, BIZL: Bizerta lagoon, GEML: Ghar El Melh lagoon, BIBL: El Biban lagoon.

Table 3 Correct classification of all individuals into their original group using traditional and Truss measurements. BIZM: Bizerta, MAHM: Mahdia, ZARM: Zarzis, BIZL: Bizerta lagoon, GEML: Ghar El Melh lagoon and BIBL: El Biban lagoon.

Sample	BIBL	BIZL	BIZM	GEML	MAHM	GABM
Traditional measurements						
BIBL	**92**	0	0	0	0	8
BIZL	0	**65**	32	4	0	0
BIZM	0	6	**58**	13	10	13
GEML	0	0	4	**50**	46	0
MAHM	0	0	7	4	**68**	21
GABM	0	3	20	3	14	**60**
Truss measurements						
BIBL	**92**	0	0	0	8	0
BIZL	0	**86**	7	7	0	0
BIZM	0	8	**82**	10	0	0
GEML	0	0	15	**80**	4	0
MAHM	4	0	0	0	**85**	11
GABM	0	0	0	0	7	**93**

Bold text: Percentage of individuals correctly classified in their original group.

El Biban lagoon was discriminated from all other samples by DF2 and such distinction was mainly explained by the V11 variable which is related to the head length.

The plot obtained with DF1 and DF2 for lagoon samples showed a clear significant discrimination between them (Fig. 6a) (Wilk's $\lambda = 0.0174$, $F = 12.875$, $P < 0.001$). The overall assignment of individuals into their original sample (PCS) was 98.83% whereas values ranged from 97% to 100% (Table 4). Across DF1, the distinction of El Biban lagoon sample from Bizerta and Ghar El Melh lagoons seemed to be related again to V6 and V18 (peduncle region) (Table 2). The observed discrimination between Ghar El Melh and Bizerta lagoon samples, highlighted along DF2, seemed to be related to V25 variable which defines the head length (pre-dorsal length) (Table 2). In fact, Ghar El Melh lagoon specimens showed the highest average of V25 ($t_{GEML\text{-}BIZL} = 21.734$, $P < 0.001$, ddl = 55).

The spatial projection of the marine samples on the factorial plane defined by the two first functions (DF1 and DF2) showed also a total discrimination (Wilk's $\lambda = 0.0271$, $F = 13.793^{***}$, $P < 0.001$) between northern and southern samples (Fig. 6b). The discrimination of Bizerta marine sample (BIZM) was highlighted by DF1. The overall assignment of individuals into their original sample (PCS) was 95.33%. These values ranged from 97% to 100%. This distinction seemed to be attributed to three Truss elements (V4, V6 and V18) which define the posterior body part (Table 2). Along the DF2, the two south-eastern samples, Mahdia and Gabes

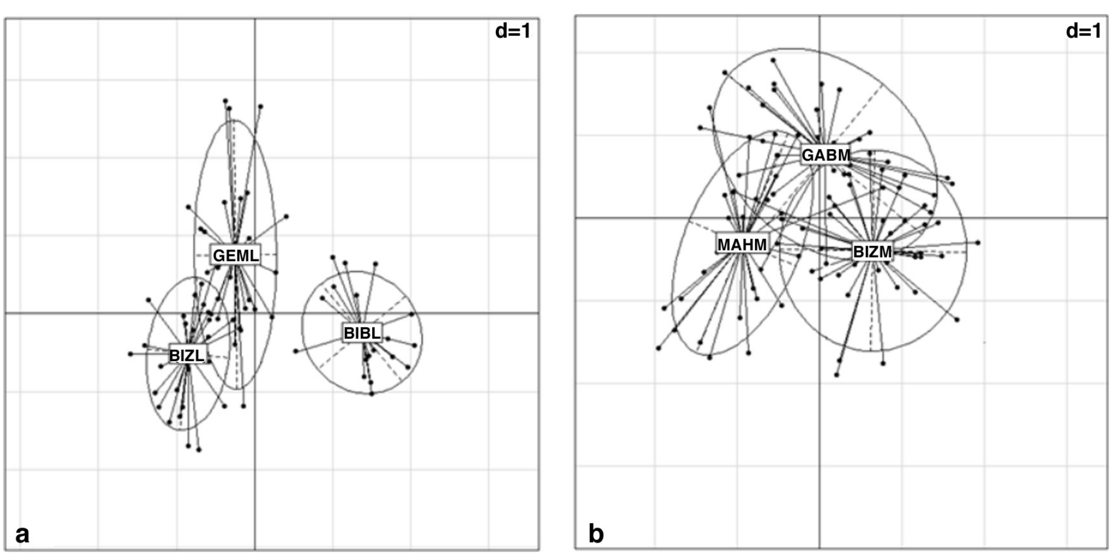

Figure 4 Plot of the first two discriminant functions of DFA scores with lagoon(a) and marine (b) samples using traditional measurements. BIZM: Bizerta, MAHM: Mahdia, GABM: Zarzis, BIZL: Bizerta lagoon, GEML: Ghar El Melh lagoon, BIBL: El Biban lagoon.

Table 4 Correct classification of lagoon individuals into their original group using traditional and Truss measurements. BIZM: Bizerta, MAHM: Mahdia, ZARM: Zarzis, BIZL: Bizerta lagoon, GEML: Ghar El Melh lagoon and BIBL: El Biban lagoon.

Sample	BIBL	BIZL	GEML
Traditional measurements			
BIBL	**92**	8	0
BIZL	0	**89**	11
GEML	0	11	**89**
Truss measurements			
BIBL	**100**	0	0
BIZL	0	**97**	3
GEML	0	0	**100**

Bold text: Percentage of individuals correctly classified in their original group.

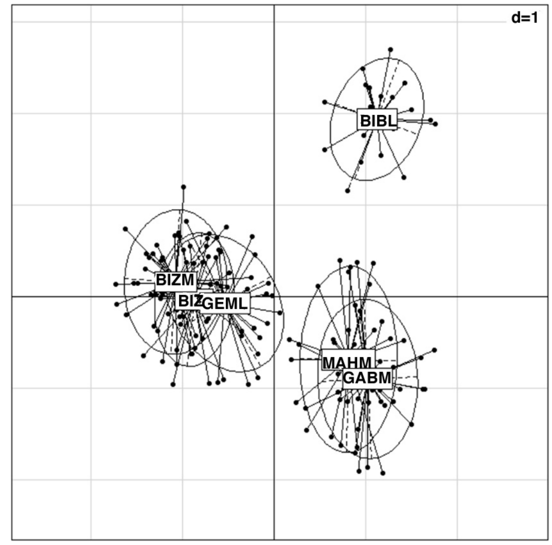

Figure 5 Plot of the first two discriminant functions of DFA scores with all samples using Truss measurements. BIZM: Bizerta, MAHM: Mahdia, GABM: Zarzis, BIZL: Bizerta lagoon, GEML: Ghar El Melh lagoon, BIBL: El Biban lagoon.

Gulf, were discriminated (Fig. 6b). Such variation was explained by V5 which define the posterior part of the body (Table 2). Moreover, the application of the *t*-test showed that El Mahdia specimens have the highest averages of V5 ($t_{MAHM\text{-}GABM}$ = 11.809, $P < 0.05$, ddl = 59).

4. Discussion

The morphometric analysis of six samples of *D. sargus* along Tunisian coasts revealed the discrimination of El Biban lagoon sample from all the remaining ones. This discrimination was highlighted with the two approaches. Different degrees of divergence were also detected between northern and southern samples, and between lagoon and marine samples. Several variables were implicated in this dissimilarity. These variables are mainly related to the head and the posterior part of the body.

Generally, fish exhibit greater morphological variability than other invertebrates and seem to be more sensitive to environmental fluctuations (Allendorf, 1988; Dunham et al., 1979; Thompson, 1991; Wimberger, 1992). Such variability may be the result of different selective regimes generated by the type of habitat where the fish live (Slatkin, 1985; Swain and Foote, 1999) creating environmental discriminations. Indeed, sampling localities have different environmental features (Table 1) which may cause morphological adaptations. Several studies have demonstrated the relationships between morphological and functional traits of fish and ecological niches (Albouy et al., 2011; Farré et al., 2013; Price et al., 2011), e.g. body-shape adaptation to microhabitat utilisation.

Table 5 Correct classification of marine individuals into their original group using traditional and Truss measurements. BIZM: Bizerta, MAHM: Mahdia, ZARM: Zarzis, BIZL: Bizerta lagoon, GEML: Ghar El Melh lagoon and BIBL: El Biban lagoon.

Sample	BIZM	MAHM	GABM
Traditional measurements			
BIZM	**79**	8	13
MAHM	4	**75**	21
GABM	20	13	**67**
Truss measurements			
BIZM	**100**	0	0
MAHM	0	**89**	11
GABM	0	3	**97**

Bold text: Percentage of individuals correctly classified in their original group.

Therefore, the divergence between El Biban sample and other samples seemed to be related to several measurements accounted for by the head ($leng_{op}$, $Ø_{eye}$ and V11) and the posterior body part (V6 and V18). The same statement was raised by Palma and Andrade (2002). They showed a morphometric divergence between northern Mediterranean *D. sargus* samples and Atlantic ones related particularly to the head variables. These authors attributed the observed dissimilarity to environmental conditions and to ecological niches. They implied also the contribution of the natural geographical barriers, such as the Gibraltar Strait, to the emergence of differences between populations.

Indeed, morphometric variation results from differences in developmental rates and how the population responds to varying environmental conditions (Burns et al., 2009; Cachéra, 2013; Turan et al., 2004). Thus, the head morphological variation can be related to feeding behaviours (Delariva and Agostinho, 2001; Hyndes et al., 1997) or the exploitation of different ecological niches with different types of prey. El Biban lagoon specimens were characterised by a smaller head than the other populations. El Biban lagoon ecosystem presents some physicochemical particularities such as its high salinity (45—50‰; Neifar, 2001), its large size (30,000 ha) and its sandy bottom. These characteristics can offer a particular ecological niche to El Biban lagoon explaining such discrimination of specimens providing from it. The special hydrodynamic system in the south of Tunisia

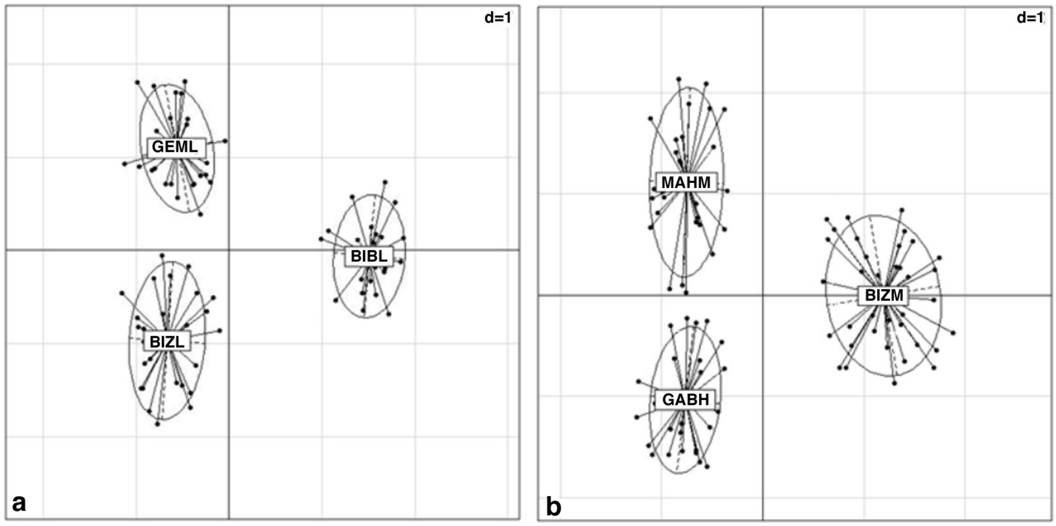

Figure 6 Plot of the first two discriminant functions of DFA scores with lagoon(a) and marine (b) samples using Truss measurements. BIZM: Bizerta, MAHM: Mahdia, GABM: Zarzis, BIZL: Bizerta lagoon, GEML: Ghar El Melh lagoon, BIBL: El Biban lagoon.

can also explain the observed variation especially at the posterior body part.

The morphological head variability explains also the discrimination between lagoons and was indicated by both approaches ($leng_{op}$, $Ø_{eye}$, $dist_{hl\text{-}op}$ and V25). This seemed to be related to intrinsic environmental characteristics of each lagoon ecosystem such as physico-chemical conditions, substrate nature and type and size of prey.

Moreover, coastal lagoon ecosystems are characterised by particular physical features (shallowness, relative isolation from the open, variable physical and ecological gradients) which create different types of habitat compared to those of the open sea (Pérez-Ruzafa et al., 2007). In addition, lagoons are richer nutritional areas that are often used as nursery areas, allowing fish larvae to develop and grow (Çoban et al., 2008). It is known that the environmental conditions influence morphometric characters (Swain and Foote, 1999) and during these early life stages, morphology is especially dependent on environmental conditions (Cheverud, 1988; Ryman et al., 1984).

Several studies showed an important variation of the head morphology. The discrimination between European samples of *Diplodus puntazzo* was also attributed to the head morphology (Palma and Andrade, 2002). Turan (2004) also associated the differentiation within Turkish *Trachurus mediterraneus* samples to head characters. Recently, the significant morphological divergence between lagoon and marine samples of Tunisian *Lithognathus mormyrus* populations was also attributed to the head morphology (Hammami et al., 2011, 2013).

The discrimination between the northern and the southern samples seemed to be particularly associated with the posterior body part especially to the peduncle region (V4, V6 and V18). This results mostly related to the swimming behaviour of the fish which varies according to species and to hydrodynamic constraints (e.g. water currents) (Costa and Cataudella, 2007). In fact, the southern marine area of Tunisia presents a complex hydrology with four different types of currents (Serbaji, 2000). The most important one is the high tidal current which creates considerable sea level oscillations (Illou, 1999; Sammari et al., 2006). This region is also characterised by particular physico-chemical features, resembling closely features of the eastern Mediterranean waters rather than the western ones. Such characteristics can instigate morphological differences between populations. These results present environmental influences as a selective pressure on the morphology of body parts like the head or the peduncle.

However, morphological divergences among fish populations can be related to genetic differentiation or interaction between environmental and genetic components (Cabral et al., 2003; Favaloro and Mazzola, 2006). For several species, morphological divergences are associated with genetic differentiation (Bergeks and Bjorklund, 2009; Lin et al., 2008). Sometimes, this kind of variation may not be directly caused by genetic factors (Ihssen et al., 1981; Turan, 1999). This seems to be the case with our data, as it cannot be explained by the genetic component because of the lack of genetic differentiation between samples of the northern and the southern sectors (Kaouèche et al., 2011). Moreover, morphological variation was observed between Atlantic and Mediterranean white seabream populations (Palma and Andrade, 2002) despite the high degree of homogeneity between samples of these areas (Bargelloni et al., 2005; Domingues et al., 2007; Gonzalez-Wanguemert et al., 2010). In the same context, homogeneity was also revealed for Tunisian *L. mormyrus* samples (Hammami et al., 2007) whereas authors demonstrated morphological heterogeneity between lagoons (Hammami et al., 2011, 2013).

Our work indicates the existence of different degrees of morphological differences between northern and southern *D. sargus* samples but also among the samples collected from different lagoons. Both approaches, Truss and traditional, converged and gave complementary results but it is clear that the Truss network provides more precise and relevant information. The phenotypic variability observed between samples suggests a strong implication of ecological conditions.

Please cite this article in press as: Kaouèche, M., et al., Morphometric variations in white seabream *Diplodus sargus* (Linneus, 1758) populations along the Tunisian coast. Oceanologia (2016), http://dx.doi.org/10.1016/j.oceano.2016.10.003

Acknowledgements

This work was supported by a scholarship from the Tunisian 'Ministère de l'Enseignement Supérieur et de la Recherche Scientifique et de la Technologie'. We are also grateful to two anonymous reviewers who helped to improve the quality of the manuscript, through their suggestions and constructive comments.

References

Albouy, C., Guilhaumon, F., Villéger, S., Mouchet, M., Mercier, L., Culioli, J.M., Tomasini, J.A., Le Loc'h, F., Mouillot, D., 2011. Predicting trophic guild and diet overlap from functional traits: statistics, opportunities and limitations for marine ecology. Mar. Ecol. Prog. Ser. 436, 17—28, http://dx.doi.org/10.3354/meps09240.

Allendorf, F.W., 1988. Conservation biology of fishes. Conserv. Biol. 2, 145—148, http://dx.doi.org/10.1111/j.1523-1739.1988.tb00165.x.

Astraldi, M., Balopoulos, S., Candela, J., Font, J., Gacic, M., Gasparini, G.P., Manca, B., Theocharis, A., Tintoré, J., 1999. The role of straits and channels in understanding the characteristics of Mediterranean circulation. Prog. Oceangr. 44, 65—108, http://dx.doi.org/10.1016/S0079-6611(99)00021-X.

Bailay, K.M., 1997. Structural dynamics and ecology of flatfish populations. J. Sea. Res. 37 (3—4), 269—280, http://dx.doi.org/10.1016/S1385-1101(97)00018-X.

Bargelloni, L., Alarcon, J.A., Alvarez, M.C., Enzo, E., Magoulas, A., Palma, J., Patarnellot, T., 2005. The Atlantic—Mediterranean transition: discordant genetic patterns in two seabream species, *Diplodus puntazzo* (Cetti) and *Diplodus sargus* (L.). Mol. Phylogenet. Evol. 36 (3), 523—535, http://dx.doi.org/10.1016/j.ympev.2005.04.017.

Ben Hassine, O.K., 1983. Les Copépodes parasites de poissons Mugilidae en Méditerranée occidentale (côtes françaises et tunisiennes). Morphologie, Bio-écologie, cycles évolutifs. (Thèse de Doctorat d'État). U.S.T.L., Montpellier, France, 452 pp.

Ben Hassine, O.K., Benmansour, B., Neifer, L., Bahri, L., Haji, T., Chaouachi, B., Labaied, M., Majed, M., 1999. L'état de la biodiversité dans les sites à activité halieutique du littoral Est de la Tunisie. In: L'homme et la mer, vol. I. 277—333.

Ben Othman, S., 1971. Observation hydrologiques: dragages et chalutages dans le Sud-Est tunisien. Bull. Inst. Natn. Scien. Tech. Mer de Salammbô 2 (2), 103—120.

Bergeks, S., Bjorklund, M., 2009. Genetic and morphological divergence reveal local subdivision of perch (*Perca fluviatilis* L.). Biol. J. Linn. Soc. 96 (4), 746—758, http://dx.doi.org/10.1111/j.1095-8312.2008.01149.x.

Blanco, B., 1992. Protection du littoral du Gouvernorat de Bizerte. Conseil de l'ordre des ingénieurs; Comité régional de Bizerte. 1—5.

Burns, J.G., Dinardo, P., Rodd, F.H., 2009. The role of predation in variation in body shape in guppies *Poecilia reticulata*: a comparison of field and common garden phenotypes. J. Fish. Biol. 75 (6), 1144—1157, http://dx.doi.org/10.1111/j.1095-8649.2009.02314.x.

Cabral, H.N., Marques, J.F., Rego, A.L., Catarino, A.I., Figueredo, J., Garcia, J., 2003. Genetic and morphological variation of *Synaptura lusitanica* Capello, 1868, along the Portuguese coast. J. Sea Res. 50 (2—3), 167—175, http://dx.doi.org/10.1016/S1385-1101(03)00060-1.

Cachéra, M., 2013. Implications of morphological and functional traits for trophic relationships within fish communities and marine trophic network architecture. (Doctoral thesis). University of Sciences and Technology, Lille, France, 249 pp.

Cadrin, S.X., Friedland, K.D., 1999. The utility of image processing techniques for morphometric analysis and stock identification. Fish. Res. 43 (1), 129—139, http://dx.doi.org/10.1016/S0165-7836(99)00070-3.

Cheverud, J.M., 1988. A comparison of genetic and phenotypic correlations. Evolution 42 (5), 958—968, http://dx.doi.org/10.2307/2408911.

Çoban, D., Saka, F., Firat, K., 2008. Morphometric comparison of cultured and lagoon caught gilthead seabream (*Sparus aurata* L. 1758). Turk. J. Zool. 32, 337—341.

Costa, C., Cataudella, S., 2007. Relationship between shape and trophic ecology of selected species of Sparids of the Caprolace coastal lagoon (Central Tyrrhenian Sea). Environ. Biol. Fish. 78 (2), 115—123, http://dx.doi.org/10.1007/s10641-006-9081-9.

Delariva, R.L., Agostinho, A.A., 2001. Relationship between morphology and diets of six neotropical loricariids. J. Fish. Biol. 58 (3), 832—847, http://dx.doi.org/10.1111/j.1095-8649.2001.tb00534.x.

Domingues, V.S., Santos, R.S., Brito, A., Alexandrou, M., Almada, V. C., 2007. Mitochondrial and nuclear markers reveal isolation by distance and effects of Pleistocene glaciations in the northeastern Atlantic and Mediterranean populations of the white seabream (*Diplodus sargus*, L.). J. Exp. Mar. Biol. Ecol. 346, 102—113, http://dx.doi.org/10.1016/j.jembe.2007.03.002.

Dunham, A.E., Smith, G.R., Taylor, J.N., 1979. Evidence for ecological character displacement in western American catostomic fishes. Evolution 33, 877—896.

Erdogan, Z., Turan, C., Koç, H.T., 2009. Morphologic and Allozyme Analyses of European anchovy (*Engraulis encrasicolus* (L. 1758)) in the Black, Marmara and Aegean Seas. Acta Adriat. 50 (1), 77—90.

Everitt, B.S., Dunn, G., 1991. Applied Multivariate Data Analysis. Edward Arnold, London, 219—220.

Farré, M., Tuset, V.M., Maynou, F., Recasens, L., Lombarte, A., 2013. Geometric morphology as an alternative for measuring the diversity of fish assemblages. Ecol. Indic. 29, 159—166, http://dx.doi.org/10.1016/j.ecolind.2012.12.005.

Favaloro, E., Mazzola, A., 2006. Meristic character counts and incidence of skeletal anomalies in the wild *Diplodus puntazzo* (Cetti, 1777) of an area of the south-eastern Mediterranean Sea. Fish. Physiol. Biochem. 32 (2), 159—166.

Fischer, W., Bauchot, M.L., Schneider, M., 1987. Fiches F.A.O. d'Identification Des Espèces Pour Les Besoins De La Pêche. Méditerranée Et Mer Noir. Zone De Pêche 37. Vol. II. Vertébrés. FAO, Rome, 761—1530.

Gonzalez-Wanguemert, M., Canovas, F., Perez-Ruzafa, A., Marcos, C., Alexandrino, P., 2010. Connectivity patterns inferred from the genetic structure of white seabream (*Diplodus sargus* L.). J. Exp. Mar. Biol. Ecol. 383, 23—31.

Guelorget, O., Frisoni, G.F., Perhuisot, J.P., 1982. Contribution a l'étude biologique de la Bahiret el Biban, lagune du Sud-Est tunisien. Symposium SGF et ASF, "Transition eaux douces — eaux salees". Mem. Soc. Geol. Fr. N.S. 144, 173—186.

Hammami, I., Bahri-Sfar, L., Kaouèche, M., Ben Hassine, O.K., 2007. Genetic characterisation of striped seabream (*Lithognathus mormyrus*) populations on both sides of a boundary area between eastern and western Mediterranean basins. Cybium 31 (2), 143—147.

Hammami, I., Bahri-Sfar, L., Ben Hassine, O.K., 2011. Morphological variations of striped seabream, *Lithognathus mormyrus*, populations along the Tunisian coast. J. Mar. Biol. Assoc. U. K. 91 (6), 1261—1271.

Hammami, I., Bahri-Sfar, L., Kaouèche, M., Grenouillet, G., Leks, S., Kara, M.H., Ben Hassine, O.K., 2013. Morphological characterization of striped seabream (*Lithognathus mormyrus*, Sparidae) in some Mediterranean lagoons. Cybium 37 (1—2), 27—139.

Hamza, A., 2003. Le statut du phytoplancton dans le golfe de Gabès. (Doctoral thesis). University of Sfax, Tunisia, 298 pp.

Harzallah, A., 2003. Transport de polluants dans la lagune de Bizerte simule par un modèle de circulation de l'eau. Bull. Inst. Natn. Scien. Tech. Mer de Salammbô 30, 121—133.

Hyndes, G.A., Platell, M.E., Potter, I.C., 1997. Relationships between diet and body size, mouth morphology, habitat and movement of six sillaginid species in coastal waters: implications for resource partitioning. Mar. Biol. 128 (4), 585—598.

Ihssen, P.E., Booke, H.E., Casselman, J.M., Mcglade, J.M., Payne, N. R., Utter, F.M., 1981. Stock identification: materials and methods. Can. J. Fish. Aquat. S.C.I. 38 (12), 1838—1855, http://dx.doi.org/10.1139/f81-230.

Illou, S., 1999. Impact Des Rejets Telluriques D'origines Domestiques Et Industrielles sur L'Environnement Côtier: Cas Du Littoral De La Ville De Sfax. (Doctoral thesis). University of Tunis II, 259 pp.

Kaouèche, M., Bahri-Sfar, L., Gonzalez-Wanguemert, M., Perez-Ruzafa, Á., Ben Hassine, O.K., 2011. Allozyme and mtDNA variation of white seabream *Diplodus sargus* populations in a transition area between western and eastern Mediterranean basins (Siculo-Tunisian Strait). Afr. J. Mar. Sci. 33 (1), 79—90, http://dx.doi.org/10.2989/1814232X.2011.572342.

Lin, J., Quinn, T.P., Hilborn, R., Hauser, L., 2008. Fine-scale differentiation between sockeye salmon ecotypes and the effect of phenotype on straying. Heredity 101 (4), 341—350, http://dx.doi.org/10.1038/hdy.2008.59.

Loy, A., Busilacchi, S., Costa, C., Ferlin, L., Cataudella, S., 2000. Comparing geometric morphometrics and outline fitting methods to monitor fish shape variability of *Diplodus puntazzo* (Teleostea: Sparidae). Aquacult. Eng. 21 (4), 104—110.

Mejri, R., Lo Brutto, S., Hassine, N., Arculeo, M., Ben Hassine, O.K., 2012. Overlapping patterns of morphometric and genetic differentiation in the Mediterranean goby *Pomatoschistus tortonesei* Miller, 1968 (Perciformes, Gobiidae) in Tunisian lagoons. Zoology 115 (4), 239—244, http://dx.doi.org/10.1016/j.zool.2012.02.002.

Molinier, R., Picard, J., 1954. Éléments de bionomie marine sur les côtes de Tunisie. Bull. Stn. Oceanogr. Peche. Salammbô 48, 3—47.

Moussa, M., Baccar, L., Ben Khemis, R., 2005. La lagune de Ghar El Melh: Diagnostic écologique et perspectives d'aménagement hydraulique. Rev. Sci. Eau. 18 (2), 13—26.

Neifar, L., 2001. Biodiversité Et Evolution Des Plathelminthes Parasites des Elasmobranches. (Doctoral thesis). University of Tunis II, Faculté Des Sciences De Tunis, 326 pp.

Palma, J., Andrade, J.P., 2002. Morphological study of *Diplodus sargus*, *Diplodus puntazzo*, and *Lithognathus mormyrus* (Sparidae) in the Eastern Atlantic and Mediterranean Sea. Fish. Res. 57 (1), 1—8.

Pérez-Ruzafa, A., Mompeán, M.C., Marcos, C., 2007. Hydrographic, geomorphologic and fish assemblage relationships in coastal lagoons. Hydrobiologia 577 (1), 107—125, http://dx.doi.org/10.1007/s10750-006-0421-8.

Price, S.A., Holzman, R., Near, T.J., Wainwright, P.C., 2011. Coral reefs promote the evolution of morphological diversity and ecological novelty in labrid fishes. Ecol. Lett. 14 (5), 462—469, http://dx.doi.org/10.1111/j.1461-0248.2011.01607.

Ramsay, J.O., Hooker, G., Graves, S., 2009. Functional Data Analysis with R and MATLAB. Springer, Dordrecht, 208 pp.

Reist, J.D., 1985. An empirical evaluation of several univariate methods that adjust for size variation in morphometric data. Can. J. Zool. 63 (6), 1429—1439.

Ryman, N., Lagercrantz, U., Andersson, L., Chakraborty, R., Rosenberg, R., 1984. Lack of correspondence between geneticand morphologic variability patterns in Atlantic herring (*Clupea harengus*). Heredity 5 (3), 687—704.

Sammari, C., Koutitonsky, V.G., Moussa, M., 2006. Sea level variability and tidal resonance in the Gulf of Gabes, Tunisia. Cont. Shelf. Res. 26, 338—350.

Sara, M., Favarolo, E., Mazzola, A., 1999. Comparative morphometrics of sharpsnout seabream (*Diplodus puntazzo* Cetti. 1777) reared in different conditions. Aquacult. Eng. 19, 195—209.

Serbaji, M.M., 2000. Utilisation d'un SIG Multi-Sources pour la compréhension et la gestion intégrée de l'écosystème côtier de la région de Sfax (Tunisie). (Doctoral thesis). University of Tunis II, 152 pp.

Silva, A., 2003. Morphometric variation among sardine (*Sardina pilchardus*) populations from the northeastern Atlantic and the westernMediterranean. ICES J. Mar. Sci. 60 (6), 1352—1360.

Slatkin, M., 1985. Gene flow in natural populations. Ann. Rev. Ecol. Evol. Syst. 16, 393—430.

Strauss, R.E., Bookstein, F.L., 1982. The truss: body from reconstructions in morphometrics. Syst. Zool. 31 (2), 113—135.

Swain, D., Foote, C.J., 1999. Stocks and chameleons: the use of phenotypic variation in stock identification. Fish. Res. 43, 113—128.

Thompson, J.D., 1991. Phenotypic plasticity as a component of evolutionary chance. Trends. Ecol. Evol. 6 (8), 246—249, http://dx.doi.org/10.1016/0169-5347(91)90070-E.

Turan, C., 1999. A note on the examination of morphometric differentiation among fish populations: the truss system. Turk. J. Zool. 23, 259—263, doi:10.1.1.584.1003.

Turan, C., 2004. Stock identification of Mediterranean horse mackerel (*Trachurus mediterraneus*) using morphometric and meristic characters. ICES J. Mar. Sci. 61 (5), 774—781, http://dx.doi.org/10.1016/j.icesjms.2004.05.001.

Turan, C., Basusta, N., 2001. Comparison of morphometric characters of twaite shad (Alosa fallax nilotica, Geoffroy Saint-Hilaire, 1808) among three areas in Turkish seas. B. Fr. Peche. Piscic. 362/363, 1027—1035.

Turan, C., Erguden, D., Turan, F., Gurlek, M., 2004. Genetic and morphologic structure of *Liza abu* (Heckel, 1843) populations from the rivers Orontes, Euphrates and Tigris. Turk. J. Vet. Anim. Sci. 28 (4), 729—734.

Turan, C., Yalcin, Ş., Turan, F., Okur, E., Akyurt, İ., 2005. Morphometric comparisons of African catfish, *Clarias gariepinus*, populations in Turkey. Folla. Zool. 54 (1—2), 165—172.

Turan, C., Oral, M., Özturk, B., Duzgunes, E., 2006. Morphometric and meristic variation between stocks of Bluefish (*Pomatomus saltatarix*) in the Black, Marmara, Aegean and Northeastern Mediterranean Seas. Fish. Res. 79 (1), 139—147.

Wainwright, P.C., Bellwood, D.R., Westneat, M.W., Grubich, J.R., Hoey, A.S., 2004. A functional morphospace for the skull of labrid fishes: patterns of diversity in a complex biomechanical system. Biol. J. Linn. Soc. 82, 1—25.

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 (3), 197—218.

Zakhama, R., Sghaier, Y.R., Charfi, F., 2005. Biodiversité des amphipodes Gammaridae associés à l'herbier de *Posidonia oceanica* des côtes orientales de la Tunisie. INOC — Mar. Coast. Protected. Areas 274—277.

Please cite this article in press as: Kaouèche, M., et al., Morphometric variations in white seabream *Diplodus sargus* (Linneus, 1758) populations along the Tunisian coast. Oceanologia (2016), http://dx.doi.org/10.1016/j.oceano.2016.10.003