Journal of the Marine Biological Association of the United Kingdom, 2011, 91(6), 1261–1271.
doi:10.1017/S0025315410002201

Morphological variations of striped seabream, *Lithognathus mormyrus*, populations along the Tunisian coast

IBTISSEM HAMMAMI, LILIA BAHRI-SFAR AND OUM KALTHOUM BEN HASSINE

Research Unit of Biology, Ecology and Parasitology of Aquatic Organisms, Department of Biology, Faculty of Science of Tunis, University Campus, El Manar, 2092 Tunis, Tunisia

Morphological variations of Tunisian Lithognathus mormyrus *populations were investigated using 41 morphometric measurements (27 truss elements and 14 traditional measurements) and eight meristic characters collected from ten marine and lagoon samples. Statistical analyses (e.g. discriminant function analysis (DFA)) performed separately to truss and traditional data revealed a significant degree of morphological dissimilarity of lagoon samples (Bizerta, Ghar El Melh and El Biban lagoons). For these three lagoon environments the overall assignment of individuals into their original sample (percentage classification success) by DFA was 94% for truss elements and 98% for traditional measurements. This morphological discrimination among lagoon samples, revealed with traditional measurements, seems to be associated only with the anterior part of the body (especially with the pre-orbit and snout length). However, for truss analyses, it was explained by both anterior and posterior parts (peduncle region). Statistical analyses for only marine samples showed partial overlapping with significant morphometric variation of the Chebba and Gabès samples mainly related to the anterior part of the body, for the first sample, but also to the posterior region, for the second one. These morphometric variations are often due to environmental conditions and mainly to the exploitation of different ecological niches that are particularly limited by the availability, type and size of prey. Thus, truss and traditional approaches are complementary and provide more accurate explanations of such a morphological discrimination. Meristic character analyses showed homogeneity of striped seabream samples, except for the Ghar El Melh lagoon sample which quietly differed from the others. This distinction was mainly explained by the number of soft anal rays.*

Keywords: striped seabream, *Lithognathus mormyrus*, morphological variations, truss approach, meristic characters

Submitted 30 October 2009; accepted 26 November 2010; first published online 14 March 2011

INTRODUCTION

The Mediterranean Sea has a complex history marked by several events, like glaciation episodes (Krijgsman *et al.*, 1999; Patarnello *et al.*, 2007). During this period, the cyclical variations in sea level and surface temperature were involved and significantly influenced the physical connection between water masses and population connectivity patterns (Patarnello *et al.*, 2007). A sufficient degree of isolation may result in notable genetic and phenotypic divergence among marine populations within a species (Turan, 2004; Lin *et al.*, 2008).

Sparidae is one of the most diversified teleost families. It includes, considering all their geographical range, nearly 110 species of which 24 (belonging to 11 genera) are found in the Atlanto-Mediterranean region (Bauchot & Hureau, 1986). In the Mediterranean Sea, Sparidae are of great interest for fisheries and aquaculture. Nowadays, diversification is one of the greatest challenges for further aquaculture development (Hernández-Cruz *et al.*, 1999). Some Sparidae species, like gilthead seabream, *Sparus aurata*, and sharpsnout seabream, *Diplodus puntazzo*, are already produced commercially (Saka *et al.*, 2004; Kamaci *et al.*, 2005; Dimitriou *et al.*, 2007). Other species such as striped seabream, *Lithognathus mormyrus*, are good candidates for diversification programmes (Kentouri & Divanach, 1983; Saka *et al.*, 2004).

Lithognathus mormyrus (Linnaeus, 1758) is a common species along the Mediterranean coasts (Bauchot & Hureau, 1986). It has a large geographical range covering the Atlantic Ocean from the Bay of Biscay to the Cape of Good Hope, the Western Indian Ocean and the Red and Black Seas (Bauchot & Hureau, 1986; Smith & Smith, 1986). The striped seabream is essentially a marine fish, but it is frequently encountered in lagoons and estuaries which are considered as nursery areas for juvenile fish (Monteiro *et al.*, 2010). This wide and diversified geographical distribution indicates a good adaptability to different environmental conditions, hence its importance in farming. Studies of wild fish populations are of interest in terms of assessment and management of fish stocks (Kevin, 1997; Turan, 2004).

Many studies were carried out on biology, embryonic development, genetic and morphological characterization of *L. mormyrus* on northern Mediterranean shores (Palma & Andrade, 2002; Arculeo *et al.*, 2003; Bargelloni *et al.*, 2003; Türkmen & Akyurt, 2003; Kallianiotis *et al.*, 2005). The

Corresponding author:
O.K. Ben Hassine
Email: kalthoum.benhassine@gmail.com

morphological characters, such as body shape and meristic counts, were frequently adopted to distinguish populations and showed good results (Langerhans *et al.*, 2003; Silva, 2003; Ergüden & Turan, 2005). The traditional morphometric methods have been enhanced by image processing techniques generating a better data collection with more effective descriptions of shape and using new analytical tools. These properly calibrated coordinates of morphometric locations or landmarks are generally more efficient and precise than manual distance measurements (Cadrin & Friedland, 1999). Truss networks distances between landmark coordinates were found to provide more comprehensive coverage of form with greater discriminating power (Cadrin & Friedland, 1999). This approach was previously used for *L. mormyrus* and revealed a significant morphological variability between northern Mediterranean populations (Palma & Andrade, 2002).

The case of the Tunisian coast is of great interest because it represents a boundary area between eastern and western Mediterranean basins where two water bodies with different hydrological, physical and chemical conditions are encountered (Ovchinnikov, 1966; Béranger *et al.*, 2004). Within this particular area, morphological studies of fish species like *Dicentrarchus labrax* and *Atherina boyeri* revealed significant differences with clinal variations (Trabelsi *et al.*, 2000, 2002; Bahri-Sfar & Ben Hassine, 2009).

The aim of this study was to investigate the morphological variability and shape differences of marine and lagoon Tunisian coast populations of *L. mormyrus* using the truss network system (Strauss & Bookstein, 1982), traditional measurements and meristic character analyses.

MATERIALS AND METHODS

Sampling

A total of 343 specimens were collected from 10 different locations along the Tunisian coastline. Three samples were collected from the north-eastern sector (Bizerta lagoon, Ghar El Melh lagoon and Tunis Gulf) and seven from the eastern and south-eastern sectors (Mahdia, Chebba, Sfax, Gabès, Zarzis, Djerba Island and El Biban lagoon) (Table 1; Figure 1). Sample sizes ranged between 29 and 42 individuals and all fish were captured using trammel nets. Despite the fact that a sample of 25 individuals is considered to be appropriate for the truss approach (Reist, 1985), we opted to analyse all specimens sampled in order to have more concise results.

Truss protocol

The truss protocol was used to describe the shape of the fish by defining a network of distances between anatomical landmarks (Strauss & Bookstein, 1982; Bookstein *et al.*, 1985). The landmark approach is based on placing several homologue points called 'landmarks' on the most important locations of the body shape image. The left side of each fish was photographed, with a high quality digital camera mounted on a tripod, with the fins in the extended position. All landmark coordinates were made on digital images using image software (Visilog, version 6.480). The x and y coordinates of landmarks were chosen and recorded in agreement with the current literature (Sarà *et al.*, 1999; Loy *et al.*, 2000; Palma & Andrade, 2002; Turan, 2004). Twenty-seven truss measurements were taken between 12 landmarks (Figure 2). Fourteen additional measurements (such as eye diameter (14–15), head length (1–16), pre-orbit (1–14), snout length (1–13) and others were obtained using six traditional morphometric points (from 13 to 18) and were added to morphometric data (Figure 2). Calibration was achieved for each specimen by measuring a known distance on a millimetre scale in each photograph. All morphometric measurements were performed and analysed using the R 2.11.1 software. Precision was tested by digitizing one specimen from each sample twenty times and calculating the error variance for each variable.

Meristic counts

Eight meristic characters were selected for analyses: numbers of hard and soft rays in the dorsal fin (HD and SD), soft anal fin rays (AR), left pectoral fin rays (LP), right pectoral fin rays (RP), number of lateral line scales (SL), number of gillrakers on the first left and right branchial arch (GR) and vertebrate number (VN). These meristic characters were counted under a binocular microscope. The number of vertebrae was counted after boiling the fish and removing the muscles.

Statistical analyses

The morphometric and meristic characters were used separately in multivariate analyses. Truss and traditional data were logarithm transformed in order to increase linearity

Table 1. Sample locations of *Lithognathus mormyrus*, environment, code, geographical coordinates, number of individuals and mean standard length (MSL; average ± SD).

Sample	Environment	Code	Geographical coordinates	Sample size	MSL (cm)
Bizerta	Lagoon	LBIZ	37°13′N 9°51′E	30	17.3 ± 2.1
Ghar El Melh	Lagoon	LGM	37°10′N 10°11′E	36	15.8 ± 1.5
Tunis Gulf	Sea	TGS	36°48′N 10°18′E	37	14.2 ± 1.3
Mahdia	Sea	MAS	35°30′N 11°04′E	30	14.0 ± 1.1
Chebba	Sea	CHS	35°13′N 11°10′E	42	14.3 ± 1.1
Sfax	Sea	SFS	34°43′N 10°46′E	29	12.2 ± 0.8
Gabès	Sea	GAS	33°53′N 10°07′E	31	14.6 ± 0.7
Zarzis	Sea	ZAS	33°29′N 11°07′E	34	13.6 ± 2.1
Djerba	Insular	IJE	33°47′N 11°03′E	33	12.7 ± 0.9
El Biban	Lagoon	LBIB	33°16′N 11°17′E	41	15.5 ± 1.6

https://doi.org/10.1017/S0025315410002201 Published online by Cambridge University Press

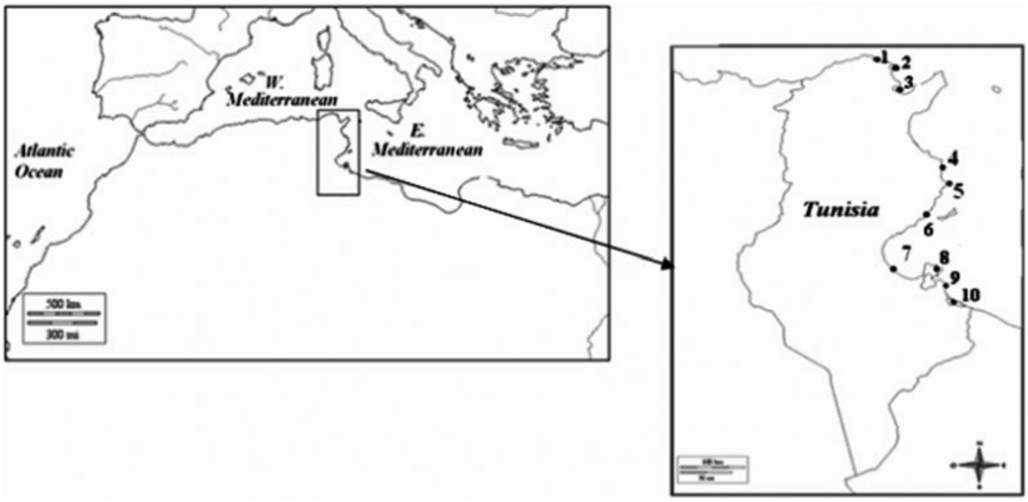

Fig. 1. Sampling localities of *Lithognathus mormyrus*: (1) Bizerta lagoon; (2) Ghar El Melh lagoon; (3) Tunis Gulf; (4) Mahdia; (5) Chebba; (6) Sfax; (7) Gabès; (8) Djerba Island; (9) Zarzis; (10) El Biban lagoon.

and multivariate normality (Pimentel, 1979). For morphometric analyses, it was important to eliminate any size effect especially when comparing fish of different sizes since the present study focused on shape variation and not that of size (Turan, 1999). Besides, an allometric approach (Reist, 1985) was adopted to remove size-dependent variation:

$$M_{\mathrm{trans}} = \log M - \beta(\log SL - \log SL_{\mathrm{mean}})$$

where M_{trans} is the transformed measurement, M the original measurement, β the within-group slope regressions of log M against log SL, SL the standard length of the fish and SL_{mean} the overall mean of the standard length. The test of size effect for meristic counts was done using correlations between these characters and standard length of samples (Costa *et al.*, 2003; Turan, 2004).

Univariate analysis of variance (ANOVA) was performed to test whether the averages of morphometric and meristic variables differed among the studied populations. In addition, the *t*-test was established to infer whether the averages of one variable are significantly different between two considered samples.

To illustrate the differences or similarities between the studied samples and the contribution of each character to group separation, discriminant function analysis (DFA) was assessed. DFA finds linear combinations of variables (discriminant functions) in order to provide the best separation of classes. Wilks' values were estimated to test the significance of such discrimination for a combination of variables. Discriminant functions were used to classify individuals into samples. The classification success rate (PCS) was evaluated based on the percentage of individuals correctly assigned

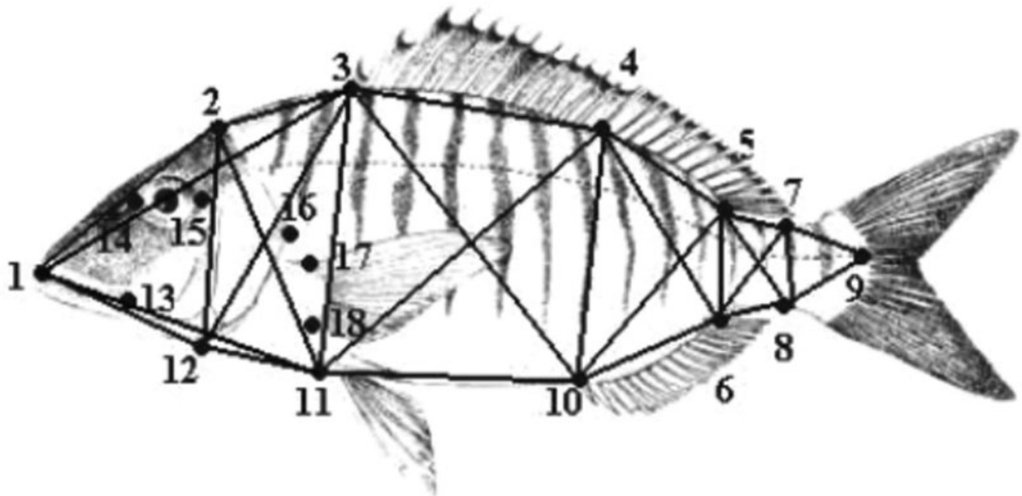

Fig. 2. Location of landmarks (1 to 12) and traditional morphometric points (13 to 17) used in this study. Lines indicate the morphometric measures used for constructing a truss network on *Lithognathus mormyrus*. Landmarks were illustrated as black dots: anterior tip of snout (1); end of the head (2); front insertion point of dorsal fin (3); insertion of first soft dorsal fin ray (4); end of dorsal fin (5); rear extremity of the anal fin (6); rear extremity of the lateral line (9); forward insertion of the anal fin (10); points of maximum curvature of the peduncle (7–8); forward insertion point of the pelvic fin (11); posterior insertion of the sub-operculum (12); rear extremity of the upper jaw (13); eye diameter (14–15); posterior extremity of the operculum (16); forward insertion point of the pectoral fin (17); rear extremity point of the pectoral fin (18).

https://doi.org/10.1017/S0025315410002201 Published online by Cambridge University Press

Table 2. Loadings from discriminant function of the truss and traditional measurements for *Lithognathus mormyrus*. Univariate statistics (ANOVA). Significance levels; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

Variable	All samples			Lagoon samples			Marine samples		
	DF1	DF2	F	DF1	DF2	F	DF1	DF2	F
Truss elements									
V1: 1–2	−0.537	0.174	12.180***	0.665	0.415	41.669***	−0.238	0.295	6.907***
V2: 2–3	0.050	−0.238	4.842***	−0.218	−0.034	2.059	−0.166	0.313	5.898***
V3: 3–4	−0.067	0.092	3.719***	0.004	0.034	0.036	−0.048	0.065	5.461***
V4: 4–5	0.157	−0.184	7.530***	−0.070	−0.263	2.381	0.083	0.552	12.395***
V5: 5–7	0.645	0.085	14.385***	−0.590	−0.145	20.718***	0.579	0.065	11.262***
V6: 7–9	−0.108	0.022	4.723***	−0.162	0.022	1.110	−0.217	0.175	6.256***
V7: 8–9	−0.002	−0.052	2.668	−0.208	−0.137	2.454	−0.135	0.203	5.422 ***
V8: 6–8	0.597	0.029	12.499***	−0.523	−0.253	17.484***	0.535	0.101	10.368***
V9: 6–10	0.050	−0.233	4.063***	−0.136	−0.234	2.518	−0.096	0.325	6.242***
V10: 10–11	0.435	0.166	8.869***	−0.520	0.088	14.392***	0.323	0.393	13.715***
V11: 11–12	−0.065	0.477	11.226***	0.466	0.262	13.778***	0.294	0.261	6.643***
V12: 1–12	−0.493	−0.470	18.571***	0.400	−0.011	7.487***	−0.672	0.314	20.386***
V13: 1–3	−0.531	0.019	10.979***	0.580	0.451	31.918***	−0.365	0.279	6.526***
V14: 1–11	−0.734	−0.042	19.382***	0.775	0.198	50.474***	−0.486	0.287	8.596***
V15: 2–12	−0.409	−0.306	9.358***	0.428	−0.088	9.065***	−0.431	0.361	11.676***
V16: 2–11	−0.335	−0.099	7.508***	0.445	−0.067	9.743***	−0.246	0.236	6.878***
V17: 3–12	−0.134	0.078	3.716***	0.145	0.171	1.798	−0.063	0.378	6.489***
V18: 3–11	−0.064	0.005	3.332***	0.041	0.047	0.135	−0.053	0.269	5.222***
V19: 3–10	0.342	−0.083	4.469***	−0.397	−0.067	7.532***	0.197	0.371	4.716***
V20: 4–11	0.283	0.167	6.335***	−0.338	−0.026	5.145**	0.286	0.215	9.162***
V21: 4–10	0.533	−0.129	17.276***	−0.499	−0.282	16.529***	0.461	0.430	20.868***
V22: 4–6	0.458	−0.139	12.443***	−0.419	−0.240	10.761***	0.346	0.438	14.208***
V23: 5–10	0.342	−0.200	12.302***	−0.406	−0.423	15.723***	0.203	0.297	11.352***
V24: 5–6	0.604	0.064	14.639***	−0.627	−0.154	24.713***	0.519	0.198	13.223***
V25: 5–8	0.595	0.100	11.356***	−0.521	−0.134	14.988***	0.581	0.053	9.925***
V26: 7–6	0.465	−0.035	7.827***	−0.421	−0.346	13.650***	0.399	0.178	7.519***
V27: 7–8	0.110	−0.179	6.399***	0.131	−0.581	13.556***	0.202	0.099	4.103***
Traditional measurements									
V28: 1–13	0.132	0.707	13.981***	0.028	0.867	41.450***	0.101	−0.231	4.786***
V29: 1–16	−0.006	0.880	20.794***	−0.187	0.862	50.474***	0.243	−0.195	8.971***
V30: 1–10	−0.022	0.549	7.069***	−0.135	0.576	14.072***	0.415	−0.552	8.983***
V31: 1–17	−0.035	0.793	17.120***	−0.224	0.861	48.506***	0.104	−0.033	4.244***
V32: 1–18	−0.046	0.782	15.820***	−0.228	0.828	42.972***	0.162	−0.046	3.554**
V33: 1–14	−0.831	0.455	101.210***	−0.959	0.198	351.410***	0.079	−0.409	7.142***
V34: 2–16	0.172	0.041	10.868***	0.211	0.435	9.397***	−0.665	−0.157	10.365***
V35: 12–16	−0.078	0.471	7.628***	−0.309	0.417	12.341***	0.336	−0.553	12.651***
V36: 2–10	0.042	−0.319	5.296***	0.191	−0.338	5.867**	0.071	−0.355	6.222***
V37: 2–17	0.048	0.212	6.900***	−0.016	0.372	4.663*	−0.351	0.048	7.638***
V38: 3–16	0.179	−0.414	11.199***	0.347	−0.203	8.192***	−0.621	−0.263	11.633***
V39: 5–11	0.077	−0.452	6.700***	0.234	−0.511	13.397***	−0.174	−0.552	7.238***
V40: 14–15	0.095	0.751	13.293***	−0.080	0.722	23.719***	0.626	−0.175	9.112***
V41: 17–18	−0.008	0.123	2.816	−0.135	0.302	3.973*	−0.005	−0.286	2.949**

into the original sample. These statistical tests were performed using R 2.11.1 software.

RESULTS

Truss analysis

The ANOVA of 27 truss elements revealed significant differences ($P < 0.001$) among localities for all variables (Table 2). Among the nine discriminant functions performed by DFA, the two first axes, explaining 41% of inter-group variability were chosen to run the analysis. Three variables substantially contributed to define the first discriminant function (V14:1–11; V5:5–7 and V24:5–6). The second function was mainly defined by the following truss elements: V11:11–12 and V12:1–12 (Table 2). These variables characterize the anterior and posterior parts of the body. The plot obtained with DF1 and DF2 showed that samples are partially overlapped. However, a distinction of some samples was highlighted, mainly among lagoon ones (Figure 3). The significance of this variation was proved by Wilks' criterion (Wilks' $\lambda = 0.035$, $F = 5.234$, $P < 0.001$). The overall assignment of individuals into their original sample by DFA was estimated to be 68% (Table 3).

The projection of lagoon samples on DF1–DF2 plane explained 58% of global variation for the first function and 42%, for the second one. The plot showed discrimination between these three lagoon environments (Figure 4). Significant differences between lagoon samples on truss

https://doi.org/10.1017/S0025315410002201 Published online by Cambridge University Press

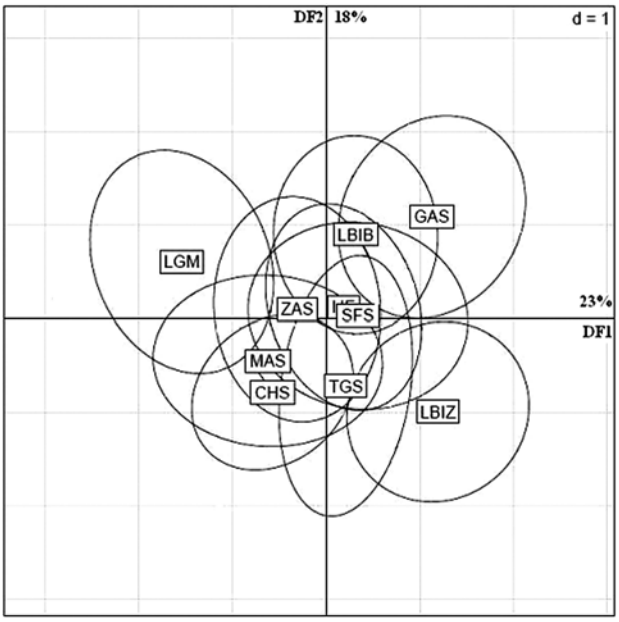

Fig. 3. Discriminant function analysis scores of truss elements on the two first discriminant functions for all samples. LBIZ, Bizerta lagoon; LGM, Ghar El Melh lagoon; TGS, Tunis Gulf; MAS, Mahdia; CHS, Chebba; SFS, Sfax; GAS, Gabès; IJE, Djerba Island; ZAS, Zarzis; LBIB, El Biban lagoon.

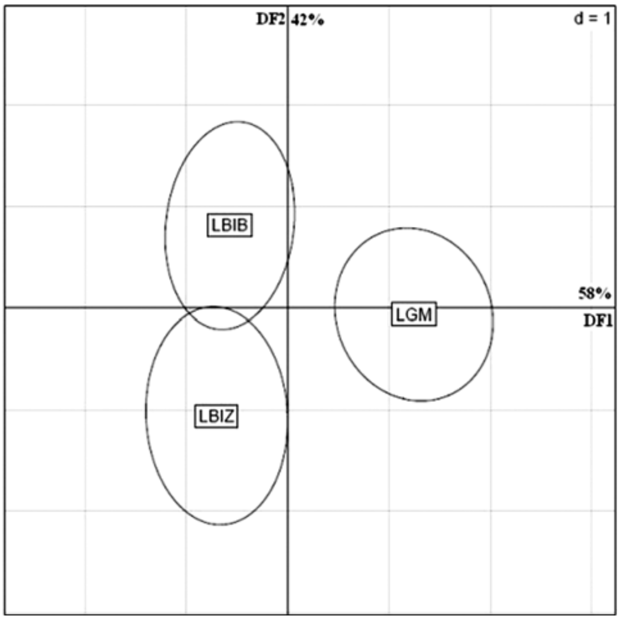

Fig. 4. Discriminant function analysis scores of truss elements on the two first discriminant functions for the three lagoon samples. LBIZ, Bizerta lagoon; LGM, Ghar El Melh lagoon; LBIB, El Biban lagoon.

variables were highlighted by Wilks' criterion (Wilks' $\lambda = 0.095$, $F = 6.564$, $P < 0.001$). The overall assignment of individuals into their original sample (PCS) by DFA was 94%, confirming such discrimination (Table 4). The distinction of the Ghar El Melh sample from the two other lagoons was mostly defined by DF1. This distinction seemed to be related to the head region, especially to V14: 1–11. In fact, Ghar El Melh has the highest average compared to El Biban and Bizerta lagoons ($t_{LGM\text{-}LBIB} = 3.45$, $P < 0.001$, ddl = 76; $t_{LGM\text{-}LBIZ} = 3.01$, $P < 0.01$, ddl = 65). The distinction of Bizerta from El Biban lagoon samples was explained by DF2 which was mainly defined by the posterior part of the body, especially by V27: 7–8. The application of the *t*-test showed that Bizerta specimens have the highest average of V27 ($t_{LBIZ\text{-}LBIB} = 5.45$, $P < 0.001$, ddl = 70).

Regarding the marine samples, their projection on the plan formed by DF1 and DF2, only explained 45% of the global variation and showed the distinction of the Gabès sample

Table 3. Correct classification of individuals into their original group for truss elements and traditional measurements. LBIZ, Bizerta lagoon; LGM, Ghar El Melh lagoon; TGS, Tunis Gulf; MAS, Mahdia; CHS, Chebba; SFS, Sfax; GAS, Gabès; IJE, Djerba Island; ZAS, Zarzis; LBIB, El Biban lagoon.

Sample	LBIZ	LGM	TGS	MAS	CHS	SFS	GAS	IJE	ZAS	LBIB
Truss elements										
LBIZ	74	0	17	3	0	3	0	3	0	0
LGM	0	76	5	3	11	0	0	0	5	0
TGS	3	0	67	0	3	10	3	11	0	3
MAS	0	11	10	48	7	3	0	7	14	0
CHS	0	0	0	0	85	8	0	5	2	0
SFS	0	3	3	0	13	57	7	10	0	7
GAS	3	0	0	3	3	7	67	7	3	7
IJE	5	0	3	0	0	6	9	62	3	12
ZAS	3	0	0	6	11	3	0	6	65	6
LBIB	2	0	5	0	2	5	5	5	0	76
Traditional measurements										
LBIZ	70	0	7	0	7	3	7	6	0	0
LGM	0	58	3	3	11	3	3	0	19	0
TGS	0	8	49	0	3	11	11	10	8	0
MAS	7	0	7	45	8	17	3	3	10	0
CHS	0	10	5	3	62	10	3	5	2	0
SFS	6	0	10	7	27	37	3	10	0	0
GAS	17	7	7	3	3	3	43	3	14	0
IJE	0	8	9	3	3	0	3	68	6	0
ZAS	0	14	14	11	3	3	6	17	32	0
LBIB	0	0	0	0	0	0	0	0	0	100

Table 4. Correct classification of individuals into their original group for lagoon samples. LBIZ, Bizerta lagoon; LGM, Ghar El Melh lagoon; LBIB, El Biban lagoon.

Sample	LBIZ	LGM	LBIB
Truss elements			
LBIZ	93	0	7
LGM	3	97	0
LBIB	7	0	93
Traditional measurements			
LBIZ	97	3	0
LGM	3	97	0
LBIB	0	0	100

(Figure 5). Wilks' criterion revealed significant inter-sample variation (Wilks' $\lambda = 0.041$, $F = 5.304$, $P < 0.001$). This variation was substantially explained by the posterior part of the body (V5: 5–7; V8: 6–8 and V25: 5–8).

Traditional morphometry

The ANOVA of 14 traditional measurements revealed highly significant average differences ($P < 0.001$) among locations for 13 variables (Table 2).

The two first discriminant functions explained 58% of the inter-group variability. Distance between snout and orbit (V33: 1–14) contributed the most to define the first function (Table 2). The second function was mainly defined by the following measurements: the pre-pectoral distance (V31:1–17 and V32:1–18), the operculum length (V29:1–16) and the eyes diameter (V40:14–15). Plotting DF1 and DF2 highlighted the discrimination of the El Biban lagoon sample (LBIB) from the others. The scatter-plot corresponding to this sample was projected on the positive side of DF1

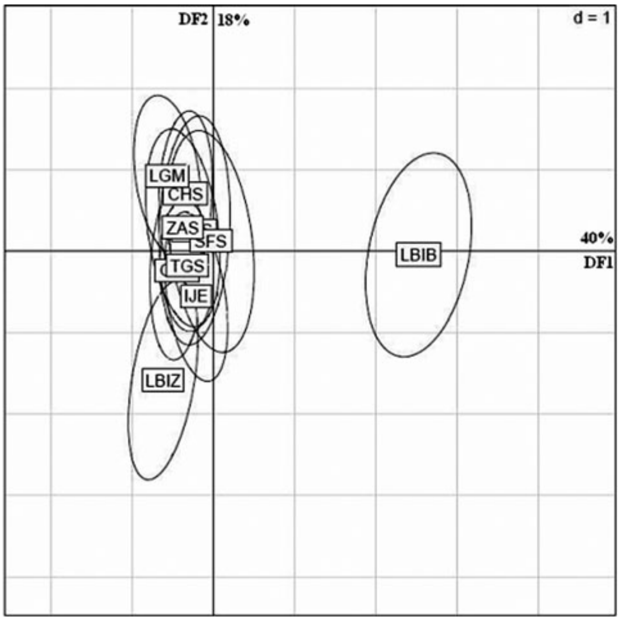

Fig. 6. Discriminant function analysis scores of traditional measurements on the two first discriminant functions for all samples. LBIZ, Bizerta lagoon; LGM, Ghar El Melh lagoon; TGS, Tunis Gulf; MAS, Mahdia; CHS, Chebba; SFS, Sfax; GAS, Gabès; IJE Djerba Island; ZAS, Zarzis; LBIB, El Biban lagoon.

(Figure 6). The remaining samples scatter-plots partially overlapped and spread along DF2. Wilks' criterion revealed significant variation (Wilks' $\lambda = 0.017$, $F = 13.666$, $P < 0.001$). The overall assignment of individuals into their original sample by DFA was estimated to be 56% for traditional morphometric variables (Table 3) and the highest proportion of properly classified individuals into their original group was observed for El Biban sample (100%). This discrimination seemed to

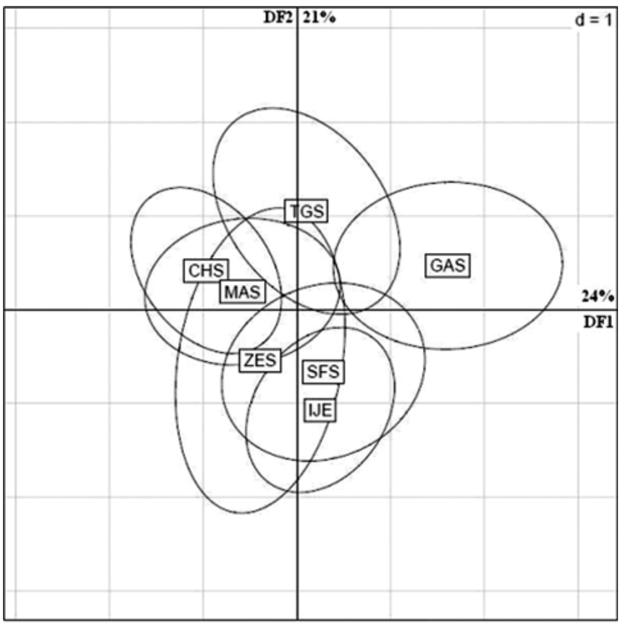

Fig. 5. Discriminant function analysis scores of truss elements on the two first discriminant functions for marine samples. TGS, Tunis Gulf; MAS, Mahdia; CHS, Chebba; SFS, Sfax; GAS, Gabès; IJE, Djerba Island; ZAS, Zarzis.

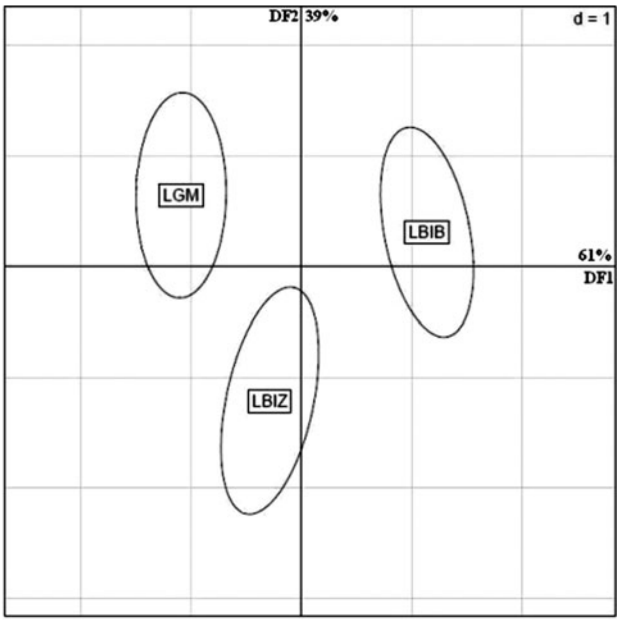

Fig. 7. Discriminant function analysis scores of traditional measurements on the two first discriminant functions for the three lagoon samples. LBIZ, Bizerta lagoon; LGM, Ghar El Melh lagoon; LBIB, El Biban lagoon.

https://doi.org/10.1017/S0025315410002201 Published online by Cambridge University Press

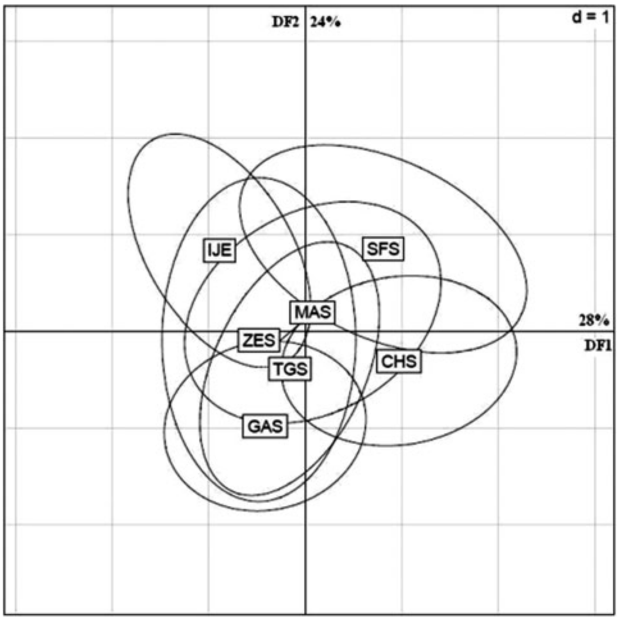

Fig. 8. Discriminant function analysis scores of traditional measurements on the two first discriminant functions for marine samples. TGS, Tunis Gulf; MAS, Mahdia; CHS, Chebba; SFS, Sfax; GAS, Gabès; IJE, Djerba Island; ZAS, Zarzis.

be especially related to the distance between snout and orbit (V33:1–14).

Similarly to the case of truss measurements, plotting lagoon samples on the plan formed by DF1 and DF2, which explained respectively 61% and 39% of the global variation, showed a high discrimination between these three lagoon environments (Figure 7). In addition, a significant difference was proved by Wilks' criterion (Wilks' $\lambda = 0.033$, $F = 29.667$, $P < 0.001$). The overall assignment of individuals into their original sample (PCS) by DFA was about 98% (Table 4) and the highest percentage of re-classification was obtained for the El Biban lagoon sample (100%). Ghar El Melh and El Biban lagoons were discriminated by DF1 and such distinction was again related to pre-orbit length (V33: 1–14). Indeed, the Ghar El Melh lagoon sample has the highest average of pre-orbit length compared to the El Biban lagoon sample ($t = 11.99$, $P < 0.001$, ddl = 76). The distinction of the Bizerta lagoon sample, by DF2, was also related to the anterior part of the body, since all characters discriminating this sample were head related (V29:1–16, V28: 1–13, V31: 1–17, V32: 1–18, and V40: 14–15). Among these variables, the snout length (V28: 1–13) seemed to be the character that mostly explained this variability. In fact, Bizerta specimens seemed to have the lowest average of snout length compared to the Ghar El Melh sample ($t = 2.09$, $P < 0.05$, ddl = 65).

The projection of the marine samples on the plan formed by DF1 and DF2 explained 52% of the global variation (Figure 8) and showed the distinction of the Chebba and Gabès samples. Wilks' criterion revealed significant inter-sample variation (Wilks' $\lambda = 0.161$, $F = 5.568$, $P < 0.001$). Morphometric variation of the Chebba sample (CHS), by DF1, seemed to be related to the anterior part of the body, especially to eye diameter (V40: 14–15). However, the variation of the Gabès sample (GAS), which was projected on the negative side of DF2, cannot be explained by a specific part of the body.

Meristics

The meristic counts of *L. mormyrus* samples are given in Table 5. The observed counts did not show any correlation with the standard length of samples (Table 6). Univariate comparison of variances between samples was highly significant ($P < 0.001$) for three meristic characters (AR, GR and SL) (Table 6). The vertebrate number (VN) was not considered in the analysis because it was constant for all samples.

The first discriminant function explained 48% of total variation and was defined by two characters: the number of gillrakers (GR) and number of lateral line scales (SL). The second DF absorbed 26% of global variation and was defined by the number of soft anal rays (AR) (Table 6). The spatial projection of the whole sample on the factorial plane defined by the first two functions (DF1 and DF2) showed a large overlapping between samples (Figure 9). The overall assignment of individuals into their original sample by DFA is 23.2% (Table 7). It showed a low proportion of correctly classified individuals to their original group (0–37%). Plotting barycentres showed overlapping scatter-plots with a slight extension for the Ghar El Melh lagoon sample.

DISCUSSION

Morphometric variability among Tunisian populations of *L. mormyrus* was highlighted using truss and traditional approaches. Using these two approaches, the analyses revealed the existence of significant morphological differences between

Table 5. Range of meristic counts of *Lithognathus mormyrus* samples. LBIZ, Bizerta lagoon; LGM, Ghar El Melh lagoon; TGS, Tunis Gulf; MAS, Mahdia; CHS, Chebba; SFS, Sfax; GAS, Gabès; IJE, Djerba Island; ZAS, Zarzis; LBIB, El Biban lagoon.

Sample	HD	SD	AR	LPR	RPR	SL	GR	VN
LBIZ	11	12–14	11–12	15–16	15–16	61–72	50–54	24
LGM	11	12–13	10–11	14–16	14–16	58–68	50–56	24
TGS	11	12–13	11–12	14–16	14–16	59–68	48–56	24
MAS	11	12–13	11–12	14–16	15–16	59–70	49–54	24
CHS	11–12	12–14	10–12	15–16	14–16	58–72	50–54	24
SFS	11	12–13	10–11	14–16	13–16	58–69	50–56	24
GAS	11–12	12–13	10–11	14–16	15–16	60–67	48–53	24
IJE	11	12–13	10–11	15–16	14–16	58–65	48–54	24
ZAS	11–12	12–14	11–12	15–16	15–16	58–67	48–54	24
LBIB	10–11	12–14	11	15–16	15–16	59–66	48–54	24

https://doi.org/10.1017/S0025315410002201 Published online by Cambridge University Press

Table 6. Correlation coefficient with standard length, loadings from discriminant function and univariate statistics (ANOVA) of the meristic characters for *Lithognathus mormyrus*. Significance levels; *, $P<0.05$; **, $P<0.01$; ***, $P<0.001$. HD and SD, number of hard and soft rays in the dorsal fin; AR, soft anal fin rays; LP, left pectoral fin rays; RP, right pectoral fin rays; SL, number of lateral line scales; GR, number of gillrakers.

Meristic characters	r	DF1	DF2	F
HD	−0.038	0.014	−0.098	1.133
SD	0.101	−0.053	0.013	0.285
AR	−0.005	−0.111	0.873	4.865***
LP	0.017	−0.183	−0.055	1.358
RP	0.076	−0.275	−0.122	2.363
SL	0.205	0.843	−0.152	8.116***
GR	0.042	0.466	0.369	3.685***

studied samples and in particular between lagoons. Using traditional data, variation between lagoon environments seemed to be only associated to the anterior region especially to the pre-orbit distance. Indeed, the Ghar El Melh and El Biban lagoons were discriminated through the pre-orbit length, which was higher in Ghar El Melh. In contrast, the Bizerta lagoon specimens were characterized by small head and snout length. Truss analyses showed discrimination between the previous samples which was related not only to the anterior part of the body but also to the posterior one. These data revealed that the El Biban lagoon specimens had not only the lowest average value for distance between snout and pelvic fin but had also the lowest average value for the height of the peduncle.

Morphometric variations obtained for marine samples, with traditional data, do not seem to be related to a specific part of the body, however, using truss data, the distinction of the Gabès sample was mainly assigned to a particular region of the body: the posterior part. Although both approaches converged and gave complementary results, it seems that the truss approach provided more accurate results.

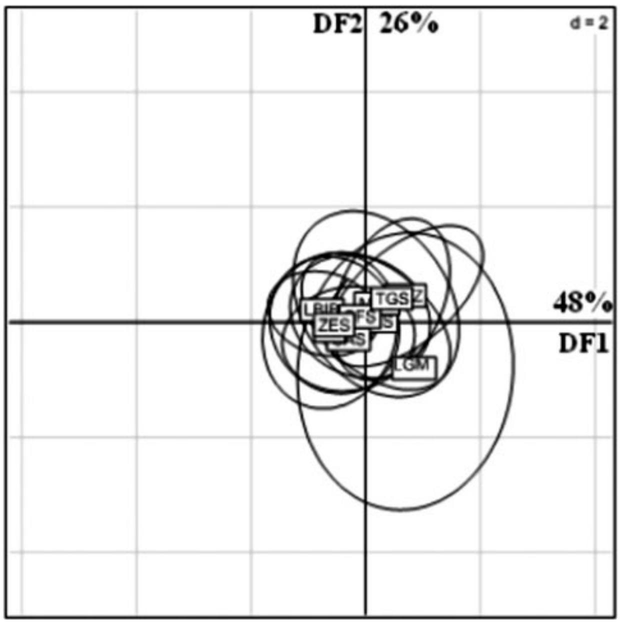

Fig. 9. Discriminant function analysis scores of meristic analysis on the two first discriminant functions for all samples. LBIZ, Bizerta lagoon; LGM, Ghar El Melh lagoon; TGS, Tunis Gulf; MAS, Mahdia; CHS, Chebba; SFS, Sfax; GAS, Gabès; IJE, Djerba Island; ZAS, Zarzis; LBIB, El Biban lagoon.

Among all characters, the head-related traits were the most contributive variables for sample discrimination, especially between lagoon samples. Variations in the head-related characteristics suggest the influence of habitat differences. The length of the snout usually depends on the availability, type and size of prey (Palma & Andrade, 2002; Turan, 2004). Feeding is a well known factor that influences head morphology. Thus, if different populations of a same species show discordant patterns of head morphology, this is often due to the exploitation of different ecological niches with varying diets (Hyndes *et al.*, 1997; Delariva & Agostinho, 2001).

Similar results regarding the head morphology were obtained by Sarà *et al.* (1999) on cultivated *D. puntazzo* reared under different conditions. Head characters have also caused differentiation between Turkish *Trachurus mediterraneus* samples (Turan, 2004) and among European samples of *D. sargus* and *D. puntazzo* (Palma & Andrade, 2002). Moreover, using geometric morphometry, Costa & Cataudella (2007) found that juveniles of *L. mormyrus* in Caprolace Lagoon (Central Tyrrhenian Sea, Italy) possess a relatively larger head region, a larger mouth gap, a longer body and a longer and narrower caudal peduncle. The authors affirmed the existence of a relation between feeding, especially preys type, size and head shape. Variations in the posterior region are mostly related to the swimming behaviour of fish which may vary according to species and hydrodynamic constraints (e.g. water currents) (Costa & Cataudella, 2007).

In each environment, individuals seemed to have adaptation characters particular to that kind of environment. Indeed, lagoon organisms, either permanent or temporary residents, show adaptive strategies in response to multiple environmental conditions (Kara & Frehi, 1997). Lagoons are richer nutritional areas than a marine environment, and are often used as nursery areas, allowing fish larvae to develop and grow (Çoban *et al.*, 2008). During these early life stages, morphology is especially dependent upon environmental conditions (Ryman *et al.*, 1984; Cheverud, 1988).

Morphological differences among Tunisian samples may also reflect differences in physico-chemical characteristics such as salinity and substrata (Savouré, 1977; Moussa *et al.*, 2005). In fact, the diversity of morphological, hydrological and climate situations lead to extreme diversity ranges of salinity and geochemical gradients.

Meristic counts variation was revealed to be quite heterogeneous among samples. Only the number of soft anal rays explained the distinction of the Ghar El Melh lagoon sample. Environmental factors, particularly salinity and temperature, could explain the variability in numbers of fin rays (Kirchhoff *et al.*, 1999). The phenotypic variation among the fish population can be explained by environmental or genetic components or their interactions (Cabral *et al.*, 2003; Favaloro & Mazzola, 2006; Bahri-Sfar & Ben Hassine, 2009). Many species showed morphometric and genetic differences within small geographical ranges which is the consequence of various factors, including environmental ones (Lin *et al.*, 2008; Bergek & Björklund, 2009). The genetic structure of the Tunisian samples was studied using allozymic markers and revealed homogeneity between marine samples and

https://doi.org/10.1017/S0025315410002201 Published online by Cambridge University Press

Table 7. Correct classification of individuals into their original group for meristic characters. LBIZ, Bizerta lagoon; LGM, Ghar El Melh lagoon; TGS, Tunis Gulf; MAS, Mahdia; CHS, Chebba; SFS, Sfax; GAS, Gabès; IJE, Djerba Island; ZAS, Zarzis; LBIB, El Biban lagoon.

Sample	LBIZ	LGM	TGS	MAS	CHS	SFS	GAS	IJE	ZAS	LBIB
LBIZ	20	7	20	7	17	20	0	6	0	3
LGM	8	37	17	3	19	3	3	0	5	5
TGS	13	3	32	0	30	8	0	3	11	0
MAS	7	7	14	0	28	3	3	14	17	7
CHS	5	11	5	3	37	18	0	15	3	3
SFS	3	3	17	2	30	20	2	13	2	8
GAS	3	3	10	1	23	3	21	16	13	7
IJE	0	3	0	0	31	15	6	30	3	12
ZAS	3	6	0	3	17	11	14	23	9	14
LBIB	0	0	0	0	19	16	3	29	7	26

heterogeneity only between the El Biban and Bizerta lagoons (Hammami *et al.*, 2007). These results highlighted the importance of the environmental component in the establishment of morphological variation in the Tunisian populations. The phenotypic variability is particularly high in fish, and it is not necessarily associated with high genetic variability (Ihssen *et al.*, 1981). In fact, some studies describing the existence of a high level of morphological variation in populations of genetically homogeneous fish confirm a major role of the environment as a basis for phenotypic variability (Ryman *et al.*, 1984; Kinsey *et al.*, 1994; Tudela, 1999).

This work revealed the existence of morphological differences between Tunisian samples mainly between lagoons for truss and traditional measurements. These two approaches are complementary and provide more accurate explanations of such a morphological discrimination. Phenotypic variability between lagoon samples suggests a strong implication of ecological conditions. Therefore, further studies on the impact of the lagoon's ecological factors and the diet in different environments are needed to better understand the contribution of the environment component to the morphological variability.

ACKNOWLEDGEMENTS

We wish to acknowledge the help of Professor Sovan Lek and Dr Gael Grenouillet, in introducing us to the truss approach, and that of Mr Moktar Diawara during the statistical processing with R software. The authors are also grateful to two anonymous referees who helped to improve the quality of the manuscript, through their suggestions and constructive comments.

REFERENCES

Arculeo M., Lo Brutto S., Sirna-Terranova M., Maggio T., Cannizzaro L. and Parrinello N. (2003) The stock genetic structure of two Sparidae species, *Diplodus vulgaris* and *Lithognathus mormyrus*, in the Mediterranean Sea. *Fisheries Research* 63, 339–347.

Bahri-Sfar L. and Ben Hassine O.K. (2009) Clinal variations of discriminative meristic characters of sea bass, *Dicentrarchus labrax* (Moronidae, Perciformes) populations on Tunisian coasts. *Cybium* 33, 211–218.

Bargelloni L., Alarcon J.A., Alvarez M.C., Penzo E., Magoulas A., Reis C. and Patarnello T. (2003) Discord in the family Sparidae (Teleostei): divergent phylogeographical patterns across the Atlantic–Mediterranean divide. *Journal of Evolutionary Biology* 16, 1149–1158.

Bauchot M.L. and Hureau J.C. (1986) Sparidae. In Whitehead P.J.P., Bauchot M.L., Hureau J.C., Nielsen J. and Tortonese E. (eds) *Fishes of the northeastern Atlantic and the Mediterranean*. Volume 2. Paris: Unesco, pp. 883–907.

Bergek S. and Björklund M. (2009) Genetic and morphological divergence reveal local subdivision of perch (*Perca fluviatilis* L.). *Biological Journal of the Linnean Society* 96, 746–758.

Béranger K., Mortier L., Gasparini G.P., Gervasio L., Astraldi M. and Crépon M. (2004) The dynamics of the Sicily Strait: a comprehensive study from observations and models. *Deep-Sea Research II* 51, 411–440.

Bookstein F.L., Chernoff B., Elder R.L., Humphries J.M., Smith G.R. and Strauss R.E. (1985) Morphometrics in evolutionary biology, the geometry of size and shape change with examples from fish. *Academy of Natural Sciences of Philadelphia Special Publication* 15, 1–277.

Cabral H.N., Marques J.F., Rego A.L., Catarino A.I., Figueiredo J. and Garcia J. (2003) Genetic and morphological variation of *Synaptura lusitanica* Capello, 1868, along the Portuguese coast. *Journal of Sea Research* 50, 167–175.

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

Cheverud J.M. (1988) A comparison of genetic and phenotypic correlations. *Evolution* 42, 958–968.

Çoban D., Saka F. and Firat K. (2008) Morphometric comparison of cultured and lagoon caught gilthead seabream (*Sparus aurata* L. 1758). *Turkish Journal of Zoology* 32, 337–341.

Costa J.L., De Almeida P.R. and Costa M.J. (2003) A morphometric and meristic investigation of Lusitanian toadfish *Halobatrachus didactylus* (Bloch and Schneider, 1801): evidence of population fragmentation on Portuguese coast. *Scientia Marina* 67, 219–231.

Costa C. and Cataudella S. (2007) Relationship between shape and trophic ecology of selected species of sparids of the Caprolace coastal lagoon (Central Tyrrhenian Sea). *Environmental Biology of Fishes* 78, 115–123.

Delariva R.L. and Agostinho A.A. (2001) Relationship between morphology and diets of six neotropical loricariids. *Journal of Fish Biology* 58, 832–847.

Dimitriou E., Katselis G., Moutopoulos D.K., Akovitiotis C. and Koutsikopoulos C. (2007) Possible influence of reared gilthead seabream (*Sparus aurata*, L.) on wild stocks in the area of the

Messolonghi lagoon (Ionian Sea, Greece). *Aquaculture Research* 38, 398–408.

Ergüden D. and Turan C. (2005) Examination of genetic and morphologic structure of seabass (*Dicentrarchus labrax* L., 1758) populations in Turkish coastal waters. *Turkish Journal of Veterinary and Animal Sciences* 29, 727–733.

Favaloro E. and 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 Physiology and Biochemistry* 32, 159–166.

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

Hernández-Cruz C.M., Salhi M., Bessonart M., Izquierdo M.S., González M.M. and Fernández-Palacios H. (1999) Rearing techniques for red porgy *Pagrus pagrus* during larval development. *Aquaculture* 179, 489–497.

Hyndes G.A., Platell M.E. and 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. *Marine Biology* 128, 585–598.

Ihssen P.E., Booke H.E., Casselman J.M., McGlade J.M., Payne N.R. and Utter F.M. (1981) Stock identification: materials and methods. *Canadian Journal of Fisheries and Aquatic Sciences* 38, 1838–55.

Kallianiotis A., Torre M. and Argyri A. (2005) Age, growth, mortality, reproduction and feeding habits of the striped seabream, *Lithognathus mormyrus* (Pisces: Sparidae), in the coastal waters of the Thracian Sea, Greece. *Scientia Marina* 69, 391–404.

Kamaci H.O., Firat K., Saka S. and Bulut M. (2005) Determination of embryonic development stage of sharpsnout seabream (*Diplodus puntazzo*, Cetti, 1977) eggs in rearing conditions. *Journal of Applied Science* 5, 546–552.

Kara M.H. and Frehi H. (1997) Etude biométrique du loup *Dicentrarchus labrax* du Golfe d'Annaba. Différenciation d'une population lagunaire voisine. *Journal de Recherche Océanographique* 22, 45–50.

Kentouri M. and Divanach P. (1983) Contribution à la connaissance du comportement et de la biologie des larves de marbré *Lithognathus mormyrus* (sparides) en élevage. *Annales de Zootechnie* 32, 135–152.

Kevin M.B. (1997) Structural dynamics and ecology of flatfish populations. *Journal of Sea Research* 37, 269–280.

Kinsey S.T., Orsoy T., Bert T.M. and Mahmoudi B. (1994) Population structure of the Spanish sardine *Sardinella aurita*: natural morphological variation in a genetically homogenous population. *Marine Biology* 118, 309–317.

Kirchhoff S., Sévigny J.M. and Couillard C.M. (1999) Genetic and meristic variations in the mummichog, *Fundulus heteroclitus*, living in polluted and reference estuaries. *Marine Environmental Research* 47, 261–283.

Krijgsman W., Hilgen F.J., Raffi I., Sierro F.J. and Wilson D.S. (1999) Chronology, causes and progression of the Messinian salinity crisis. *Nature* 400, 652–655.

Langerhans R.B., Craig A.L., 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.

Lin J., Quinn T.P., Hilborn R. and Hauser L. (2008) Fine-scale differentiation between sockeye salmon ecotypes and the effect of phenotype on straying. *Heredity* 101, 341–350.

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

Monteiro P., Bentes L., Coelho R., Correia C., Erzini K., Lino P., Ribeiro J. and Gonçalves J.M.S. (2010) Age and growth, mortality and reproduction of the striped seabream, *Lithognathus mormyrus* Linnaeus 1758, from the south coast of Portugal (Algarve). *Marine Biology Research* 6, 53–65.

Moussa M., Baccar L. and Ben Khemis R. (2005) La lagune de Ghar El Melh: diagnostic écologique et perspectives d'aménagement hydraulique. *Revue des Sciences de l'Eau* 18, 13–26.

Ovchinnikov I.M. (1966) Circulation in the surface and intermediate layers of the Mediterranean. *Oceanology* 6, 48–59.

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

Patarnello T., Volckaert F.A.M.J. and Castilho R. (2007) Pillars of Hercules: is the Atlantic–Mediterranean transition a phylogeographical break? *Molecular Ecology* 16, 4426–4444.

Pimentel R.A. (1979) *Morphometrics: the multivariate analysis of biological data*. Dubuque, IA: Kendall/Hunt Publishing Company.

Reist J.D. (1985) An empirical evaluation of several univariate methods that adjust for size variation in morphometric data. *Canadian Journal of Zoology* 63, 1429–1439.

Ryman N., Lagercrantz U., Andersson L., Chakraborty R. and Rosenberg R. (1984) Lack of correspondence between genetic and morphologic variability patterns in Atlantic herring (*Clupea harengus*). *Heredity* 53, 687–704.

Saka Ş., Çoban D. and Firat K. (2004) The study on the technology of producing seabream (*Sparus aurata* L., 1758) larvae in marine fish hatcheries in Turkey. *Ege University Journal of Fisheries and Aquatic Sciences* 21, 215–218.

Sarà M., Favarolo E. and Mazzola A. (1999) Comparative morphometrics of sharpsnout seabream (*Diplodus puntazzo* Cetti. 1777) reared in different conditions. *Aquacultural Engineering* 19, 195–209.

Savouré B. (1977) Etude hydrobiologique des lagunes du Nord de la Tunisie. *Hydrobiologia* 56, 209–224.

Silva A. (2003) Morphometric variation among sardine (*Sardina pilchardus*) populations from the northeastern Atlantic and the western Mediterranean. *ICES Journal of Marine Science* 60, 1352–1360.

Smith J.L.B. and Smith M.M. (1986) Sparidae. In Smith M.M. and Heemstra P.C. (eds) *Smith's sea fishes*. Berlin: Springer-Verlag, pp. 580–594.

Strauss R.E. and Bookstein F.L. (1982) The truss: body from reconstructions in morphometrics. *Systematic Zoology* 31, 113–135.

Trabelsi M., Quignard J.P., Tomasini J.A., Boussaid M., Folcant B. and Maamouri F. (2000) Discriminative value of the meristic characteristics of the punctuated sand smelts marine populations. *Oebalia* 26, 77–88.

Trabelsi M., Quignard J.P., Tomasini J.A., Boussaid M., Folcant B. and Maamouri F. (2002) Discriminative value of the meristic characteristics of *Atherina boyeri* Risso, 1810 Lagoon populations. *Vie et Milieu* 52, 77–84.

Tudela S. (1999) Morphological variability in a Mediterranean, genetically homogeneous population of the European anchovy, *Engraulis encrasicolus*. *Fisheries Research* 42, 229–243.

Turan C. (1999) A note on the examination of morphometric differentiation among fish populations: the truss system. *Turkish Journal of Zoology* 23, 259–263.

Turan C. (2004) Stock identification of Mediterranean horse mackerel (*Trachurus mediterraneus*) using morphometric and meristic characters. *ICES Journal of Marine Science* 61, 774–781.

and

Türkmen M. and Akyurt I. (2003) Growth characteristics, sex inversion and mortality rates of striped seabream, *Lithognathus mormyrus* L., in Iskenderun Bay. *Turkish Journal of Zoology* 27, 323–329.

Correspondence should be addressed to:
O.K. Ben Hassine
Research Unit of Biology, Ecology and
Parasitology of Aquatic Organisms
Department of Biology, Faculty of Science of Tunis
University Campus, El Manar, 2092 Tunis, Tunisia
email: kalthoum.benhassine@gmail.com

https://doi.org/10.1017/S0025315410002201 Published online by Cambridge University Press