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Morphometric and meristic variation in the Atlantic chub mackerel *Scomber colias* Gmelin, 1789 from the Moroccan coast

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ABSTRACT

Morphometric and meristic characters were used to study the variability between *Scomber colias* Gmelin, 1789 sampled from five locations in the Moroccan Atlantic coast. Eighteen morphometric measurements were taken using the image processing program, *Image J* along with seven meristic characters. Univariate analysis of variance (ANOVA) performed by Tukey HSD *post-hoc* test showed significant differences for 14 standard morphometric measurements. In principal component analysis (PCA), PC1 was resolved as general size and PC2 was resolved as shape differences. Discriminant analysis indicated the existence of four morphometric groups of *S. colias* with minor overlapping, which suggested that there is a self-recruiting population. The proportion of correctly classified Sidi Ifni (SDF) sample to their original group was 96% and showed clear separation from other groups. We concluded that Sidi Ifni samples are morphologically distinct from *S. colias* of the other four localities which could be attributed to genetic bias or environmental factors.

Keywords: Agadir, Meristic, Morocco, Morphometric, *Scomber colias*

Introduction

The Atlantic chub mackerel *Scomber colias* Gmelin, 1789 (Family: Scombridae), is a fast growing, early maturing coastal pelagic species that may reach 50 cm in total length and 13 years of age (Castro *et al.,* 2000). It has a cosmopolitan distribution in warm and temperate coastal waters of the Atlantic and the adjacent seas, such as the Mediterranean Sea, the Black Sea and the Adriatic Sea, on the continental shelf between 0 to 300 m (Collette *et al.,* 1983; Castro *et al.,* 2000; Infante *et al.,* 2007), extending from the Bay of Biscay of the eastern Atlantic north to South Africa. Also, it is present along the coast of America, from Massachusetts to Florida, the Bahamas, Gulf of Mexico, southern Venezuela, Brazil, Uruguay and Argentina (Castro *et al.,* 2000).

S. colias has earlier been described from the Atlantic coasts as a synonym of *Scomber japonicus* Houttuyn, 1782, but recent genetic studies confirmed that *S. colias* and *S. japonicus* are different species, one belonging to the Atlantic and the other to the Pacific (Infante *et al.,* 2007; Catanese *et al.,* 2010; Trucco and Buratti, 2017).

The chub mackerel *S. colias* has significant ecological and economic importance, globally and in Morocco as well, and therefore it is essential to develop knowledge base on their population and stock structure. The biometric field has been used by ichthyologists, to extract differences from the shape of specimens (Cadrin, 2000; Hermida *et al.,* 2005; Infante, 2007). Morphometric measurements and meristic counts are widely applied in the biological field to study the intra or interspecific phenotypic variations among populations. Meristic characters are the number of discrete countable structures, independent of size and stable during growth and the morphometric characters are continuous characters describing aspects of body shape (Ihssen *et al.,* 1981; Turan 2004; Erguden *et al.,* 2009; Tarkeshwar *et al.,* 2012) and are often been used to delineate stocks (Turan *et al.,* 2006). So far, many studies have been carried out on chub mackerel, dealing with different aspects of biology such as diet, age, growth, reproduction and morphometry, along both Mediterranean and Atlantic coasts and most of them are related to *S. japonicus* (Baird, 1977; Carvalho *et al.,* 2002; Perrotta *et al.,* 2005; Bayhan, 2007; Cikes *et al.,* 2011; Velasco *et al.,* 2011; Wahbi *et al.,* 2015; Ait Talborjt and El Ouizgani, 2016; Allaya *et al.,* 2016). Such data available for *S. colias* from the Moroccan Atlantic Ocean are very scanty, even though the species form a commercial fishery in the region.

The present study investigated the variability in the morphometric and meristic characters among samples of *S. colias* collected from five distant localities situated along the Moroccan Atlantic coast.

Materials and methods

Sample collection

Sampling was carried out from commercial landings of small fishing units and purse seiners. A total of 300 specimens of *S. colias*, were collected during winter in 2017, from five different fishing ports (Fig. 1), located along the Atlantic coast, namely El Jadida, Safi, Agadir, Sidi Ifni and Laayoune.

Morphometric characters

A total of 18 morphometric measurements (Erguden *et al.,* 2009; Allaya *et al.,* 2016; Gonzalez *et al.,* 2016) to the nearest 1 mm were taken from 284 specimens (Table 1) using *Image J* 1.50b, an image processing program developed for morphometric measurements using digital images (Abramoff *et al.,* 2004; Schneider *et al.,* 2012). The measurements comprised: total length (TL), fork length (FL), standard length (SL), pre-first dorsal fin length (PDL1), pre-second dorsal fin length (PDL2), pre-pectoral fin length (PPL), pre-ventral fin length (PVL), pre-anal length (PAL), head length (HL), eye diameter (ED), pre-orbital length (POL), head depth (HD), snout length (SNL), body depth (BD), depth at first dorsal (DFD), depth at second dorsal (DSD), depth at anal (DA) and peduncle depth (PD) (Fig. 2).

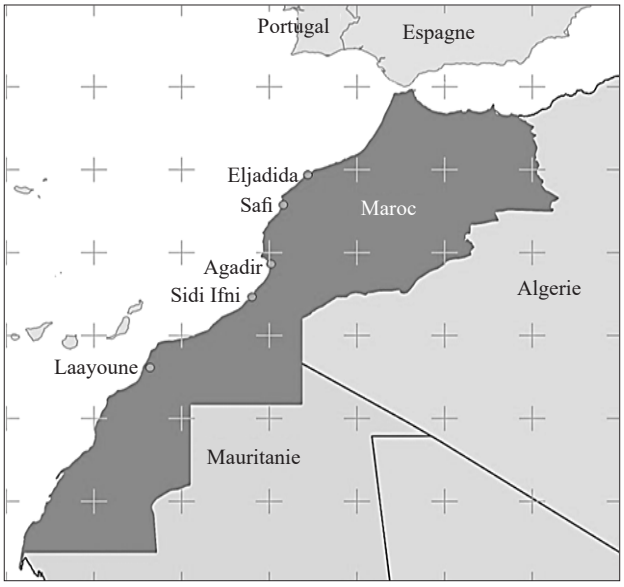

Fig. 1. Map of sampling locations for *Scomber colias*

Meristic characters

Seven meristic characters such as: number of first dorsal fin rays (DFR1), second dorsal fin rays (DFR2), anal fin rays (AFR), pectoral fin rays (PFR), ventral fin rays (VFR), dorsal finlets (DF) and ventral finlets (VF) were counted for each specimen by direct observation. After having completed all the measurements of the biological parameters, the samples were cooked in a steam apparatus, in order to count the vertebrae after removing the whole meat. All the samples were found to have 30 vertebrae.

Statistical analysis

As a first step, a simple analysis of variance was performed on the raw data (morphometric data) to test size heterogeneity among populations of different areas. The morphometric data were transformed to $\log_{10}$ before analysis to reach better approximation to multivariate normality and to eliminate size effect from the raw data (Elliot *et al*., 1995). All morphometric measurements were standardised according to the following formula (Elliott *et al.,* 1995):

$$M_{adj}=M(L_s/L_0)^b$$

where M = Original morphometric measurement, M_{adj} = Size adjusted measurement, L_0 = Standard length of the specimen and L_s = Overall mean of standard length of all fish from all samples for each variable. The parameter b was estimated for each character from the observed data as the slope of the regression of log M on log L_0 (Elliott *et al.,* 1995; Elliott *et al.,* 1995; Tudela,1999; Turan, 2004; Allaya *et al.,* 2016).

To ensure that data transformation was effective in removing the effect of size from the whole morphometric data, the correlation coefficient between transformed variables and standard length were calculated (Turanet *et al.,* 2006; Erguden *et al.,* 2009; Gonzalez, 2016). When

Table 1. Sampling details of *S. colias* used in the study

Sampling location	Sample size (N)	Standard length range (mm)			Sex (M/F)
		Min.	Max.	Mean (X)	
SAF (SAFI)	56	161.7	213.9	181.2	30♂/26♀
JD (EL JADIDA)	61	172.0	255.6	197.6	26♂/35♀
AG (AGADIR)	64	168.5	287.3	206.6	19♂/45♀
SDF (SIDI IFNI)	52	237.7	410.6	303.8	20♂/32♀
LA (LAAYOUNE)	51	192.8	270.0	238.7	21♂/30♀

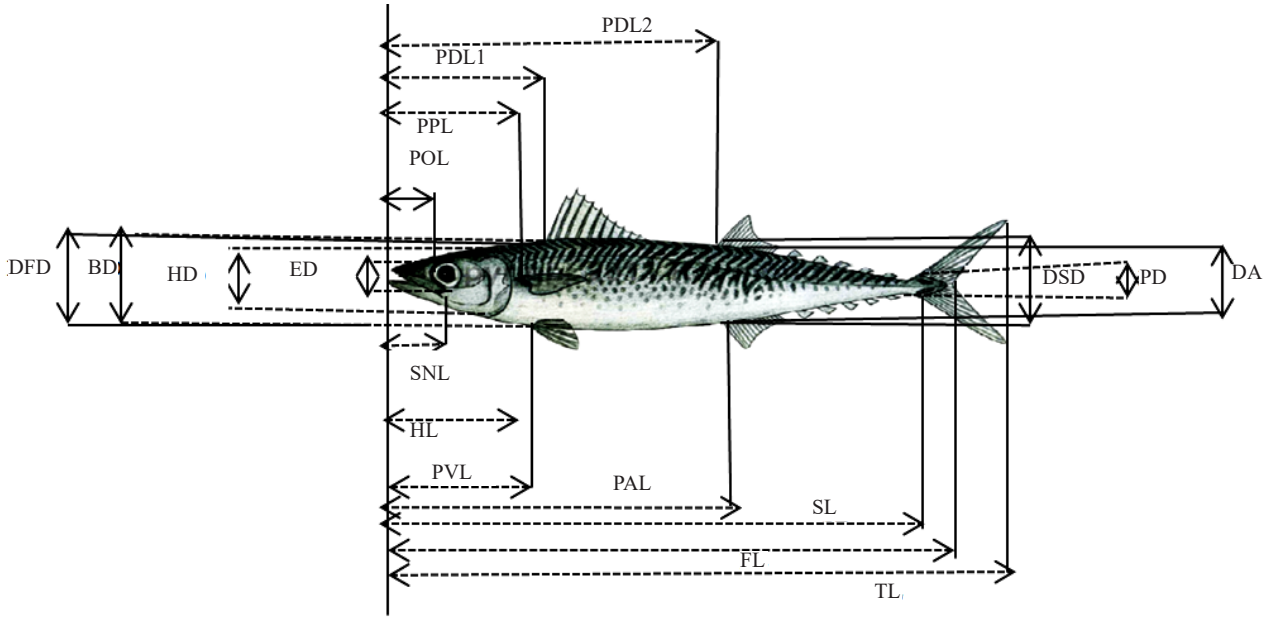

Fig. 2. Schematic drawing of *S. colias* showing details of various measurements: BD-Body depth, HD-Head depth, ED-Eye diameter, POL-Pre-orbital length, PPL-Pre-pectoral fin length, PDL1-Pre-first dorsal fin length, PDL2-Pre-second dorsal fin length, SNL-Snout length, HL-Head length, PVL-Pre-ventral fin length, PAL-Pre-anal fin length, FL-Fork length, SL-Standard length, TL-Total length, DFD-Depth at first dorsal, DSD-Depth at second dorsal, DA-Depth at anal and PD-Peduncle depth. (Drawing by Ray Simpson - modified)

the standardised measurements showed no significant correlation with standard length (SL), it was deemed that size effect had been removed successfully.

Univariate analysis ANOVA was used to evaluate differences for each morphometric character among the five populations (Turanet *et al.,* 2006) and Tukey *post-hoc* test was used for pair-wise comparison. The size compensated data were subjected to principal component analysis (PCA), a multivariate statistical method that reduces a group of variables into smaller numbers and visualises the variation in lower dimensions. Linear discriminant analysis was used to reclassify samples and to show the best separation between groups. Kruskal-Wallis test was used to examine variation in meristic characters among different samples. All statistical analyses were carried out using R ver 3.3.3. The packages used in this current study were: ade4, FactoMineR and MASS (Chessel *et al.,* 2004; Dray and Dofour 2007; Dray *et al.,* 2007; Le *et al.,* 2008).

Results

Morphometric analysis

Tukey *post-hoc* test demonstrated that Sidi Ifni (SDF) samples differed significantly from Agadir (AG) and Safi (SAF) samples by 16 morphometric measurements; from El Jadida (JD) samples by 15 measurements and Laayoune samples by 13 measurements. El Jadida (JD) samples differed significantly from Agadir samples by 12 measurements, from Laayoune samples by 9 and Safi samples by 8 measurements. *S. colias* samples from Laayoune (LA) differed significantly from Agadir samples by 15 measurements and Safi samples by 12 measurements. Safi samples differed significantly from Agadir samples by 11 measurements (Table 2).

In PCA, the first component factor (PC1) accounted for 56.82% of the overall variance, while the second component factor (PC2) explained 23.85%. All variables were positively correlated with the first component PC1 (Fig. 3). The first two components in the PCA, covered majority of the total variability; which accounted for 80.67%.

Discriminant analysis showed four natural groups. The overall assignment of individuals into their original population by linear discriminant analysis was low (80%) (Table 3). The proportion of correctly classified Sidi Ifni (SDF) sample to their original group was highest (96%) followed by Agadir (87%), El Jadida (80%), Laayoune (90%) and Safi (83%) samples (Fig. 4).

Meristic analysis

All meristic counts of samples from the five locations were analysed using the Kruskal-Wallis test, which showed significant difference ($p<0.05$) in the first dorsal

Table 2. ANOVA results of morphometric measurements performed with the Tukey HSD *post-hoc* test (a, b, c and d = means of characters)

Characters	F value (4,279)	p-value	Sample 1 (JD)	Sample 2 (SAF)	Sample 3 (AG)	Sample 4 (SDF)	Sample 5 (LA)
SL	263.2	<0.001	2,294c	2,257d	2,312c	2,480a	2,377b
PDL1	45.22	<0.001	1,919b	1,908c	1,904c	1,940a	1,921b
PDL2	42.05	<0.001	2,177bc	2,172d	2,174cd	2,187 a	2,179b
PAL	25.01	<0.001	2,197c	2,194c	2,194c	2,205a	2,201b
PPL	37.38	<0.001	1,799b	1,790bc	1,771d	1,821a	1,786c
PVL	55.97	<0.001	1,878bc	1,870c	1,859d	1,906a	1,886b
HL	37.18	<0.001	1,787b	1,777b	1,757c	1,808a	1,785b
BD	23.48	<0.001	1,561c	1,554c	1,621b	1,650a	1,639a
ED	26.76	<0.001	1,157bc	1,160bc	1,142c	1,211a	1,168b
POL	181.9	<0.001	1,226ab	1,176c	1,170c	1,246a	1,206b
HD	111.8	<0.001	1,538d	1,521e	1,562c	1,597a	1,575b
SNL	34.21	<0.001	1,393b	1,382b	1,363c	1,441a	1,397b
DFD	187.4	<0.001	1,565c	1,557c	1,630b	1,653a	1,643b
DSD	197	<0.001	1,498c	1,483d	1,548b	1,592a	1,588a
DA	213.5	<0.001	1,466c	1,446d	1,520b	1,564a	1,553a
PD	145	<0.001	0,747d	0,718e	0,788c	0,886a	0,820b

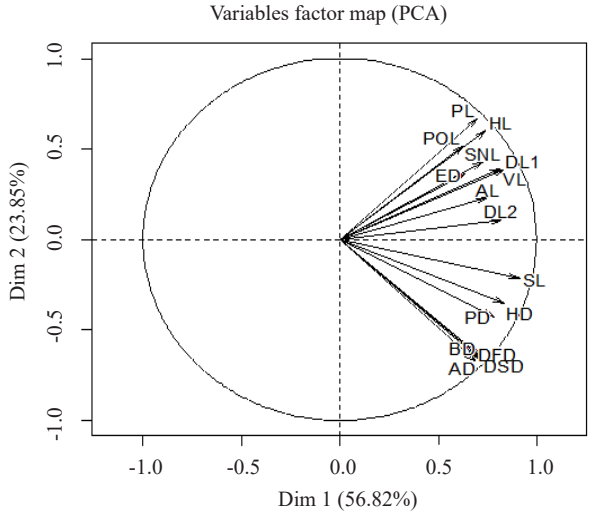

Fig. 3. Results of principal component analysis correlation circle (PCA)

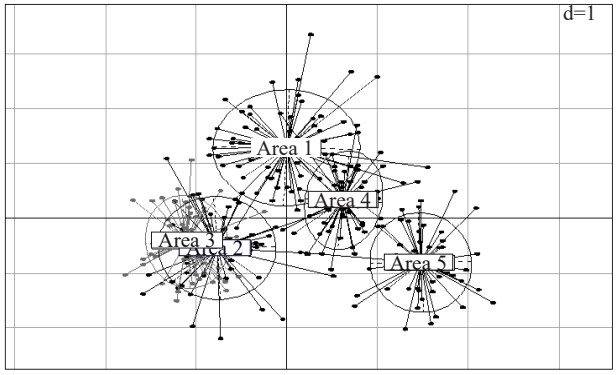

Fig. 4. Results from discriminant analysis (AREA1=Agadir, AREA2=EL Jadida, AREA3=Safi, AREA4=Laayoune, AREA5=Sidi Ifni)

Table 3. Classification matrix of individuals reallocated in each group, in the validation of discriminant analysis for morphometric data. Rows are the original sample group and columns are the reallocated group

Sample groups	Correction	AGADIR	ELJADIDA	LAAYOUNE	SAFI	SIDI IFNI	Total
AGADIR	87%	56	0	4	1	3	64
ELJADIDA	80%	1	49	2	9	0	61
LAAYOUNE	90%	4	1	46	0	0	51
SAFI	83%	0	9	0	47	0	56
SIDI IFNI	96%	0	0	2	0	50	52
Total		61	59	54	57	53	284

fin rays (DFR1), anal fin rays (AFR) and pectoral fin rays (PFR), whereas no significant differences were seen in VEF and DF2 when compared for the five areas (Table 4).

The meristic characters of *S. colias* showed minor differences, for the number of first dorsal fin rays. El Jadida and Safi samples presented the same range

Table 4. Kruskal-Wallis test of meristic characters for five locations, p=0.05, df=4H0: Null hypothesis, H1: Alternative hypothesis

Meristic characters	χ^2 value	p-value	Hypotheses
DFR1	33.144	$1.116e^{-06}$	H1
DFR2	5.0825	0.2789	H0
AFR	9.6719	0.04633	H1
VFR	2.69	0.611	H0
PFR	111.95	$<2.2e^{-16}$	H1

(8-10), while Agadir, Sidi Ifni and Laayoune showed different ranges of 7-11; 7-9 and 7-10 respectively. For the number of second dorsal fin rays, the same range (11-12) was observed for all five populations. With respect to anal fin rays and ventral fin rays, El Jadida, Safi, Sidi Ifni and Laayoune populations presented similar ranges of 11-12 and 6-6 respectively, while it was different for Agadir population (10-12) and (5-6) respectively. The number of pectoral fin rays was found to be similar for three populations (18-19), except for Agadir (16-20) and Safi (17-19) samples (Table 5).

Discussion

The results obtained by ANOVA and Tukey *post-hoc* test demonstrated significant variation in the morphometric characters across the five sampling locations. The samples of Sidi Ifni differed from that of the other four locations (Agadir, El Jadida, Laayoune and Safi) in almost all morphometric measurements, except for selected measurements like pre-orbital length (POL), which was found to be the same as El Jadida and Laayoune samples. Body depth (BD), depth at second dorsal (DSD) and depth at anal (DA) of Sidi Ifini samples were the same as that of Laayoune. Head depth (HD) and peduncle depth (PD) were the morphometric measurements that differed among all samples.

Results of PCA demonstrated that all linear measurements had a positive linear correlation with the first principal components PC1. The second principal components (PC2) showed a negative linear correlation with body depth (BD), head depth (HD), standard length (SL), depth at anal (DA), depth at first dorsal (DFD), depth at second dorsal (DSD) and peduncle depth (PD). According to Teissier (1960), the effect of size accounted for the first principal component PC1. The second component PC2 is used to visualise variations in shape. The morphometric results obtained by linear discriminant analysis revealed the existence of four clear groups which confirmed the results obtained by PCA. The first group included AREA1 (Agadir); second group AREA2 (El Jadida) and AREA3

Table 5. Variations in meristic characters from five different landing sites

Meristic character	Locality	Sample size (N)	Range (Min-Max)	Median
DFR1	El Jadida	61	8-10	9
	Safi	56	8-10	9
	Agadir	64	7-11	9
	Sidi ifni	52	7-9	9
	Laayoune	51	7-10	9
DFR2	El Jadida	61	11-12	12
	Safi	56	11-12	12
	Agadir	64	11-12	12
	Sidi ifni	52	11-12	12
	Laayoune	51	11-12	12
AFR	El Jadida	61	11-12	12
	Safi	56	11-12	12
	Agadir	64	10-12	12
	Sidi ifni	52	11-12	12
	Laayoune	51	11-12	12
VFR	El Jadida	61	6-6	6
	Safi	56	6-6	6
	Agadir	64	5-6	6
	Sidi ifni	52	6-6	6
	Laayoune	51	6-6	6
PFR	El Jadida	61	18-19	18
	Safi	56	17-19	18
	Agadir	64	16-20	18
	Sidi ifni	52	18-19	19
	Laayoune	51	18-19	18

(Safi); the third group AREA3 (Laayoune) and the fourth group AREA4 (Sidi Ifni). The second group comprising AREA2 (El Jadida) and AREA 3 (Safi) showed a major overlap, indicative of homogeneity. This may be explained by the geographic proximity of El Jadida and Safi sharing same environmental conditions. The first group AREA1 (Agadir) and the third group AREA4 (Laayoune) are close to each other, but still showed a significant difference in all morphometric characters, which may be due to variation in environmental conditions as these areas experience variability in upwelling intensity (Berrada *et al.,* 2017). The fourth group AREA4 (Sidi Ifni), which is isolated from the other groups showed huge difference from the other four populations in morphometric characters. The differences observed among four groups may suggest the relationship between phenotypic divergence and geographic distance, explaining the limited migration between the five distant areas, *viz*., El Jadida, Safi, Agadir, Laayoune and Sidi Ifni. The vast variability of size observed between samples from Sidi Ifni and other areas, could also be attributed to the way of fishing, since the fishermen use pelagic longlines instead of purse-seine to catch chub mackerel in Sidi Ifni. On the other hand, different environmental factors such as temperature and salinity as well as fishing intensity and availability of food may also contribute towards size variability **(**Tudela, 1999; Tzeng, 2004; Turan *et al.,* 2006; Balayet *et al.,* 2015; Allaya *et al*., 2016). High morphometric differentiation of Sidi Ifni samples suggests that either there may be sub-species of *S. colias* or this perhaps indicates growth responses to different habitats arising from ecological and oceanographical conditions (Erguden *et al*., 2009).

Studies on the spatio-temporal dynamism of temperature and surface salinity of the coastal zone of Morocco between Spartel Cap and Juby Cap suggest seasonal fluctuations between coastal and offshore water because of upwelling activity (Furnestin, 1959; Makaoui *et al.,* 2005). During winter season, the coastal waters of upwelling area (Safi-Essaouira and Sidi Ifni-Draa) are distinguished by a decrease in temperature and salinity (Furnestin, 1959; Makaoui *et al.,* 2005). The pelagic ecosystem of the Moroccan Atlantic coast has been reported to be influenced by the spatio-temporal variability of upwelling (Bessa *et al.,* 2018).

Roldan *et al.* (2000) reported that, head size is a critical as well as a principal factor influencing variations between populations in South-West Atlantic Ocean. The variations may be attributable to growth responses to different oceanographic and ecological conditions **(**Roldan *et al.,* 2000). Erguden *et al*. (2009) and Allaya (2016) reported that these morphometric characters also show variations in the Mediterranean, Tunisian Sea, the North-Eastern Mediterranean, Aegan, Marmara and the Black Sea.

Results obtained from Kruskal-Wallis, revealed a significant difference in some meristic characters among samples; such as dorsal fin rays 1, anal fin rays and pectoral fin rays. Perhaps, this variation in meristic characters could be attributed to genetic structure or environmental factors. Major variability was observed in two meristic characters *viz*., the first dorsal fin rays (DFR1) and the pectoral fin rays (PFR). El Jadida and Safi populations had the same number of first dorsal fin rays (8-10) which were supposed to be from the same population because of similar environmental conditions and geographical proximity, while Agadir, Sidi Ifni, Laayoune samples had different range of 7-11; 7-9; and 7-10 respectively. The number of pectoral fin rays were found similar for El Jadida, Laayoune and Sidi Ifni (18-19), which were found different for Agadir (16-20) and Safi (17-19) samples. Chase (2014) reported that the meristic characters are partially affected by environmental conditions during embryonic stages and therefore, the variations in meristic counts can indicate some degree of geographic separation between populations during early life stages. In general, fishes are sensitive to environmental changes, which make them adapt quickly by changing necessary morphometric characters (Hossain *et al*., 2010; Mollah *et al*., 2012).

In the present study, considerable morphological variability was found between samples of *S. colias* from Sidi Ifni and from the four other localities in the Moroccan coast. Morphological studies on *S. colias* are scarce in the Moroccan Atlantic coast and therefore, further studies need to be carried out on the morphological characters of the chub mackerel populations from north and south Morocco coasts for deriving more conclusive inferences. Also, it would be better to use molecular genetic markers such as microsatellites (Shaw *et al.,* 1999; Turan, 2015) to examine genetic component of phenotypic differentiation between different locations.

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