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Morphometric variation of *Spicara flexuosum* Rafinesque, 1810 (Teleostei: Sparidae) inhabiting the Sea of Marmara, the Aegean and the Mediterranean Coast of Türkiye

by

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Abstract

In the present study, intraspecific morphometric distribution of *Spicara flexuosum* was investigated along the five locations on the Turkish coast based on eight morphological characters. A total of 116 samples were obtained along the Turkish coasts (Istanbul, Yalova [Armutlu], Izmir, Mersin and Antalya) by using trawlers and the handline fishing method within the period in 2014–2015. Principal component analysis and the dendrogram-based Euclidean distance method were used to evaluate different morphometric traits among five locations. The most important ratios of the morphometric loading characters were the head length to interorbital distance, head length to eye diameter, maximum body height two to head height, and head height to head length. The classification matrix based on the discriminant function analysis showed that 94.7% of original grouped were correctly classified. Principal component and cluster analysis showed the existence of two morphologically differentiated groups of *S. flexuosum*. First one composed of Istanbul and Yalova and the second one consisted of Izmir, Mersin and Antalya. This study is the first description of the intraspecific distribution of morphometric characters for *S. flexuosum* along the Turkish coast as well as the Mediterranean region for fisheries management purposes.

Key words: Morphometric, Turkish Straits System, *Spicara flexuosum*, principal component analysis, Mediterranean

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1. Introduction

Black Sea and the Mediterranean fish resources are important bio reservoirs in the world. The Mediterranean Sea, considered to be one of the important semi-enclosed bodies of water, contains 4% of the marine fish species biodiversity of the world (Keskin et al. 2011). Considering Black Sea fauna, a total of 161 species was present in the Turkish Black Sea and approximately 62.73% of the fish species was of Atlanto-Mediterranean origin (Keskin 2010). *Spicara* spp. (picarels) are members of the Sparidae family groups and are small to medium-sized fish (Froese & Pauly 2022). These family groups are an essential component of the Mediterranean as well as the Black Sea bioresources. *Spicara flexuosum* is observed in the eastern Atlantic, Mediterranean, and Black Sea (Salekhova 1979, Tortonose 1986, Golani et al. 2006). *Spicara flexuosum* (Rafinesque, 1810) (previously known as *Spicara flexuosa* in the literature) is now genetically identified (Şalcıoğlu et al. 2021) and has been renamed S. *flexuosum* in the FishBase (Froese & Pauly 2022).

Variations in the growth and development of fish caused by environmental factors lead to differences in body shape even within the same genus and species (Mejri et al. 2012, Firmat et al. 2012). Species identification and differentiation and stock structure are useful for developing management strategies and will conserve biodiversity associated with species, subspecies, and stocks (Turan et al. 2005, Cadrin et al. 2014). Identifying the intra- and interspecific differences of fish by using morphometric traits with variable life history characteristics is quite important for understanding population dynamics and evaluating sustainable resources (Turan et al. 2005, Siddik et al. 2016).

The morphometric characters of fish species are influenced by genotype and environmental factors. Moreover, identification of stock with pronounced phenotypic and genetic differentiation among fish populations within a species serves to facilitate managing the stock separately, to determine stock-wise population abundance, and to accomplish the objectives of fisheries stock assessment by modelling (Rawat et al. 2017). Moreover, morphometric characters are considered to be phenetic characters (characters of adaptive variation) and habitat variables directly influence the phenotype of an organism (Vidalis et al. 1997, Bears et al. 2008, Pigliucci 2005). Intra-specific variation in fish morphology is quite an important concept for an understanding of the response of organisms to environmental challenges across fish populations (Shuai et al. 2018).

Morphometric analyses were previously available and used for inter- and intra-specific differentiation of fish species in the literature, such as *Pomatomus saltatrix* from the Aegean, Black Sea, and the Mediterranean (Turan et al. 2006) and the Sea of Marmara (Bal et al. 2021) and the three *Scorpena* species from the Aegean, Black, Mediterranean and the Marmara Sea (Yedier & Bostancı 2021). Different metric and meristic characters and their relative distributions were also observed for phylogenetic determination and taxonomy of freshwater fishes for *Luciobarbus barbulus* in the Persian Gulf Basin *(*Khaefi et al. 2017, Khaefi et al. 2018), three Gourami species in Indonesia (Perdana et al. 2021) and some marine fish species, such as *Chromis chromis* (Aydın & Öztürk 2021) *Sciaena umbra* (Aydın & Bodur 2021) in the Black Sea.

Meristic and morphometric studies were previously observed (Vasilieva & Salekhova 1983, Rizkalla 1996) in the literature about the species *Spicara*. Some studies were about biology, growth, nutrition (Soykan et al. 2010), while others involved length-weight relationships (İşmen et al. 2007, Soykan et al. 2010, Dalgıç et al. 2021, Şalcıoğlu & Sönmez 2022), the sexual dimorphism of *Spicara flexuosum* (Karadurmuş et al. 2022) and morphological identification of *Spicara flexuosum* and *Spicara maena* (Minos et al. 2013, Kuzminova & Martemyanova 2020).

Some morphometric characters and population characteristics of *Spicara flexuosum* species were previously evaluated in the literature; however, none of the studies covered the intraspecific distribution of *S. flexuosum* species from coastal areas of Türkiye to identify morphometric characteristics of each stock in the five different locations (Istanbul, Yalova (Armutlu), Izmir, Mersin, and Antalya). This study aims to evaluate the morphometric data based on the distribution of *S. flexuosum* sampling from Turkish coastal waters for fisheries management purposes.

2. Materials and methods

2.1. Fish sampling

A total of 116 *Spicara flexuosum* specimens were obtained between 2014 and 2015. Sampling of fish specimens was conducted out of the spawning period (if possible) in order to minimize the influence of the gonadal maturity and sexual dimorphism of the species (Zei 1941). Coordinates of the studied locations, sampling date, number of the samples from each location, minimum-maximum fish lengths and fishing methods of *S. flexuosum* populations in the

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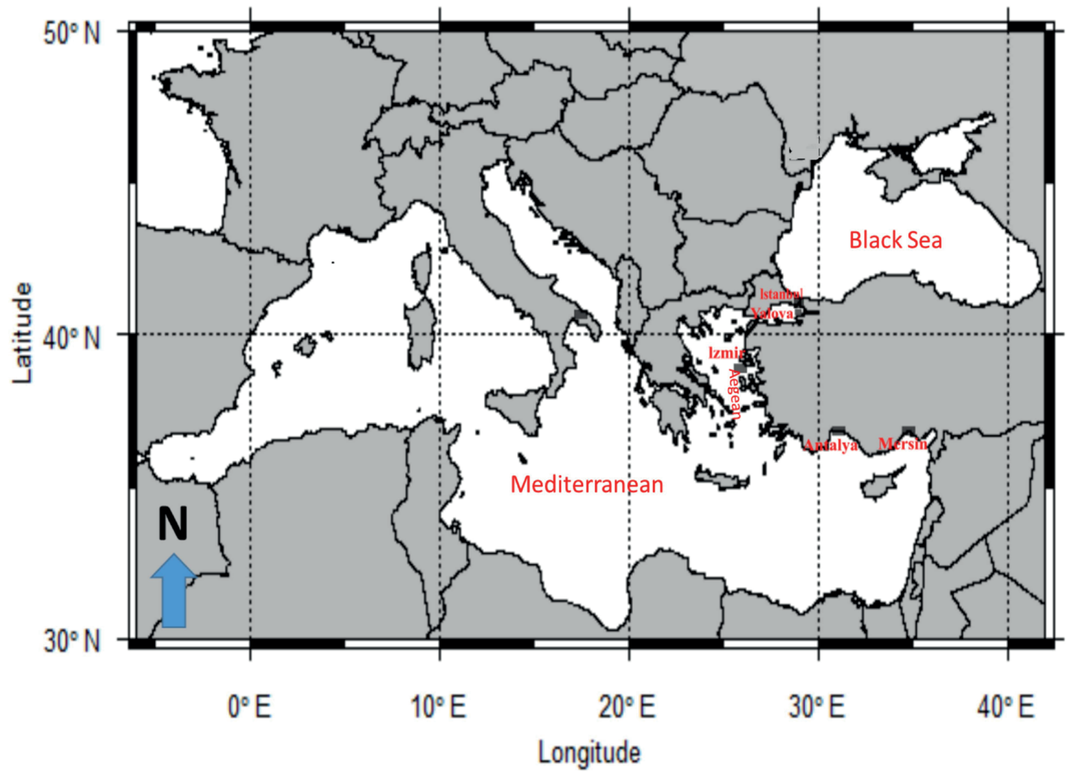

Figure 1

Sampling locations of *Spicara flexuosum*

Marmara, the Aegean and the Eastern Mediterranean seas are shown in (Table 1), (Fig. 1).

Fish samples were identified based on the diagnostic morphological characters (Golani et al. 2006, Minos et al. 2013). All measurements were usually made on the left side. Morphometric measurements were conducted by a Vernier caliper at 0.1 mm intervals. Sex was determined whenever possible.

Table 1

Coordinates of the studied locations, sampling dates, fishing methods features and sampling depth, number of the samples and minimum and maximum length of *S. flexuosum* populations in the Marmara Sea, Aegean Sea and the Eastern Mediterranean

Locations	Longitude and latitude	Sampling date	Fishing methods (features and depth)	Number of the samples	Minimum Maximum Total Length (cm)
Istanbul (Marmara Sea)	40.5382480º N 29.4102180º E	23.02.2014	Handline fishing (30 m)	23	11.04 – 17.22
Mersin (Eastern Mediterranean)	36.333359º N 34.162964º E	23.06.2014	Bottom trawl net (20–100 m)	20	11.5 – 14.5
Antalya (Eastern Mediterranean)	36.836517º N 30.836772º E	12.10.2014	Bottom trawl net (40 m)	21	12 – 13.5
Izmir (Aegean Sea)	38.4051556º N 26.8099964º E	14.11.2014	Bottom trawl net (30 m)	22	11.9 – 14.5
Yalova (Armutlu) (Marmara Sea)	40.4934567º N 28.7786335º E	05.09.2015	Handline fishing (20 m)	30	13.4 – 17.27

2.2. Data analysis

A total of eight characters were used for each measurement, the abbreviations of which are: TL (Total Length), SL (Standard Length), HH (Head Height), HL (Head Length), MBH1 (Maximum Body Height 1), MBH2 (Maximum Body Height 2), ED (Eye Diameter) and IO (InterOrbital Distance) (Fig. 2). All morphometric measurements were standardized using the following equation (Reist 1986) to eliminate the effect of fish sizes on the variables.

where V_{trans} is the transformed morphometric variable, V is the original value of the measurement, SL is the standard length of each fish, SL means is the overall

$$V_{trans} = logV - b(log SL - log SL_{mean})$$

mean standard length of each fish from each region, and b is the slope of the relation between log V and log SL (Reist 1986).

Descriptive statistics such as minimum values, maximum values, standard error and standard deviation, and the mean values of each morphometric trait were calculated. Coefficients of variations (Vc) of each character were also computed according to the formula for each measurement (Avşar 2016).

$$V_C = \frac{Sd}{mean} \times 100$$

Correlations between some morphometric traits and length data were also evaluated according to the formula given below:

Relationships between fish standard length (SL), head height, or MBH1 and metric characters (y) were estimated by linear regression analysis:

$$y = a + bSL$$

where intersect (a) and slope (b) were found by least-squares estimation. (Bagenal & Tesch, 1978). The correlation coefficient (R^2) was used to evaluate the strength of this relationship.

Morphometric characters were also tested for normality and homogeneity of variances using the Kolmogorov-Smirnov test and the Levene test, respectively. An analysis of variance (ANOVA) of morphometric characters was conducted to test for variation among populations. MANOVA was also used to determine significant variation between different sex groups. Principal component analysis (PCA) was used to evaluate the relationships between morphometric traits and five populations. The PCA was used to extract the principal components and to identify and distinguish between the five populations (Hammer et al. 2001). Factor loadings greater than 0.30 magnitude were taken into account for the intraspecific distribution of populations (Yedier & Bostancı 2021). Discriminant function analysis (DFA) was used for classifying populations with a classification matrix. Dendrogram-based Euclidean distance method was also used between different locations based on hierarchical clustering (Ward 1963). All statistical analysis was done by statistical package PAST Version 4.10., Microsoft Excel 2013 and IBM SPSS Statistics version 22.0 for Windows package software (IBM Corp., Armonk, NY, USA).

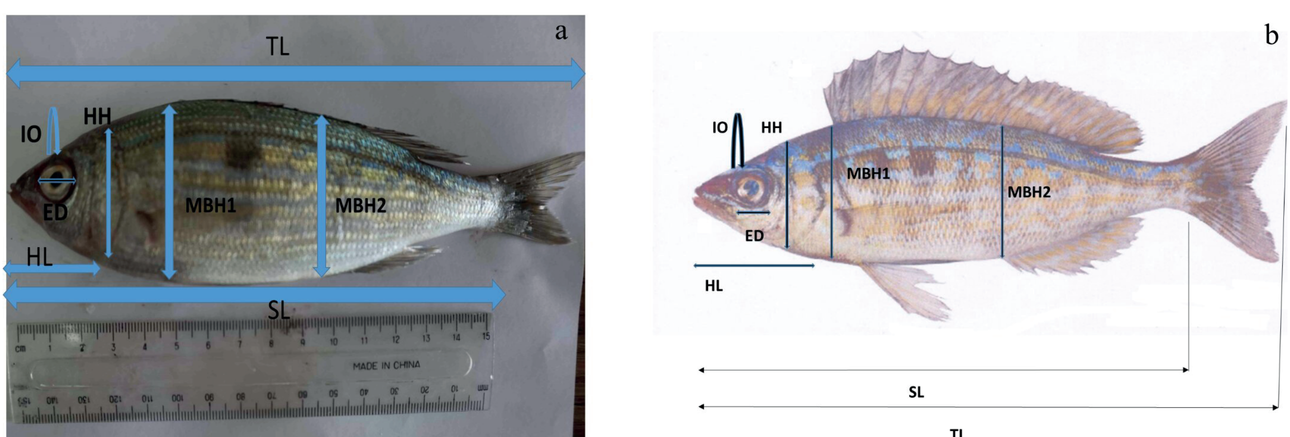

Figure 2

Morphometric characters of *S. flexuosum*. A) Original specimen collected from this study. B) The fish photo is modified by Iglésias (2014). Abbreviations in the photos are defined in the text.

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3. Results

Descriptive statistics and relative distributions of all individuals with respect to some important morphometric traits are presented in Supplementary Table 1. Among all characters, the most variable characters are the head length (V.C = 17.7%), maximum body height one (V.C = 16.41%) and the eye diameter (V.C = 16.13%). The least variable characters are the standard length (V.C = 11.84 %) and the total length (V.C = 12.13%). Regarding the variation of the relative distribution of characters, the most variable ratio of the characters are HL/IO (V.C = 14.37%) and HL/ED (V.C = 13.56%) and the least variable ratio is TL/MBH1 (V.C = 7.27%). Among all characters and relative ratios of distributions, none of the results were highly variable, and these results were corroborated with each morphometric and distribution ratio character.

As stated in Supplementary Table 2, the correlation coefficients of HH/SL, HL/SL, MBH2/SL, TL/MBH1, HL/HH (> 0.700) are relatively high, and there is a strong positive relationship between the observed characters.

The mean total length of 116 specimens in this study was 14.22 ± 1.72 cm. Measurements of eight morphometric characters (Supplementary Table 3) and ratio of the some morphometric characters (Supplementary Table 4) were evaluated based on the five locations. As seen in the Supplementary Table 4, TL/MBH1 values from Izmir (4.15 cm), and Antalya (4.22 cm) were found to be greater than those in Istanbul, Yalova (Armutlu) and Mersin (3.74 – 3.93 cm), and HL/ED values from Istanbul (3.20 cm) and Yalova (Armutlu) (3.67 cm) were found to be greater than those in the Izmir, Mersin and Antalya (2.92 – 3.10 cm) populations.

3.1. Multivariate and cluster analyses

All morphometric characters showed normality ($p > 0.05$) based on the Kolmogorov-Smirnov test and homogeneous variance ($p > 0.05$) by the Levene test. Multivariate principal components and cluster analyses were evaluated based on the eight morphometric traits and the relative ratio of some morphometric traits. Considering all morphometric characters and five location groups, significant differences were observed among all *S. flexuosum* populations (One –Way ANOVA, $F = 276.9$; $p = 8.977 \times 10^{-27}$). However, significant differences were not observed between sexes (MANOVA, $p = 0.234$). Principal component and cluster analyses were conducted by evaluating the data of male and female individuals together.

Principal component analyses of the eight morphometric traits were 80.001% for (PCA1), 18.044% for (PCA2), 1.8096% for (PCA3) and 0.14582% for (PCA4), which resulted in 100% of the total variation. All Eigen values were positive and all of these variables have influenced the morphological variation of *S. flexuosum* (Table 2). Principal component loadings were evaluated based on the cut-off value of 0.3 (positive or negative) (Snoeks 2004). The highest loading characters were the head length and maximum body height 1 for PCA 1, eye diameter and interorbital distance for PCA 2, interorbital distance and maximum body height 2 and head length for PCA 3, and head height and head length for PCA 4 (Table 2).

Principal component analyses of the relative ratio of some morphometric traits were evaluated based on the previous study for *Spicara* species from Minos et al. (2013) and on the results from the first principal component analysis. The principal component ratio of the morphometric traits exhibited 60.101% for (PCA 1), 28.198% for (PCA 2), 8.7805% for (PCA 3) and 2.9201% for (PCA 4) resulting in 100% of the total variation (Table 3). The most important morphometric loading characters were HL/IO and HL/ED for PCA 1, MBH2/HH and HL/IO for PCA 2, HL/ED and HH/HL for PCA

Table 2

Principal component loadings scores, Eigen values and variance based on eight morphometric traits

	PC1	PC2	PC3	PC4
Eigenvalues	0.018318	0,00413467	0.00041466	0.00034135
Variance (%)	80.001	18.044	1.8096	0.14582
Character				
HL	0.47363	0.20971	-0.54221	-0.54121
HH	0.42562	-0.095071	-0.19134	0.44293
MBH1	0.44763	-0.33877	0.22099	-0.36621
MBH2	0.38956	-0.34459	0.47519	-0.058186
SL	-7.2803E-17	5.8203E-16	-5.503E-15	5.352E-15
TL	0.32853	-0.21941	-0.22798	0.58388
ED	0.2943	0.65851	0.00334703	0.17156
IO	0.21877	0.48136	0.58547	0.055326

Table 3

Principal component loadings scores, Eigen values and variance based on the relative ratio of each morphometric trait

	PC1	PC2	PC3	PC4
Eigenvalues	0.00373899	0.00175425	0.00546240	0.000181664
Variance (%)	60.101	28.198	8.7805	2.9201
Character				
HL/SL	-0.063376	0.016927	0.050071	0.3927
HH/SL	0.21956	-0.090208	-0.21436	0.39744
HH/HL	0.1363	0.28853	0.55127	0.23751
MBH2/SL	0.027696	0.22781	-0.13991	0.24869
TL/MBH1	-0.25438	-0.2234	0.3019	-0.60892
HL/ED	0.54835	0.039031	0.60801	-0.030984
MBH2/HH	0.2144	0.81048	-0.27264	-0.38802
HL/IO	0.71907	-0.38488	-0.30481	-0.21743

3, and HH/SL, HL/SL and TL/MBH1 for PCA 4 (Table 3). The forth principal component loadings (PCA 4) represented allometric size factor and were eliminated. HL/IO, HL/ED, MBH2/HH and HH/HL were then used for intraspecies discrimination of each groups. The classification matrix based on the discriminant function analysis showed that 94.7% of the original group were correctly classified (Table 4).

Table 4

Classification matrix (percentage) based on the discriminant function analysis of five *S. flexuosum* populations from Turkish coastal waters

Population	Predicted group membership				
	Istanbul	Yalova	Mersin	Izmir	Antalya
Istanbul	100	-	-	-	-
Yalova	-	96.2	-	-	-
Mersin	-	-	99.0		-
Izmir	-	3.8	-	100	3.5
Antalya	-	-	1.00	-	96.5

Hierarchical clustering analyses based on the eight morphometric characters with Euclidean distance method indicated that (Fig. 3), [Izmir, Mersin, Antalya]; and [Istanbul, Yalova] populations were clustered around each other. This result was also supported by the Principal Component Analysis (Fig. 4). The minimum Euclidian distance was found between Mersin-Izmir populations.

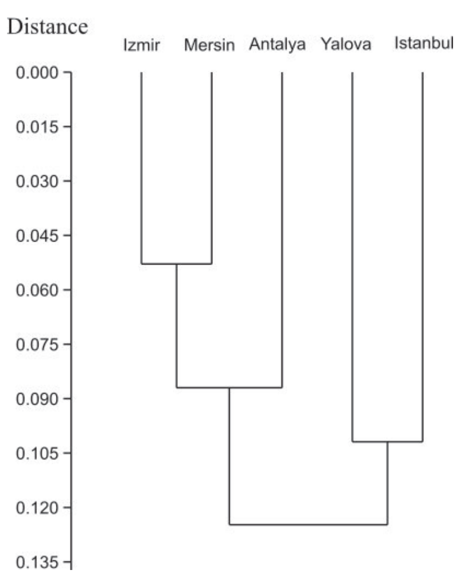

Figure 3

Cluster analysis based on the Euclidean distance method for *S. flexuosum* populations from eight morphometric characteristics

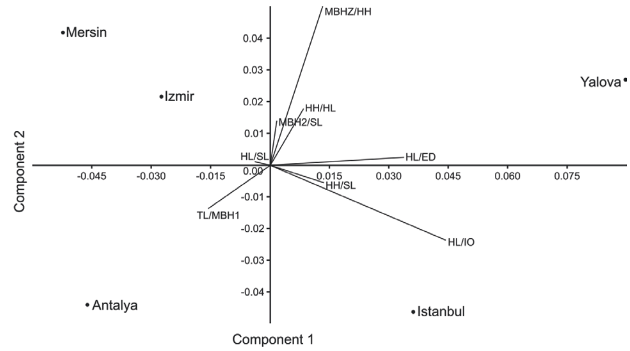

Figure 4

Principal component diagram based on the ratio of the morphometric traits for *S. flexuosum* populations from each location

4. Discussion

Morphometric characters of fish species are an important resource to measure and distinguish the intraspecific variation of different stocks (Turan et al. 2005, Cadrin et al. 2014). In this study, the intraspecific discrimination of *Spicara flexuosum* inhabiting the Istanbul, Yalova (Armutlu), Izmir, Mersin and Antalya populations was performed based on the PCA and cluster-based morphometric results.

Considering measurements of the mean total length values of *S. flexuosum,* all individuals within the range of length group 11.04 to 17.27 cm similar to other studies of *S. flexuosum* from France (14 cm), (Bauchot 1987); Izmir Bay (Türkiye) (9.20 – 15.5 cm) (Mater et al. 2001); Portugal (10 – 19.2 cm) (Borges et al. 2003); and Crimea in the Black Sea (7.1 – 19.2 cm) (Melnikova & Kuzminova 2022) and Ordu in the Black Sea (11.5 – 23.5 cm) (Karadurmuş et al. (2022). Parameters of the morphometric regression revealed that correlation coefficient values (R^2) of the TL/MBH1 are found to be greater than 0.800, similar to the findings in the study of *S. flexuosom* in Egyptian coastal waters (Rizkalla 1996) (BD/TL) > 0.900. Similar to this study, significant correlation of the morphological data was also found between the standard length and body depth of *Spicara flexuosum* in Turan (2011).

Descriptive statistics and variation coefficient of each morphometric character of *S. flexuosum* showed that most variable characters are the head length, maximum body height one and the eye diameter. Karadurmuş et al. (2022) investigated sexual dimorphism and some morphometric characters of *S. flexuosum* along the coast of the Black Sea. It was found that eye diameter (V.C. 9.17% for females and V.C. 6.17% for males) was the most variable character for both females and males, similar to the results in the current study (V.C. 16.13%). However unlike the results of the current study of the variation of the head length (V.C 17.7%), little variation was observed of the head length of *Spicara flexuosum* specimens in the Black Sea region (Karadurmuş et al. 2022) for males (V.C 2.62%) and females (V.C. 3.20%). This result could be related to the different sampling locations and the time of the sampling. Head- and eye-related morphological differences have been previously observed according to habitat differences (physical characteristics of each habitat, e.g. water temperature, current, also chemical characteristics, e.g. O_2, water clarity (Shuai et al. 2018) and also by feeding behaviour and diet conditions between different fish populations from the Eastern Atlantic and the Mediterranean (Palma & Andrade 2002). Different head morphology exhibited by different populations of the same species indicated the utilisation of different ecological niches (Hyndes et al. 1997). According to Chiba et al. (2009), many morphological characters were evolved in Sparidae family members as a result of adaptive radiation of various habitats, and this concept was important the evolution and distribution of Sparid members, including *Spicara* species. Several studies from the literature revealed that eye diameter, head length and body depth characteristics were the most variable characteristics and distinctions of fish stocks both among *Spicara maena* and *S. flexuosum* (Kuzminova & Martemyanova 2020) *Scorpaena* spp. (Yedier and Bostancı 2021), Sparids (Palma & Andrade 2002, Delariva & Agostinho 2001) and intraspecific variation of fish species *Pomatomus saltatrix* (Bal et al. 2021), African freshwater fish (Turan et al. 2005), and European anchovy (Khan et al. 2022).

The results from this study indicated that the most important ratio of the morphometric characters from PCA were HL/IO and HL/ED for PCA 1, MBH2/HH and HL/IO for PCA 2, and HL/ED and HH/HL for PCA 3. Similar to Minos et al. (2013), no significant morphometric differences results were observed between the sexes of the same species in this study. Similar to current study result, HH/HL was also found to be an informative characteristic for interspecies discrimination of two species of *Spicara* (*Spicara maena* and *Spicara flexuosa*) as previously stated by Minos et al. (2013) and Kuzminova & Martemyanova (2020). HL, ED, IO, MBH1 and MBH2 values were also found to be informative characteristics of different stocks of *Spicara smaris* whose populations absent from significant gender differences in the North Aegean Sea (Vidalis et al. 1997).

Finally, current results from morphometric analysis indicate the existence of two morphologically differentiated groups of *Spicara flexuosum*. First group composed of Istanbul and Yalova (from Marmara Sea) and the second one consisted of Izmir, Mersin and Antalya (Aegean and Mediterranean Sea) populations whose distances were almost proportional to the geographical distances between the sampling localities. Thus, the results obtained from this study could be related to the differences in the environmental conditions, such as temperature, pH, turbidity, habitat (Wimberger 1992, Turan et al. 2005, Crow et al. 2007, Shuai et al. 2018) spawning sites, and homing behaviour (Danancher & Garcia-Vazquez 2011), as previously observed in the literature.

The Turkish Strait System, specifically the Dardanelles Strait, could have been instrumental in the observed differentiation. Significant hydrographical differences, in particular physical barriers (currents, water velocity and temperature) (Zheng et al. 2001, Shuai et al. 2018) between the Marmara, the Aegean and the Eastern Mediterranean seas could have an influence on the morphological variation and distribution of this fish species. Overall, fish functional morphological traits were understood to be influenced by physical properties of water, such as flow and temperature within fresh water (Chapman et al. 2015, Shuai et al. 2018) and salinity differences among marine water habitat (Winans 1984, Vidalis et al. 1997, Erdoğan et al. 2009). The spatial distribution of fish species was previously investigated in different fish species populations in three different seas in Turkish coastal waters, and most of the studies reported that species from the Black Sea populations were separated from the Marmara, Aegean and the Mediterranean Sea (Turan et al. 2006, Yedier & Bostancı 2021, Bal et al. 2021).

5. Conclusion

The results from this study indicated that Izmir, Mersin, Antalya on the one hand; and Istanbul, Yalova populations on the other, were clustered and more closely related to each other. Geographical isolation of each sub group from the Marmara (Istanbul, Yalova), the Aegean (Izmir) and the Mediterranean (Mersin, Antalya) was also observed among these samples within the morphometric results. As a result of this, these populations might be considered as separate stocks for fisheries management purposes. Regarding morphometric characteristics, the head length, eye diameter, and interorbital distance were determined to be promising tools for the population structure of *S. flexuosum* (both female and male individuals) along the Turkish coast. Further morphometric traits related to the tail and the caudal peduncle should be necessary tools for morphometric studies for the fisheries management purposes for this genus.

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Conflict of Interest

The author has no relevant financial or nonfinancial interests to disclose. The author has no conflict of interest to declare that is relevant to the content of this article.

Data availability statement

All data are found in the main text and the supplementary file.

Ethical approval

The work raises no ethical issues. All fish examined were from commercial fishing activities and none of them were killed for the specific purpose of the study.

References

Avşar, D. (2016). Balıkçılık Biyolojisi ve Populasyon Dinamiği [Fisheries Biology and Population Dynamics]. Nobel Press. (In Turkish) https://doi.org/10.37609/akya.561

Aydın, M., & Bodur, B. (2021). Morphologic Characteristics and Length-Weight Relationships of *Sciaena umbra* (Linnaeus, 1758) in the Black Sea Coast. *Marine Science and Technology Bulletin, 10*(1), 8–15. https://doi.org/10.33714/masteb.738661

Aydın, M., & Öztürk, R. Ç. (2021). Biometrics Characters, Length-Weight Relationships and Genetic Properties of Damselfish, *Chromis chromis* (Linnaeus, 1758) (Osteichthyes: Pomacentridae) from the Black Sea. *Acta Aquatica Turcica, 17*(2), 186–194. https://doi.org/10.22392/actaquatr.788314

Bagenal, J. B., & Tesch, F. W. (1978). Methods for assessment of fish production in freshwaters (3rd ed.). Blackwell Science Publications.

Bal, H., Yanık, T., & Türker, D. (2021). Assessment of morphological variation between stocks of bluefish, *Pomatomus saltatrix* (Actinopterygii, Perciformes, Pomatomidae), in the Aegean Sea, Black Sea, and Sea of Marmara. *Acta Ichthyologica et Piscatoria, 51*(1), 85–94. https://doi.org/10.3897/aiep.51.63319

Bauchot, M. L. (1987). Poissons osseux. In W. Fischer, M. L. Bauchot, & M. Schneider (Eds.), Fiches FAO d'identification pour les besoins de la pêche. (rev. 1). Méditerranée et mer Noire. Zone de pêche 37 (Vol. II, pp. 891–1421). Commission des Communautés Européennes and FAO. (In French)

Bears, H., Drever, M. C., & Martin, K. (2008). Comparative morphology of dark eyed juncos *Junco hyemalis* breeding at two elevations: A common aviary experiment. *Journal of Avian Biology, 39*, 152–162. https://doi.org/10.1111/j.2008.0908-8857.04191.x

Borges, T. C., Olim, S., & Erzini, K. (2003). Weight–length relationships for fish species discarded in commercial fisheries of the Algarve (southern Portugal). *Journal of Applied Ichthyology, 19*(6), 394–396. https://doi.org/10.1111/j.1439-0426.2003.00480.x

Cadrin, S. X., Karr, L. A., & Mariani, S. (2014). Stock identification methods: an overview. In S. X. Cadrin, L. A. Kerr, & S. Mariani (Eds.), Stock Identification Methods. Elsevier, 32 Jamestown Road, London NW1 7BY, UK, 225 Wyman Street, Waltham, MA 02451, USA, 525 B Street, Suite 1800, San Diego, CA 92101-4495 (pp. 1–5)., https://doi.org/10.1016/B978-0-12-397003-9.00001-1

Chapman, B. B., Hulthén, K., Brönmark, C., Nilsson, P. A., Skov, C., Hansson, L. A., & Brodersen, J. (2015). Shape up or ship out: Migratory behaviour predicts morphology across spatial scale in a freshwater fish. *Journal of Animal Ecology, 84*(5), 1187–1193. https://doi.org/10.1111/1365-2656.12374 PMID:25823702

Chiba, S. N., Iwatsuki, Y., Yoshino, T., & Hanzawa, N. (2009). Comprehensive phylogeny of the family Sparidae (Perciformes: Teleostei) inferred from mitochondrial gene analyses. *Genes & Genetic Systems, 84*(2), 153–170. https://doi.org/10.1266/ggs.84.153 PMID:19556709

Crow, K. D., Munehara, H., Kanamoto, Z., Balanov, A., Antonenko, D., & Bernardi, G. (2007). Maintenance of species boundaries despite rampant hybridization between three species of reef fishes (Hexagrammidae): Implications for the role of selection. *Biological Journal of the Linnean Society. Linnean Society of London, 91*(1), 135–147. https://doi.org/10.1111/j.1095-8312.2007.00786.x

Dalgıç, G., Ergün, I. O., Onay, H., & Ceylan, Y. (2021). Determination of some biological characteristics and population parameters of the blotched picarel (*Spicara flexuosa* Rafinesque, 1810) distributed in the Eastern Black Sea (Rize – Hopa). *Marine Science and Technology Bulletin, 10(2)*, 142–153. https://doi.org/10.33714/masteb.814299

Danancher, D., & Garcia-Vazquez, E. (2011). Genetic population structure in flatfishes and potential impact of aquaculture and stock enhancement on wild populations in Europe. *Reviews in Fish Biology and Fisheries, 21*(3), 441–462. https://doi.org/10.1007/s11160-011-9198-6

Delariva, R. L., & Agostinho, A. A. (2001). Relationship between morphology and diets of six neotropical loricariids. *Journal of Fish Biology, 58*(3), 832–847. https://doi.org/10.1111/j.1095-8649.2001.tb00534.x

Erdoğan, 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 Adriatica, 50*(1), 77–90.

Firmat, C., Schliewen, U. K., Losseau, M., & Alibert, P. (2012). Body shape differentiation at global and local geographic scales in the invasive cichlid *Oreochromis mossambicus. Biological Journal of the Linnean Society. Linnean Society of London, 105*(2), 369–381. https://doi.org/10.1111/j.1095-8312.2011.01802.x

Froese, R., & Pauly, D. (Eds.). (2022). FishBase. World Wide Web electronic publication. Retrieved on February 17, 2022, from http://www.fishbase.org

Golani, D., Öztűrk, B., & Başusta, N. (2006). Centracanthidae. In D. Golani, B. Öztürk, & N. Başusta (Eds.), Fishes of the eastern Mediterranean (pp. 168–169). Turkish Marine Research Foundation.

Hammer, Ø., Harper, D. A. T., & Ryan, P. D. (2001). Past: Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologia Electronica, 4*(1), 4–9. http://palaeo-electronica.org/2001_1/past/issue1_01.htm

Hyndes, G., Platell, M., & Potter, I. (1997). Relationships between diet and body size, mouth morphology, habitat and movements of six *Sillaginid* species in coastal waters: Implications for resource partitioning. *Marine Biology, 128*(4), 585–598. https://doi.org/10.1007/s002270050125

Iglésias, S. P. (2014). Handbook of the marine fishes of Europe and adjacent waters (A natural classification based on collection specimens, with DNA barcodes and standardized photographs) (Vol. II). Actinopterygians., http://iccanam.mnhn.fr, Retrieved February 20, 2018, from.

İşmen, A., Özen, Ö., Altınağaç, U., Özekinci, U., & Ayaz, A. (2007). Weight-length relationships of 63 fish species in Saros Bay, Turkey. *Journal of Applied Ichthyology, 23*(6), 707–708. https://doi.org/10.1111/j.1439-0426.2007.00872.x

Karadurmuş, U., Ustaoğlu, D., & Aydın, M. (2022). Sex Inversion, Sexual Dimorphism, and Morphological Differences of *Spicara flexuosa* (Sparidae). *Journal of Ichthyology, 62*(5), 777–785. https://doi.org/10.1134/S0032945222050058

Keskin, Ç. (2010). A review of fish fauna in the Turkish Black Sea. *Journal of the Black Sea/Mediterranean Environment, 16*(2), 195–210.

Keskin, Ç., Turan, C., & Ergüden, D. (2011). Distribution of the demersal fishes on the continental shelves of the Levantine and North Aegean Seas (Eastern Mediterranean). *Turkish Journal of Fisheries and Aquatic Sciences, 11*(3), 413–423. https://doi.org/10.4194/trjfas.2011.0311

Khaefi, R., Teimori, A., & Esmaeili, H. R. (2017). Phylogenetic relationships and taxonomy of *Luciobarbus barbulus* (Heckel, 1847) (Teleostei: Cyprinidae). *Journal of Ichthyology, 57*(6), 835–845. https://doi.org/10.1134/S0032945217060078

Khaefi, R., Esmaeili, H. R., & Chermahini, M. A. (2018). Natural hybridization of *Luciobarbus barbulus* x *Luciobarbus kersin* and *Luciobarbus barbulus* x *Luciobarbus xanthopterus* in the Persian Gulf Basin. *Turkish Journal of Fisheries and Aquatic Sciences, 18*(12), 1399–1407. https://doi.org/10.4194/1303-2712-v18_12_08

Khan, U., Bal, H., Battal, Z. S., & Seyhan, K. (2022). Using otolith and body shape to discriminate between stocks of European anchovy (Engraulidae: *Engraulis encrasicolus*) from the Aegean, Marmara and Black Seas. *Journal of Fish Biology, 101*(6), 1452–1465. https://doi.org/10.1111/jfb.15216 PMID:36097416

Kuzminova, N., & Martemyanova, K. (2020). Distinctive features of species of *Spicara* genus in Sevastopol coastal area. *Eurasian Journal of Biological and Chemical Sciences, 3*(1), 189–194.

Mater, S., Malkav, S., & Şahinoğlu-Bayhan, B. (2001). A study on some biological peculiarities of the picarel *Spicara flexuosa* Rafinesque, 1810 distributed in the bay of Izmir Aegean Sea. *Su Urünleri Dergisi, 18*(1-2), 25–32.

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 (Jena, Germany), 115*(4), 239–244. https://doi.org/10.1016/j.zool.2012.02.002 PMID:22749615

Melnikova, E. B., & Kuzminova, N. (2022). Comparative characteristics of individual growth of *Spicara flexuosa* and *Spicara maena* (Pisces: Centracanthidae) inhabiting the south-western shelf of Crimea, Black Sea. *Journal of Survey in Fisheries Sciences, 8*(3), 17–31. https://doi.org/10.18331/SFS2022.8.3.2

Minos, G., Imsiridou, A., & Katselis, G. (2013). Use of morphological differences for the identification of two picarel species *Spicara flexuosa* and *Spicara maena* (Pisces: Centracanthidae). *Mediterranean Marine Science, 14*(3), 26–31. https://doi.org/10.12681/mms.423

Palma, J., & 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), 1–8. https://doi.org/10.1016/S0165-7836(01)00335-6

Perdana, A. W., Batubara, A. S., Nur, F. M., Syahril, A., & Muchlisin, A. (2021). Morphometric analysis of three species gourami group (Osphronemidae) from Aceh waters, Indonesia.

IOP Conf. Series: *Earth and Environmental Science, 674*, 012087. IOP Publishing https://doi.org/10.1088/1755-1315/674/1/012087

Pigliucci, M. (2005). Evolution of phenotypic plasticity: Where are we going now? *Trends in Ecology & Evolution, 20*(9), 481–486. https://doi.org/10.1016/j.tree.2005.06.001 PMID:16701424

Rawat, S., Benakappa, S., Kumar, J., Naik, K., Pandey, G., & Pema, C. (2017). Identification of fish stocks based on truss morphometric: A review. *Journal of Fisheries and Life Sciences, 2*(1), 9–14.

Reist, J. D. (1986). An empirical evaluation of coefficients used in residual and allometric adjustment of size covariation. *Canadian Journal of Zoology, 64*(6), 1363–1368. https://doi.org/10.1139/z86-203

Rizkalla, S. I. (1996). A comparative study on the morphometric characters of fishes belonging to family: Centracanthidae in the Egyptian Mediterranean waters. *Journal of the Faculty of Marine Science (Jeddah), 7*(1), 255–261. https://doi.org/10.4197/mar.7-1.22

Salekhova, L. P. (1979). *Centracanthidae fishes of the genus* Spicara *from the Mediterranean and Black Sea. Haykova-Dumka*. Kiev Academy of the Science.

Shuai, F., Yu, S., Lek, S., & Li, X. (2018). Habitat effects on intra-species variation in functional morphology: Evidence from freshwater fish. *Ecology and Evolution, 8*(22), 10902–10913. https://doi.org/10.1002/ece3.4555 PMID:30519416

Siddik, M., Chaklader, M., Hanif, M., Islam, M., Sharker, M., & Rahman, M. (2016). Stock identification of critically endangered olive barb, *Puntius sarana* (Hamilton, 1822) with emphasis on management implications. *Journal of Aquaculture Research & Development, 7*(2), 1–6. https://doi.org/10.4172/2155-9546.1000411

Snoeks, J. (2004). The Cichlid Diversity of Lake Malawi/Nyasa/Niassa: Identification, Distribution and Taxonomy (1st ed.). Cichlid Press.

Soykan, O., İlkyaz, A. T., Metin, G., & Kınacıgil, H. T. (2010). Growth and reproduction of blotched picarel (*Spicara maena* Linneaus. 1758) in the central Aegean Sea. Turkey. *Turkish Journal of Zoology, 34*(4), 453–459. https://doi.org/10.3906/zoo-0903-29

Şalcioğlu, A., Gubili, C., Krey, G., Sakinan, S., & Bilgin, R. (2021). Molecular characterization and phylogeography of Mediterranean picarels (*Spicara flexuosa, S. maena* and *S. smaris*) along the coasts of Turkey and the Eastern Mediterranean. *Regional Studies in Marine Science, 45*(6), 101836. https://doi.org/10.1016/j.rsma.2021.101836

Şalcioğlu, A. Ş., & Sönmez, A. Y. (2022). Length-weight relationships and relative condition factor of *Spicara flexuosum* (Rafinesque, 1810) inhabiting the Black Sea and the Turkish Straits System. *Marine Science and Technology Bulletin, 11*(3), 271–279. https://doi.org/10.33714/masteb.1146686

Tortonose, E. (1986). Centracanthidae. In Fish of the North-eastern Atlantic and Mediterranean (Whitehead, P. J. P., Bauchot, M. L., Hureau, J. C., Nielsen, J. and Tortonese, E., eds), Paris: UNESCO, 2, pp. 908–911.

Turan, C., Oral, M., Öztürk, B., & Düzgünes, E. (2006). Morphometric and meristic variation between stocks of bluefish (*Pomatomus saltatrix*) in the Black, Marmara, Aegean and Northeastern Mediterranean Seas. *Fisheries Research, 79*(1-2), 139–147. https://doi.org/10.1016/j.fishres.2006.01.015

Turan, C., Yalcin, S., Turan, F., Okur, E., & Akyurt, I. (2005). Morphometric comparisons of African catfish, *Clarias gariepinus*, populations in Turkey. *Folia Zoologica, 54*(1-2), 165–172.

Turan, C. (2011). The systematic status of the Mediterranean *Spicara* species (Centracanthidae) inferred from mitochondrial 16s rDNA sequence and morphological data. *Journal of the Black Sea/Mediterranean Environment, 17*(1), 14–31.

Vasilieva, E. D., & Salekhova, L. P. (1983). The precision of diagnoses of the *Spicara* (Perciformes, Centracanthidae) species based on osteological features. *Zoological Journal, 62*(7), 1044–1056.

Vidalis, K., Markakis, G., & Tsimenides, N. (1997). Discrimination between populations of picarel *Spicara smaris* L., 1758) in the Aegean Sea, using multivariate analysis of phenetic characters. *Fisheries Research, 30*(3), 191–197. https://doi.org/10.1016/S0165-7836(96)00571-1

Ward, J. H., Jr. (1963). Hierarchical grouping to optimize an objective function. *Journal of the American Statistical Association, 58*(301), 236–244. https://doi.org/10.1080/01621459.1963.10500845

Wimberger, P. H. (1992). Plasticity of fish body shape. The effects of diet, development, family and age in two species of *Geophagus* (Pisces: Cichlidae). *Biological Journal of the Linnean Society. Linnean Society of London, 45*(3), 197–218. https://doi.org/10.1111/j.1095-8312.1992.tb00640.x

Winans, G. A. (1984). Mutivariate morphometric variability in Pasific salmon-technical demonstration. *Canadian Journal of Fisheries and Aquatic Sciences, 41*(8), 1150–1159. https://doi.org/10.1139/f84-136

Yedier, S., & Bostanci, D. (2021). Intra- and interspecific discrimination of *Scorpaena* species from the Aegean, Black, Mediterranean and Marmara seas. *Scientia Marina, 85*(3), 197–209. https://doi.org/10.3989/scimar.05185.018

Zheng, X. D., Wang, R. C., Wang, X. F., Xiao, S., & Chen, B. (2001). Genetic variation in populations of the common Chinese cuttlefish *Sepiella maindroni* (Mollusca: Cephalopoda) using allozymes and mitochondrial DNA sequence analysis. *Journal of Shellfish Research, 20*(3), 1159–1165.

Zei, M. (1941). Studies on the morphology and taxonomy of the Adriatic species of Maenidae. *Acta Adriatica, 2*(4), 1-189.

Supplementary Table 1

Descriptive statistics and variation coefficient of each morphometric characters of *S. flexuosum*

Metric characters	Min.	Max.	Mean	SD	SE	VC
SL	9.03	16.1	11.79	1.39	0.13	11.84
HH	2.05	4.12	2.79	0.44	0.04	15.8
HL	2.34	4.55	3.13	0.56	0.05	17.7
MBH1	2.7	5.1	3.608	0.59	0.06	16.41
MBH2	2.5	4.6	3.39	0.51	0.05	15.1
ED	0.8	1.55	0.97	0.15	0.01	16.13
IO	0.7	1.47	0.93	0.12	0.01	13.2
TL	11.04	17.27	14.22	1.72	0.16	12.13
HH/HL	0.7	1.12	0.89	0.08	0.01	9.08
MBH2/SL	0.24	0.36	0.28	0.02	0.001	7.34
TL/MBH1	3.2	4.93	3.98	0.28	0.02	7.27
HL/ED	2.5	5	3.25	0.44	0.04	13.56
HL/SL	0.21	0.33	0.26	0.02	0.002	9.5
HH/SL	0.2	0.29	0.23	0.01	0.001	8.01
MBH2/HH	0.93	1.5	1.22	0.10	0.009	8.41
HL/IO	2.5	5	3.330	0.478	0.044	14.37

Supplementary Table 2

Parameters of the morphometric regression, equation and correlation coefficient

Morphometric ratio	Regression equation	R^2
HL/SL	Y = 2.105x + 5.1944	0.702
HH/SL	Y = 2.7095x + 4.2273	0.736
MBH2/SL	Y = 2.3681x + 3.7576	0.756
MBH2/HH	Y = 0.7313x + 0.3787	0.679
TL/MBH1	Y = 2.6683x + 4.5953	0.838
HL/HH	Y = 0.6717x + 0.6866	0.712

Supplementary Table 3

Measurements of eight morphometric characters and their standard deviations of *S. flexuosum* among five locations

	HL	HH	MBH1	MBH2	SL	TL	ED	IO
Istanbul	3.88 ± 0.55	3.25 ± 0.44	3.99 ± 0.47	3.66 ± 0.45	13.28 ± 1.55	15.66 ± 1.63	1.22 ± 0.17	1.10 ± 0.15
Yalova	3.25 ± 0.35	3.09 ± 0.23	4.25 ± 0.33	3.95 ± 0.26	12.67 ± 0.63	15.88 ± 0.81	0.88 ± 0.04	0.89 ± 0.03
Mersin	2.92 ± 0.36	2.58 ± 0.30	3.34 ± 0.22	3.21 ± 0.26	11.11 ± 0.66	13.05 ± 0.80	1.00 ± 0.05	1.00 ± 0.05
Izmir	2.75 ± 0.17	2.44 ± 0.11	3.11 ± 0.13	3.01 ± 0.13	10.86 ± 0.52	12.90 ± 0.60	0.88 ± 0.04	0.89 ± 0.02
Antalya	2.74 ± 0.22	2.42 ± 0.17	3.03 ± 0.26	2.85 ± 0.20	10.52 ± 0.66	12.76 ± 0.43	0.88 ± 0.04	0.85 ± 0.06

Supplementary Table 4

The ratio of morphometric characters and their standard deviations of *S. flexuosum* among five locations

	HL/SL	HH/SL	HH/HL	MBH2/SL	TL/MBH1	HL/ED	MBH2/HH	HL/IO
Istanbul	0.29 ± 0.02	0.24 ± 0.02	0.84 ± 0.07	0.27 ± 0.01	3.93 ± 0.18	3.20 ± 0.35	1.13 ± 0.09	3.54 ± 0.10
Yalova	0.25 ± 0.02	0.24 ± 0.01	0.95 ± 0.07	0.31 ± 0.01	3.74 ± 0.21	3.67 ± 0.48	1.28 ± 0.10	3.67 ± 0.49
Mersin	0.26 ± 0.02	0.23 ± 0.01	0.89 ± 0.09	0.28 ± 0.01	3.90 ± 0.15	2.92 ± 0.34	1.25 ± 0.10	2.92 ± 0.34
Izmir	0.25 ± 0.01	0.22 ± 0.01	0.89 ± 0.31	0.27 ± 0.01	4.15 ± 0.23	3.10 ± 0.19	1.23 ± 0.06	3.08 ± 0.21
Antalya	0.26 ± 0.01	0.23 ± 0.01	0.88 ± 0.05	0.27 ± 0.01	4.22 ± 0.33	3.10 ± 0.23	1.04 ± 0.07	3.23 ± 0.27