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Intra- and interspecific discrimination of *Scorpaena* species from the Aegean, Black, Mediterranean and Marmara seas

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Summary: This study was conducted to discriminate five *Scorpaena* species and populations of each species according to morphometric characters. A total of 1865 fish specimens were collected from the eight locations in the four Turkish seas: Antalya, Balıkesir, Çanakkale, Hatay, İzmir, Marmara Ereğlisi, Ordu and Şile. In the study, 26 morphometric traits were measured for intra- and interspecific discrimination of five *Scorpaena* species. The data were subjected to analysis of variance, principal components analysis (PCA) and canonical discriminant analysis. As results of the PCA, 10 traits for *S. maderensis* and *S. scrofa,* 12 traits for *S. elongata* and 13 traits for *S. notata* and *S. porcus* were found to be important for intraspcific discrimination. The overall classification scores of intraspecific discrimination were determined as 94.6% for *S. elongata*, 90.5% for *S. maderensis*, 96.7% for *S. notata*, 96.5% for *S. porcus* and 92.2% for *S. scrofa*. The PCA indicated that 13 morphometric measurements among the 26 traits are important in the interspecific discrimination of five *Scorpaena* species. The cross-validated canonical discriminant analysis was correctly classified as 97.4% at the *Scorpaena* species level. The discrimination of correctly classified species ranged from 94.8% to 100%. Finally, we demonstrated that the morphometric characters examined in the present study can be used successfully in the intra- and interspecific discrimination of *Scorpaena* species from different habitats.

Keywords: *Scorpaena*; morphometric; intra- and interspecific; discriminant analysis; four seas.

Discriminaciones intra e interespecies: especies de *Scorpaena* del mar Negro, el mar Egeo, el mar de Mármara y Mediterráneo

Resumen: Este estudio se realizó para discriminar cinco especies de *Scorpaena* y poblaciones de cada especie en función de los caracteres morfométricos. Se recolectaron un total de 1865 especímenes de peces de los ocho lugares como Antalya, Balıkesir, Çanakkale, Hatay, İzmir, Marmara Ereğlisi, Ordu y Şile en los cuatro mares turcos. En el estudio, se midieron 26 rasgos morfométricos para discriminaciones intra e interespecies de cinco especies de *Scorpaena*. Los datos se sometieron a ANOVA, análisis de componentes principales (PCA) y análisis discriminante canónico (CDA). Como resultado del PCA, 10 rasgos para *S. maderensis* y *S. scrofa*, 12 rasgos para *S. elongata*, 13 rasgos para *S. notata* y *S. porcus* son importantes para la discriminación intraespecífica. Las puntuaciones generales de clasificación de discriminación intraespecífica se determinaron como 94,6% para *S. elongata*, 90,5% para *S. maderensis*, 96,7% para *S. notata*, 96,5% para *S. porcus* y 92,2% para *S. scrofa*. La PCA indicó que 13 medidas morfométricas entre los 26 rasgos son importantes en la discriminación interespecífica de cinco especies de *Scorpaena*. El análisis discriminante canónico con validación cruzada clasificó correctamente como 97,4% a nivel de la especie *Scorpaena*. La discriminación de especies correctamente clasificadas osciló entre 94,8 y 100%. Finalmente, demostramos que los caracteres morfométricos examinados en el presente estudio se pueden utilizar con éxito en las discriminaciones intra e interespecies de especies de *Scorpaena* de diferentes hábitats.

Palabras clave: *Scorpaena*; morfométrico; intra e interespecies; análisis discriminante; cuatro mares.

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INTRODUCTION

There are more than 32000 species of fish, accounting for over half of all vertebrate animals (Nelson et al. 2016). They are dispersed over wide geographic areas, and the environmental conditions can affect traits such as reproduction, fertility and longevity (Rawat et al. 2017). The situations experienced by fish species in their life cycle may also affect their morphometric characteristics. Variations in growth, development and maturation of fish caused by environmental factors cause differences in body shape even within the same genus and species (Cadrin 2000). Information on stock structure, species identification and differentiation is useful for developing management strategies that will help conserve biodiversity associated with species, subspecies, and stocks (Turan et al. 2005, Cadrin et al. 2014). Furthermore, identifying the intra- and interspecific differences/similarities of fish with variable life history characteristics is quite important for understanding population dynamics and evaluating sustainable harvests (Turan et al. 2005, Cadrin et al. 2014). There is also a need to determine how many stocks are managed in a given area and clarify how different stocks are susceptible to fishing pressure and unfavourable environmental conditions (Baldwin et al. 2012). Since genotypic and phenotypic differentiation between fish populations that occurs due to isolation may lead to speciation or the formation of a different population, it is important to examine the degree of differentiation at both the intra- and interspecific levels. Morphometric analyses have been used for inter- and intraspecific identification/distinction of many freshwater and marine fish species. such as *Rastrelliger kanagurta* from peninsular India (Jayasankar et al. 2004), *Clarias gariepinus* from Turkey (Turan et al. 2005), *Pomatomus saltatrix* from the Aegean, Black, and Mediterranean seas (Turan et al. 2006), the genus *Puntius* from Assam, India (Choudhury et al. 2011), *Catla catla* from India (Ujjainia and Kohli 2011), rattail fish from New Zealand (Ibáñez and Jawad 2018), *Barbonymus* spp. from Aceh, Indonesia (Batubara et al. 2018) and *Macrognathus pancalus* from Bangladesh (Mahfuj et al. 2019a).

The family Scorpaenidae includes approximately 23 genera (from 210 to 223 species) distributed both in marine and freshwater waters at medium and great (more than 700 m) depths in a variety of aquatic habitats (Froese and Pauly 2020). Scorpaenid systematics are complicated and unsettled (Froese and Pauly 2020). Arculeo and Lo Brutto (2014) and Akalın et al. (2011) indicated that many species of the Scorpaenidae families are quite difficult to define morphologically because small individuals especially are very similar and the characters for describing species are not easy to use. The family includes many fish species that are mostly found in marine waters but rarely spread to freshwaters. One of the popular genera in the family Scorpaenidae is the *Scorpaena* genus. Currently, six valid species are recognized in this genus from the Turkish coasts; the black scorpionfish (*S. porcus* Linnaeus, 1758) and the small red scorpionfish (*S. notata* Rafinesque, 1810) in the Aegean, Black, Mediterranean and Marmara seas; the slender rockfish (*S. elongata* Cadenat, 1943), the Madeira rockfish (*S. maderensis* Valenciennes, 1833) and Cadenat's rockfish (*S. loppei* Cadenat, 1943) from the Mediterranean Aegean seas; and the red scorpionfish (*S. scrofa* Linnaeus, 1758) from the Agean, Mediterranean and Marmara seas. Five species belonging to the *Scorpaena* genus are reported in large numbers in Turkish waters, but *S. loppei* is reported in very few numbers (Keskin and Eryılmaz 2009).

Many studies have provided detailed information with diagnostic features on the distribution and biology of *Scorpaena* species (Hureau and Litvinenko 1986, Fischer et al. 1987, Morato et al. 2001). However, no detailed study has been made on the discrimination of *Scorpaena* species in Turkish marine waters, and only a few studies have been made on Scorpaeniformes species in the Mediterranean Sea. These studies were addressed using cytogenetics (Caputo et al. 1998), meristic characters and genetic analysis of the mitochondrial 16S rDNA gene (Turan et al. 2009). The literature includes a limited number of morphometric studies of the genus *Scorpaena*, but no morphology-based study in which intra- and interspecific comparisons were made together. The present study was therefore undertaken to investigate the intra- and interspecific discrimination of five *Scorpaena* species (*S. elongata, S. maderensis, S. notata, S. porcus* and *S. scrofa*) inhabiting the Aegean, Black, Mediterranean and Marmara seas on the basis of morphometric characters.

MATERIALS AND METHODS

Ethical statement

All protocols for fish capture were approved by the Turkish Agricultural Research and Policy General Directorate. The care and use of experimental animals complied with Ordu University Animal Experiments Local Ethics Committee animal welfare laws, guidelines and policies, as approved by the Ordu University Animal Experiments Local Ethics Committee (No:82678388/08).

Sampling

Fish samples were collected during the 2019-2020 fishing season from the eight locations along the coastline of Turkey's four seas (Fig. 1); İzmir (Aegean Sea), Antalya and Hatay (Mediterranean Sea) for *S. elongata*; Antalya (Mediterranean Sea), Balıkesir and İzmir (Aegean Sea) for *S. maderensis*; İzmir (Aegean Sea), Hatay (Mediterranean Sea), Marmara Ereğlisi (Sea of Marmara) and Şile (Black Sea) for *S. notata*; İzmir (Aegean Sea), Hatay (Mediterranean Sea), Marmara Ereğlisi (Sea of Marmara) and Ordu (Black Sea) for *S. porcus*; and Çanakkale (Sea of Marmara), İzmir (Aegean Sea) and Hatay (Mediterranean Sea) for *S. scrofa.* All samples were preserved and fixed in 70% ethanol and deposited at Ordu University.

Fig. 1. – Sampling locations of *Scorpaena* spp. from the Aegean, Black, Mediterranean and Marmara seas.

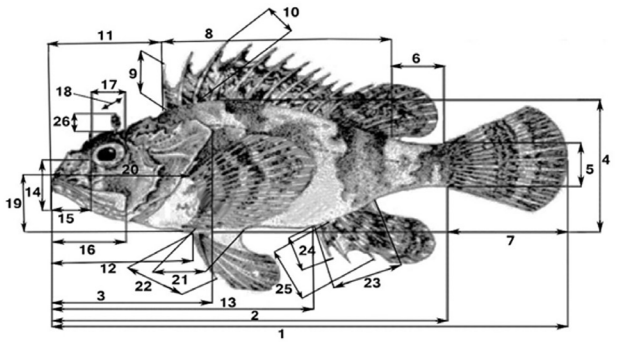

Fig. 2. – Morphometric measurements used in this study on *Scorpaena* sp. (Ferri et al. 2010, modified).

Morphometric analysis

A total of 26 metric measurements were used: total length (TL) (1), standard length (SL) (2), head length (HL) (3), body height (BL) (4), caudal peduncle height (CPH) (5), caudal peduncle length (CPL) (6), caudal fin length (CL) (7), dorsal fin base length (DBL) (8), shortest dorsal fin spine length (SDL) (9), longest dorsal fin spine length (LDL) (10), predorsal length (PDL) (11), preventral length (PVL) (12), preanal length (PAL) (13), preorbital height (POH) (14), snout length (NL) (15), maxilla length (ML) (16), eye diameter (ED) (17), interorbital distance (IOD) (18), pectoral fin base length (PBL) (19), prepectoral length (PPL) (20), ventral fin base length (VBL) (21), ventral fin spine length (VSL) (22), anal fin base length (ABL) (23), shortest anal fin spine length (SAL) (24), longest anal fin spine length (LAL) (25) and supraocular tentacle length (STL) (26) (Fig 2). These metric measurements from each individual were taken on the left side of the fish body by the same researcher using a digital caliper (±0.01 mm) and a millimetre ruler (±0.1 cm). The sex of each fish sample was determined by internal inspections after the morphometric measurements had been obtained.

Statistical analysis

The data were tested for normality and homogeneity of variances using the Kolmogorov-Smirnov (K-S) test and the Levene test, respectively. In addition, we investigated whether there was a difference between the data of male and female individuals. An analysis of variance (ANOVA) with Tukey comparisons of morphometric characters was conducted to test for variation among populations and species. Moreover, before running further analysis, the size effects of all morphometric variables were eliminated, as described by Elliott et al. (1995). The equation is as follows: $M_{adj}=M(L_s/L_o)^b$, where M is the original value of the morphometric measure, M_{adj} is the adjusted size of the measure, L_o is the standard length of the fish and L_s is the mean of the standard length of all fish. The parameter b was estimated for each character from the observed data of slope of the regression of logM in $logL_o$, using all fishes. Size-adjusted data were subjected to principal component analysis (PCA) and canonical discriminant analysis (CDA) to identify intra- and interspecific differences of the five *Scorpaena* species. Large factor loadings (positive or negative) of PCA indicate that a particular variable has a strong relationship to a particular principal component. Loadings of at least 0.3 magnitude were taken into account when making intra- and interspecific distinctions. The UPGMA clustering method was used to generate a dendrogram for intra- and interspecific discrimination of the genus *Scorpaena* by computing the Euclidian distance values of morphometric measurements. Wilks' lambda (λ) was used

Table 1. – Descriptive statistics (Mean±SD) and ANOVA results of morphometric measurements of S. elongata populations.

Morphometric Measurements	Antalya (n=109)	Hatay (n=113)	İzmir (n=110)	ANOVA F values	ANOVA P values
TL (cm)	15.81±4.11[b]	14.10±2.72[c]	17.26±3.05[a]	24.98	0.001
SL (cm)	12.68±3.43[b]	11.23±2.25[c]	13.94±2.54[a]	26.64	0.001
HL (cm)	5.14±1.25[b]	4.71±0.94[c]	5.76±1.05[a]	26.22	0.001
BL (mm)	41.69±12.80[b]	36.30±8.06[c]	46.18±8.10[a]	27.93	0.001
CPH (mm)	12.18±3.65[a]	10.55±2.04[b]	12.21±2.21[a]	13.68	0.001
CPL (mm)	11.72±4.57[a]	9.73±1.59[b]	10.13±2.00[b]	13.52	0.001
CL (cm)	3.13±0.70[b]	2.89±0.54[c]	3.38±0.57[a]	17.86	0.001
DBL (cm)	7.64±2.05[b]	6.80±1.40[c]	8.39±1.52[a]	25.07	0.001
SDL (mm)	10.78±1.96[b]	10.79±1.82[b]	11.79±1.36[a]	12.31	0.001
LDL (mm)	21.34±5.11[b]	19.22±3.40[c]	23.18±3.79[a]	25.48	0.001
PDL (cm)	3.88±1.34[b]	3.70±0.62[b]	4.25±0.73[a]	9.56	0.001
PVL (cm)	5.21±1.33[b]	4.64±0.91[c]	5.66±1.01[a]	24.38	0.001
PAL (cm)	9.05±2.64[b]	8.39±1.61[c]	10.22±1.87[a]	21.96	0.001
POH (mm)	11.30±2.74[b]	10.30±1.99[c]	12.50±2.30[a]	24.26	0.001
NL (mm)	12.42±3.25[b]	11.37±2.15[c]	13.66±2.31[a]	21.54	0.001
ML (mm)	27.13±6.92[b]	24.29±4.47[c]	29.81±5.21[a]	27.04	0.001
ED (mm)	17.84±3.25[a]	17.11±2.41[a]	11.28±2.15[b]	203.03	0.001
IOD (mm)	6.26±1.14[a]	5.34±1.04[b]	6.50±1.12[a]	34.75	0.001
PBL (mm)	15.85±3.78[b]	14.60±2.51[c]	17.34±2.76[a]	22.31	0.001
PPL (cm)	5.02±1.64[b]	4.68±0.93[b]	5.69±1.04[a]	19.08	0.001
VBL (mm)	4.67±1.77[b]	3.95±1.25[c]	6.38±1.71[a]	68.56	0.001
VSL (mm)	18.77±3.56[b]	18.12±2.81[b]	19.97±2.69[a]	10.64	0.001
ABL (mm)	17.75±4.15[b]	16.37±2.79[c]	19.77±3.05[a]	28.62	0.001
SAL (mm)	8.04±1.48[b]	7.44±1.10[c]	8.74±1.18[a]	29.48	0.001
LAL (mm)	18.82±3.95[b]	17.60±2.69[c]	20.49±2.96[a]	22.34	0.001
STL (mm)	2.23±0.04[a]	2.14±0.03[a]	2.22±0.06[a]	1.16	0.314

Table 2. – Jackknife classification matrix of the discriminant canonical analysis applied to the three *S. elongata* populations from the coastline of Turkey's two seas.

	Predicted Group Membership		
Population	Antalya	İzmir	Hatay
Antalya	**91.7 (100)**	-	8.3 (9)
İzmir	-	**100.0 (110)**	-
Hatay	8.0 (9)		**92.0 (104)**
Overall: 94.6% of original grouped cases correctly classified.			

The correct classification percentages and numbers are in bold; the number of individuals is given in parentheses.

to evaluate both intra- and interspecific discrimination performance of the CDA. Interspecific and intraspecific variances, total variances and their percentages of agreement between real and predicted group membership were calculated for both the populations and *Scorpaena* species. Jackknife cross-validation procedures were used to validate similarities for both the populations and the species. All tests were conducted using the SPSS (V.21.0) and Past (V.2.17c).

RESULTS

Intraspecific discrimination

A total of 1865 fish individuals belonging to five species (*S. elongata, S. notata, S. maderensis, S. porcus* and *S. scrofa*) from the eight locations of the Aegean, Black, Mediterranean and Marmara seas were studied for morphometric analysis. The morphometric variables showed normality (P>0.05; K-S test) and homogeneous variance (P>0.05; Levene test). There was no statistically significant difference in terms of morphometric data between female and male individuals (P>0.05; t-test). For this reason, intra- and interspecific discrimination analyses were carried out by evaluating the data of male and female individuals together.

Scorpaena elongata

A total of 332 *S. elongata* individuals were sampled from the Antalya, İzmir and Hatay stations in the Aegean and Mediterranean seas. The descriptive analysis of morphometric measurements of *S. elongata* is presented in Table 1. The one-way ANOVA shows significant (P<0.05) differences in all the morphometric measurements (except for STL) among the *S. elongata* populations (Table 1). As a result of the PCA, it was determined that 12 morphometric measurements taken from the samples (body height, longest dorsal fin spine length, preanal length, preorbital height, snout length, maxilla length, eye diameter, pectoral fin base length, ventral fin base length, ventral fin spine length, anal fin base length and longest anal fin spine length) are quite important in the intraspecific distinction of the *S. elongata*. Morphometric ratios were calculated between these important morphometric characters and standard length for each *S. elongata* population (Supplementary Table S1). These morphometric measurements were selected for the CDA. It was determined that the first two functions are important for the CDA analysis performed for the *S. elongata* populations (F1[97.4%], λ=0.008, P<0.001; F2[2.6%], λ=0.420,

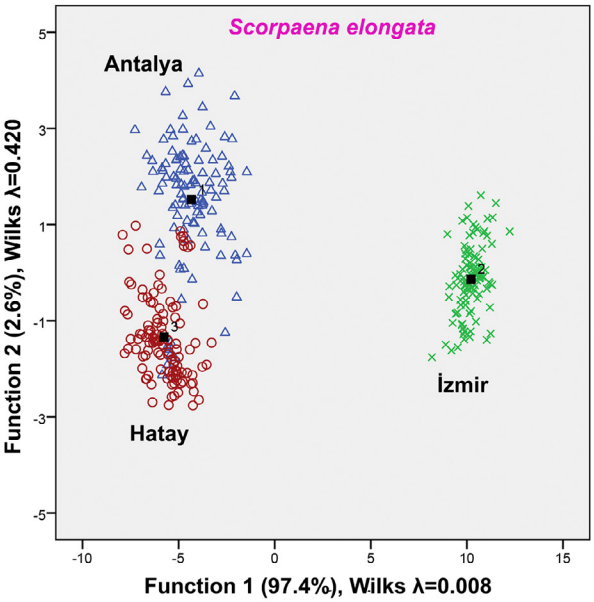

Fig. 3. – Intraspecific discrimination of *S. elongata* using morphometric characters.

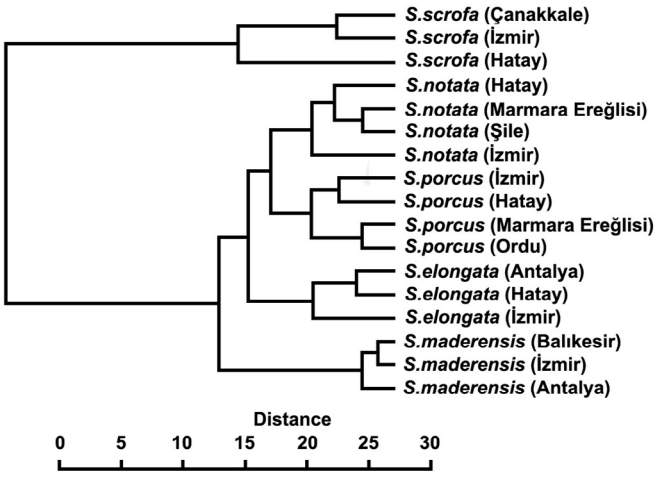

Fig. 4. – The intra- and interspecific dissimilarity of *Scorpaena* species based on the Euclidian distance of morphometric measurements by hierarchical cluster analysis (UPGMA).

P<0.001) (Fig 3). It was determined by CDA results that these 12 characters taken from the fish samples were quite effective for discriminating three *S. elongata* populations from each other and that they achieved 94.6% success in the intraspecific distinction of *S. elongata* (Table 2). *S. elongata* populations were clustered by hierarchical cluster analyses of meristic data. Antalya and Hatay were the closest *S. elongata* populations and İzmir the most divergent one (Fig. 4).

Scorpaena maderensis

A total of 326 *S. maderensis* individuals were sampled from the Antalya, Balıkesir and İzmir stations in the Aegean and Mediterranean seas. The descriptive analysis of morphometric measurements of *S. maderensis* is presented in Table 3. ANOVA revealed that there were significant (P<0.05) differences in the TL, SL, HL, BL, CPL, CL, SDL, LDL, PAL, POH, NL, VBL, ABL and LAL measurements among *S. maderensis* populations, and there was no statistically significant (P>0.05) difference in the CPH, DBL, PDL, PVL, ML, ED, IOD, PBL, PPL, VSL, SAL and STL measurements (Table 3). The PCA analysis indicated that ten morphometric measurements taken from the samples (body height, longest dorsal fin spine length, preanal length, preorbital height, maxilla length, caudal peduncle height, caudal peduncle length, pectoral fin base length, anal fin base length and longest anal fin spine length) are quite important in the intraspecific distinction of *S. maderensis*. Morphometric ratios were calculated between these important morphometric characters and standard length for each *S. maderensis* population (Supplementary Table S2). These morphometric measurements were selected for the CDA. It was determined that the first two functions were important for the CDA analysis performed for the *S. maderensis* populations

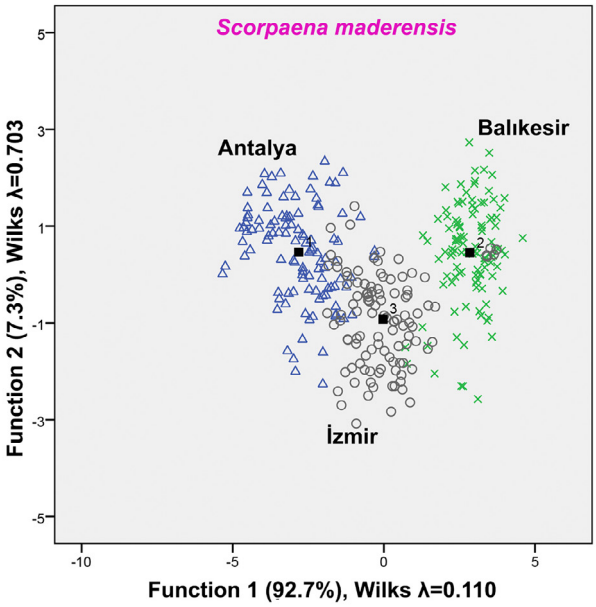

Fig. 5. – Intraspecific discrimination of *S. maderensis* using morphometric characters.

(F1 [92.7%], λ=0.110, P<0.001; F2[7.3%], λ=0.703, P<0.001) (Fig 5). The CDA results showed that these 10 characters taken from the fish samples were quite effective for discriminating three *S. maderensis* populations from each other and that they achieved 90.5% success in the intraspecific distinction of *S. maderensis* (Table 4). *S. maderensis* populations were clustered by hierarchical cluster analyses of meristic data. Balıkesir and İzmir were the closest *S. maderensis* populations and Antalya the most divergent one (Fig. 4).

Scorpaena notata

A total of 428 *S. notata* individuals were sampled from the İzmir, Hatay, Marmara Ereğlisi and Şile stations in the Aegean, Black, Mediterranean and Mar-

Table 3. – Descriptive statistics (Mean±SD) and ANOVA results of morphometric measurements of *S. maderensis* populations.

Morphometric Measurements	Antalya (n=109)	Balıkesir (n=109)	İzmir (n=108)	ANOVA F values	ANOVA P values
TL (cm)	12.46±1.78^{b}	13.07±1.52^{a}	12.69±1.58^{ab}	3.82	0.023
SL (cm)	9.55±1.44^{b}	10.03±1.20^{a}	9.77±1.27^{ab}	3.50	0.031
HL (cm)	3.98±0.62^{b}	4.17±0.50^{a}	4.05±0.55^{ab}	3.18	0.043
BL (mm)	34.08±5.11^{b}	36.27±4.34^{a}	34.57±4.79^{b}	6.32	0.002
CPH (mm)	10.13±1.44^{a}	9.81±1.23^{a}	10.18±1.28^{a}	2.42	0.090
CPL (mm)	8.13±0.97^{a}	6.48±0.57^{c}	7.23±0.92^{b}	104.23	0.001
CL (cm)	2.91±0.38^{b}	3.03±0.32^{a}	2.94±0.34^{ab}	3.61	0.028
DBL (cm)	6.12±0.95^{a}	6.38±0.80^{a}	6.16±0.77^{a}	2.91	0.056
SDL (mm)	9.68±1.42^{a}	9.34±1.42^{a}	8.73±1.11^{b}	14.29	0.001
LDL (mm)	16.15±2.28^{b}	17.12±1.78^{a}	15.66±1.79^{b}	15.66	0.001
PDL (cm)	2.87±0.45^{b}	3.00±0.37^{a}	2.93±0.39^{ab}	2.99	0.052
PVL (cm)	3.82±0.53^{a}	3.88±0.41^{a}	3.86±0.47^{a}	0.43	0.650
PAL (cm)	6.67±1.04^{b}	7.07±0.90^{a}	6.77±0.91^{ab}	5.16	0.006
POH (mm)	8.41±1.31^{b}	8.84±1.19^{a}	8.54±1.24^{ab}	3.43	0.034
NL (mm)	10.79±1.49^{a}	10.82±1.45^{a}	10.38±1.19^{a}	3.36	0.036
ML (mm)	20.32±3.03^{a}	21.01±2.36^{a}	20.56±2.64^{a}	1.87	0.156
ED (mm)	9.23±1.00^{a}	9.13±0.84^{a}	9.29±0.84^{a}	0.87	0.421
IOD (mm)	5.55±0.65^{a}	5.56±0.57^{a}	5.54±0.85^{a}	0.01	0.988
PBL (mm)	13.60±2.13^{a}	14.14±1.77^{a}	13.68±1.86^{a}	2.50	0.084
PPL (cm)	3.64±0.50^{a}	3.68±0.43^{a}	3.69±0.45^{a}	0.47	0.626
VBL (mm)	4.56±0.57^{a}	4.44±0.48^{ab}	4.38±0.51^{b}	3.27	0.039
VSL (mm)	14.85±1.47^{a}	14.51±1.39^{a}	14.42±1.25^{a}	2.87	0.058
ABL (mm)	16.56±1.96^{b}	17.31±1.77^{a}	16.63±1.75^{b}	5.49	0.005
SAL (mm)	9.55±1.06^{a}	9.46±0.99^{a}	9.35±0.80^{a}	1.11	0.332
LAL (mm)	17.24±1.81^{a}	17.68±1.41^{a}	17.19±1.51^{a}	3.07	0.048
STL (mm)	4.40±0.61^{a}	4.21±0.42^{a}	4.29±0.49^{a}	0.02	0.979

Table 4. – Jackknife classification matrix of the discriminant canonical analysis applied to the three *S. maderensis* populations from the coastline of Turkey's two seas.

	Predicted Group Membership		
Population	Antalya	Balıkesir	İzmir
Antalya	**90.8 (99)**	-	9.2 (10)
Balıkesir	-	**94.5 (103)**	5.5 (6)
İzmir	9.3 (10)	4.6 (5)	**86.1 (93)**
Overall: 90.5% of original grouped cases correctly classified.			

The correct classification percentages and numbers are in bold; the number of individuals is given in parentheses.

mara seas. The descriptive analysis of morphometric measurements of *S. notata* is presented in Table 5. ANOVA revealed significant (P<0.05) differences in all the morphometric measurements among the *S. notata* populations (Table 5). As a result of the PCA, it was determined that 13 morphometric measurements taken from the samples (body height, caudal peduncle height, caudal peduncle length, longest dorsal fin spine length, preorbital height, snout length, maxilla length, eye diameter, pectoral fin base length, anal fin base length, longest anal fin spine length, supraocular tentacle length and ventral fin spine length) are quite important in the intraspecific distinction of *S. notata*. Morphometric ratios were calculated between these important morphometric characters and standard length for each *S. notata* population (Supplementary Table S3). These morphometric measurements were selected for the CDA. It was determined that the first three functions were important for the CDA analysis performed for the *S. notata* populations (F1[94.7%], λ=0.003, P<0.001; F2[5.2%], λ=0.200, P<0.001; F3[0.1%], λ=0.947, P<0.019) (Fig. 6). It was determined from the CDA results that these 13 characters taken from the fish samples were quite effective for discriminating four *S. notata* populations from each other and that they achieved 96.7% success in the intraspecific distinction of *S. notata* (Table 6). *S. notata* populations were clustered by hierarchical cluster analyses of meristic data. Marmara Ereğlisi and Şile are the closest populations that were sister populations to the Hatay population. İzmir was the most divergent *S. notata* population (Fig. 4).

Scorpaena porcus

A total of 459 *S. porcus* individuals were sampled from the İzmir, Hatay, Marmara Ereğlisi and Ordu stations in the Aegean, Black, Mediterranean and Marmara seas. The descriptive analysis of morphometric measurements of *S. porcus* is presented in Table 7. The one-way ANOVA showed significant (P<0.05) differences in all the morphometric measurements among the *S. porcus* populations (Table 7). The PCA analysis indicated that 13 morphometric measurements taken from the samples (body height, caudal peduncle height, caudal peduncle length, shortest dorsal fin spine length, longest dorsal fin spine length, snout length, maxilla length, eye diameter, pectoral fin base length, anal fin base length, longest anal fin spine length, supraocular tentacle length and ventral fin spine length) are quite important for the intraspe-

Table 5. – Descriptive statistics (Mean±SD) and ANOVA results of morphometric measurements of *S. notata* populations.

Morphometric Measurements	Hatay (n=106)	İzmir (n=106)	Marmara Ereğlisi (n=107)	Şile (n=109)	ANOVA F values	ANOVA P values
TL (cm)	15.55±3.58^{b}	18.73±3.63^{a}	13.52±2.59^{c}	13.57±2.73^{c}	63.86	0.001
SL (cm)	12.00±2.84^{b}	14.46±2.85^{a}	10.41±2.06^{c}	10.43±2.19^{c}	61.54	0.001
HL (cm)	5.10±1.38^{b}	6.33±1.33^{a}	4.31±0.92^{c}	4.36±0.92^{c}	71.49	0.001
BL (mm)	42.08±8.31^{b}	48.09±8.44^{a}	37.94±7.68^{c}	37.77±7.44^{c}	39.37	0.001
CPH (mm)	11.80±2.98^{b}	14.66±3.19^{a}	10.25±2.04^{c}	10.41±2.28^{c}	62.60	0.001
CPL (mm)	8.12±2.59^{b}	10.40±2.63^{a}	6.73±1.18^{c}	6.86±1.75^{c}	77.39	0.001
CL (cm)	3.56±0.77^{b}	4.28±0.79^{a}	3.11±0.55^{c}	3.15±0.55^{c}	69.31	0.001
DBL (cm)	7.38±1.45^{b}	8.51±1.47^{a}	6.65±1.34^{c}	6.65±1.39^{c}	40.68	0.001
SDL (mm)	10.65±2.53^{b}	12.67±2.50^{a}	9.60±2.14^{c}	9.21±1.55^{c}	52.43	0.001
LDL (mm)	21.08±5.98^{b}	27.28±6.18^{a}	17.47±2.96^{c}	17.47±2.78^{c}	101.60	0.001
PDL (cm)	3.53±0.80^{b}	4.05±0.73^{a}	3.04±0.59^{c}	3.11±0.68^{c}	46.82	0.001
PVL (cm)	4.81±1.33^{b}	6.11±1.39^{a}	4.01±0.73^{c}	4.04±0.76^{c}	85.66	0.001
PAL (cm)	8.53±2.15^{b}	10.27±2.09^{a}	7.28±1.53^{c}	7.31±1.65^{c}	60.23	0.001
POH (mm)	8.72±2.41^{b}	11.65±3.13^{a}	7.36±1.51^{c}	7.29±1.57^{c}	87.37	0.001
NL (mm)	13.84±4.20^{b}	17.66±4.41^{a}	11.46±2.42^{c}	11.42±2.60^{c}	74.53	0.001
ML (mm)	25.78±6.98^{b}	32.05±7.05^{a}	21.71±3.89^{c}	21.97±4.32^{c}	75.39	0.001
ED (mm)	11.17±3.17^{b}	14.21±3.18^{a}	9.31±1.36^{c}	9.32±1.45^{c}	94.87	0.001
IOD (mm)	6.88±1.96^{b}	8.78±1.92^{a}	5.80±1.10^{c}	5.83±1.22^{c}	81.98	0.001
PBL (mm)	16.84±4.13^{b}	20.69±4.36^{a}	14.50±2.86^{c}	14.58±3.20^{c}	66.14	0.001
PPL (cm)	4.49±1.12^{b}	5.43±1.13^{a}	3.81±0.71^{c}	3.84±0.76^{c}	67.79	0.001
VBL (mm)	5.30±1.17^{b}	6.04±1.12^{a}	4.61±0.85^{c}	4.62±0.93^{c}	47.36	0.001
VSL (mm)	17.71±4.41^{b}	21.63±4.35^{a}	14.62±2.17^{c}	14.78±2.17^{c}	97.08	0.001
ABL (mm)	19.29±2.99^{b}	21.11±2.88^{a}	17.61±2.67^{c}	17.63±2.86^{c}	36.40	0.001
SAL (mm)	10.64±1.94^{b}	11.69±1.72^{a}	9.59±1.61^{c}	9.77±1.67^{c}	32.81	0.001
LAL (mm)	20.17±3.78^{b}	22.59±3.16^{a}	17.97±2.31^{c}	18.21±2.52^{c}	54.70	0.001
STL (mm)	3.15±0.99^{c}	6.67±1.64^{a}	4.27±0.69^{b}	2.69±0.58^{d}	51.56	0.001

Table 6. – Jackknife classification matrix of the discriminant canonical analysis applied to the four *S. notata* populations from the coastline of Turkey's four seas.

Population	Predicted Group Membership İzmir	Hatay	Marmara Ereğlisi	Şile
İzmir	**100.0 (106)**	-	-	-
Hatay	-	**100.0 (106)**	-	-
Marmara Ereğlisi	-	-	**93.5 (100)**	6.5 (7)
Şile	-	-	6.4 (7)	**93.6 (102)**
Overall: 96.7% of original grouped cases correctly classified.				

The correct classification percentages and numbers are in bold; the number of individuals is given in parentheses.

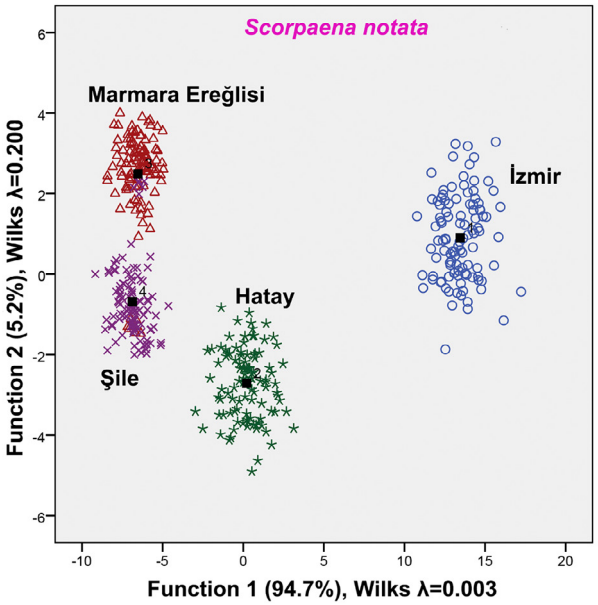

Fig. 6. – Intraspecific discrimination of *S. notata* using morphometric characters.

cific distinction of the *S. porcus*. Morphometric ratios were calculated between these important morphometric characters and standard length for each *S. porcus* population (Supplementary Table S4). These morphometric measurements were selected for the CDA. It was determined that the first three functions are important for the CDA analysis performed for the *S. porcus* populations (F1[90.2%], λ=0.002, P<0.001; F2[5.6%], λ=0.090, P<0.001; F3[4.2%], λ=0.330, P<0.001) (Fig. 7). It was determined from the CDA results that these 13 characters taken from the fish samples were quite effective for discriminating four *S. porcus* populations from each other and that they achieved 96.5% success in the intraspecific distinction of *S. porcus* (Table 8). *S. porcus* populations were clustered by hierarchical cluster analyses of meristic data. Two branches were produced by UPGMA: the first was made up of İzmir and Hatay populations; the second was made up of Marmara Ereğlisi and Şile populations. These were the closest *S. porcus* populations (Fig.4).

Scorpaena scrofa

A total of 320 *S. scrofa* individuals were sampled from the Çanakkale, İzmir and Hatay stations in the

Table 7. – Descriptive statistics (Mean±SD) and ANOVA results of morphometric measurements of *S. porcus* populations.

Morphometric Measurements	Hatay (n=114)	İzmir (n=115)	Marmara Ereğlisi (n=115)	Ordu (n=115)	ANOVA F values	ANOVA P values
TL (cm)	16.55±3.98^{b}	18.56±4.27^{a}	14.56±3.82^{c}	13.94±4.15^{c}	30.85	0.001
SL (cm)	12.85±3.28^{b}	14.56±3.43^{a}	11.81±3.12^{bc}	10.78±3.43^{c}	27.42	0.001
HL (cm)	5.26±1.31^{b}	6.31±1.53^{a}	5.02±1.36^{b}	4.52±1.52^{c}	31.99	0.001
BL (mm)	48.48±12.37^{b}	63.53±15.88^{a}	45.04±12.55^{b}	39.18±12.74^{c}	69.06	0.001
CPH (mm)	13.42±4.01^{b}	14.92±3.72^{a}	11.59±3.29^{c}	10.67±3.47^{c}	31.62	0.001
CPL (mm)	10.50±2.37^{b}	13.94±3.71^{a}	9.42±2.63^{c}	8.80±2.63^{c}	73.52	0.001
CL (cm)	3.70±0.73^{b}	4.02±0.85^{a}	2.74±0.73^{d}	3.23±0.80^{c}	58.89	0.001
DBL (cm)	8.14±2.04^{b}	8.94±2.04^{a}	6.98±1.83^{c}	6.81±1.99^{c}	30.12	0.001
SDL (mm)	12.31±3.43^{b}	13.87±3.05^{a}	10.36±2.80^{c}	9.76±3.10^{c}	42.46	0.001
LDL (mm)	19.53±3.85^{b}	23.46±4.56^{a}	17.58±4.81^{c}	17.85±4.31^{c}	44.02	0.001
PDL (cm)	3.94±1.07^{b}	4.62±1.15^{a}	3.68±1.01^{b}	3.25±1.21^{c}	30.94	0.001
PVL (cm)	5.16±1.34^{b}	5.61±1.31^{a}	4.45±1.23^{c}	4.07±1.24^{c}	33.92	0.001
PAL (cm)	9.24±2.38^{b}	10.94±2.78^{a}	8.67±2.33^{b}	7.71±2.72^{c}	32.35	0.001
POH (mm)	9.19±2.45^{b}	10.07±2.41^{a}	7.29±1.92^{c}	6.97±1.94^{c}	53.72	0.001
NL (mm)	13.84±3.28^{b}	15.94±3.91^{a}	12.45±3.32^{c}	11.65±3.71^{c}	32.19	0.001
ML (mm)	27.16±6.48^{b}	31.13±7.42^{a}	24.24±6.43^{c}	23.02±7.17^{c}	31.77	0.001
ED (mm)	11.00±1.91^{b}	15.64±3.64^{a}	8.86±2.44^{d}	9.85±2.26^{c}	148.49	0.001
IOD (mm)	6.61±1.69^{b}	9.32±2.22^{a}	6.10±1.64^{bc}	5.77±1.75^{c}	89.70	0.001
PBL (mm)	17.64±4.27^{b}	22.19±5.31^{a}	18.65±5.06^{b}	15.75±5.52^{c}	33.14	0.001
PPL (cm)	4.88±1.33^{a}	5.19±1.26^{a}	4.07±1.11^{b}	3.82±1.15^{b}	33.00	0.001
VBL (mm)	5.63±1.21^{a}	5.22±1.47^{a}	5.50±1.63^{a}	4.61±0.88^{b}	13.59	0.001
VSL (mm)	17.92±3.92^{b}	22.27±4.52^{a}	17.56±4.71^{b}	15.38±4.18^{c}	51.32	0.001
ABL (mm)	20.46±4.49^{b}	22.89±4.17^{a}	17.58±4.63^{c}	17.54±4.45^{c}	39.06	0.001
SAL (mm)	11.34±2.49^{b}	13.08±2.61^{a}	9.81±2.62^{c}	9.65±2.54^{c}	45.15	0.001
LAL (mm)	20.02±3.47^{b}	21.71±3.32^{a}	16.71±4.74^{d}	18.28±3.70^{c}	36.44	0.001
STL (mm)	10.93±1.95^{b}	15.46±3.62^{a}	8.86±2.43^{d}	9.81±2.33^{c}	1380.04	0.001

Table 8. – Jackknife classification matrix of the discriminant canonical analysis applied to the four *S. porcus* populations from the coastline of Turkey's four seas.

Population	Predicted Group Membership İzmir	Hatay	Marmara Ereğlisi	Ordu
İzmir	**100.0 (115)**	-	-	-
Hatay	-	**100.0 (114)**	-	-
Marmara Ereğlisi	-	-	**93.0 (107)**	7.0 (8)
Ordu	-	-	7.0 (8)	**93.0 (107)**
Overall: 96.5% of original grouped cases correctly classified.				

The correct classifications percentages and numbers are in bold; the number of individuals is given in parentheses.

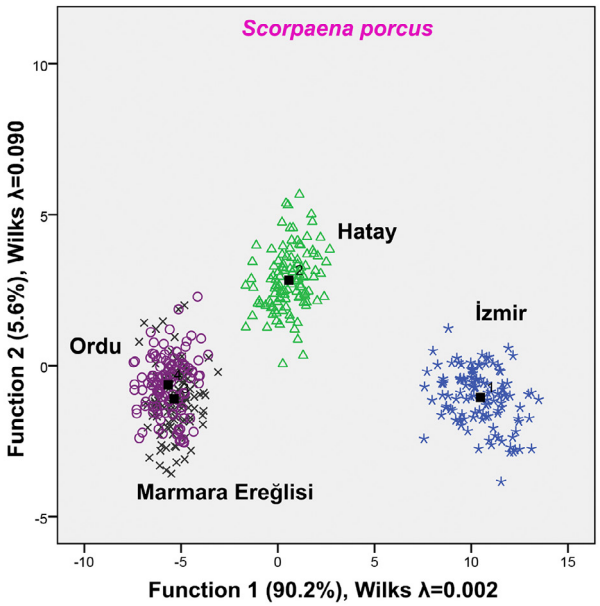

Fig. 7. – Intraspecific discrimination of *S. porcus* using morphometric characters.

Aegean, Mediterranean and Marmara seas. The descriptive analysis of morphometric measurements of *S. scrofa* is presented in Table 9. ANOVA revealed significant (P<0.05) differences in all the morphometric measurements (except for PPL and STL) among the *S. scrofa* populations (Table 9). As a result of the PCA, it was determined that ten morphometric measurements taken from the samples (body height, caudal peduncle height, shortest dorsal fin spine length, longest dorsal fin spine length, preorbital height, snout length, maxilla length, pectoral fin base length, ventral fin spine length and anal fin base length) are quite important in the intraspecific distinction of *S. scrofa*. Morphometric ratios were calculated between these important morphometric characters and standard length for each *S. porcus* population (Supplementary Table S5). These morphometric measurements were selected for the CDA. It was determined that the first two functions were important for the CDA analysis performed for the *S. scrofa* populations (F1[93.7%], λ=0.055, P<0.001; F2[6.3%], λ=0.600, P<0.001) (Fig. 8). It was determined from the CDA results that these 10 characters taken from the fish samples were quite effective for discriminating four *S. scrofa* populations from each other and that they achieved 92.2% success in the intraspecific distinction of *S. scrofa*

Table 9. – Descriptive statistics (Mean±SD) and ANOVA results of morphometric measurements of *S. scrofa* populations.

Morphometric Measurements	Çanakkale (n=107)	Hatay (n=107)	İzmir (n=106)	ANOVA F values	ANOVA P values
TL (cm)	22.88±5.03[a]	19.90±5.63[b]	21.57±3.91[a]	9.90	0.001
SL (cm)	17.71±3.77[a]	15.59±4.29[b]	16.71±3.01[ab]	8.60	0.001
HL (cm)	7.74±1.79[a]	6.65±1.98[b]	7.51±1.43[a]	11.63	0.001
BL (mm)	57.99±12.96[a]	50.75±14.27[b]	56.04±10.77[a]	9.22	0.001
CPH (mm)	18.22±4.46[a]	15.42±4.73[b]	17.47±3.34[a]	12.59	0.001
CPL (mm)	14.28±3.06[a]	12.64±3.45[b]	13.16±2.59[b]	8.14	0.001
CL (cm)	5.18±1.31[a]	4.31±1.38[b]	4.86±0.95[a]	13.62	0.001
DBL (cm)	10.33±2.06[a]	9.39±2.62[b]	9.87±1.71[ab]	5.10	0.007
SDL (mm)	16.10±3.35[a]	12.98±2.68[c]	14.78±2.60[b]	31.43	0.001
LDL (mm)	33.28±8.33[a]	27.04±7.67[c]	30.66±5.87[b]	19.36	0.001
PDL (cm)	5.86±1.37[a]	5.19±1.59[b]	5.83±1.09[a]	8.11	0.001
PVL (cm)	7.32±1.65[a]	6.42±1.86[b]	6.97±1.32[a]	8.21	0.001
PAL (cm)	13.58±3.06[a]	11.78±3.36[b]	12.85±2.39[a]	9.91	0.001
POH (mm)	22.97±5.26[a]	19.68±5.83[b]	22.41±4.21[a]	12.44	0.001
NL (mm)	21.80±6.04[a]	17.58±6.44[b]	21.42±3.98[a]	18.59	0.001
ML (mm)	39.55±8.75[a]	34.12±9.56[b]	37.42±7.03a	11.08	0.001
ED (mm)	17.57±2.14[a]	16.75±1.99[b]	17.13±1.84[ab]	4.55	0.011
IOD (mm)	10.42±2.79[a]	8.33±2.91[b]	10.34±2.01[a]	22.32	0.001
PBL (mm)	25.09±6.08[a]	20.56±6.21[b]	24.69±4.12[a]	21.60	0.001
PPL (cm)	6.60±1.47[a]	6.59±1.91[a]	6.26±1.19[a]	1.67	0.191
VBL (mm)	7.80±1.88[a]	6.14±2.13[b]	7.30±1.73[a]	20.94	0.001
VSL (mm)	25.52±4.60[a]	22.44±5.09[b]	25.35±3.25[a]	16.70	0.001
ABL (mm)	24.50±5.10[a]	21.76±5.55[b]	23.31±3.41[a]	8.84	0.001
SAL (mm)	13.01±3.11[a]	10.94±3.43[b]	12.44±1.38[a]	15.67	0.001
LAL (mm)	24.39±4.49[a]	22.34±5.30[b]	23.81±2.53[a]	6.52	0.002
STL (mm)	1.72±0.32[a]	1.68±0.20[a]	1.71±0.18[a]	0.99	0.374

Table 10. – Jackknife classification matrix of the discriminant canonical analysis applied to the four *S. scrofa* populations from the coastline of Turkey's three seas.

	Predicted Group Membership		
Population	Çanakkale	İzmir	Hatay
Çanakkale	**87.9 (94)**	12.1 (13)	-
İzmir	10.4 (11)	**89.6 (95)**	-
Hatay	-	0.9 (1)	**99.1 (106)**
Overall: 92.2% of original grouped cases correctly classified.			

The correct classification percentages and numbers are in bold; the number of individuals is given in parentheses.

(Table 10). *S. scrofa* populations were clustered by hierarchical cluster analyses of meristic data. Çanakkale and İzmir were the closest *S. scrofa* populations and Hatay the most divergent (Fig. 4).

Interspecific discrimination

A total of 1865 individuals belonging to five *Scorpaena* species were sampled from the Antalya, Balıkesir, Çanakkale, İzmir, Hatay, Marmara Ereğlisi, Ordu and Şile stations in the Aegean, Black, Mediterranean and Marmara seas. The descriptive analysis of morphometric measurements of five *Scorpaena* species is presented in Table 11. The one-way ANOVA showed significant (P<0.05) differences in all the morphometric measurements among the *Scorpaena* species (Table 11). The PCA analysis indicated that 13 morphometric measurements taken from the samples (body height, caudal peduncle height, caudal peduncle length, longest dorsal fin spine length, preorbital height, snout length, maxilla length, eye diameter, pectoral fin base length, anal fin base length, longest anal fin spine length, supraocular tentacle length and ventral fin spine length) were quite important for the interspecific discrimination of five *Scorpaena* species. These morphometric measurements were selected for the CDA. It was determined that the first four functions were important for the CDA analysis performed for the

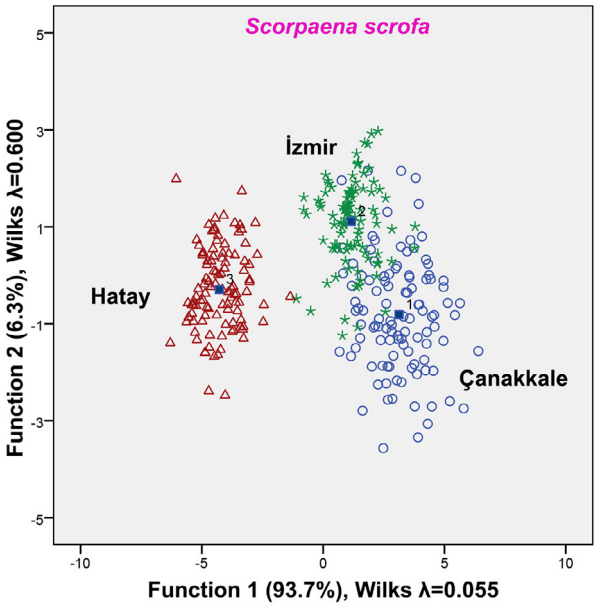

Fig. 8. – Intraspecific discrimination of *S. scrofa* using morphometric characters.

Table 11. – Descriptive statistics (Mean±SD and range) and ANOVA results of morphometric measurements of five *Scorpaena* species.

Morphometric Measurements	*S. elongata* (n=332)	*S. maderensis* (n=326)	*S. notata* (n=428)	*S. porcus* (n=459)	*S. scrofa* (n=320)	ANOVA F values	ANOVA P values
TL (cm)	15.71±3.57^{b} (9.2-23.6)	12.74±1.64^{c} (8.7-16.6)	15.33±3.80^{b} (9.5-22.9)	15.90±4.44^{b} (8.4-25.1)	21.45±5.05^{a} (8.9-33.4)	214.96	0.001
SL (cm)	12.60±1.14^{b} (7.1-18.9)	9.80±0.23^{d} (6.7-12.9)	11.81±1.66^{c} (7.2-17.7)	12.50±1.43^{b} (6.3-19.8)	16.68±0.92^{a} (7.1-25.6)	1347.22	0.001
HL (cm)	5.21±0.46^{b} (2.9-7.9)	4.08±0.17^{d} (2.6-5.6)	5.02±0.84^{c} (2.7-8.2)	4.95±0.35^{c} (2.5-8.6)	7.29±0.55^{a} (3.2-10.7)	1612.65	0.001
BL (mm)	41.16±4.48^{c} (21.05-68.98)	35.07±1.64^{d} (22.86-46.20)	41.53±4.59^{c} (25.60-62.95)	45.41±4.78^{b} (22.30-90.21)	54.93±4.04^{a} (22.18-82.92)	1010.49	0.001
CPH (mm)	11.61±0.97^{c} (5.79-19.71)	10.05±0.43^{d} (6.46-13.64)	11.75±1.84^{c} (6.72-19.46)	12.60±1.81^{b} (5.52-22.67)	16.99±1.45^{a} (6.57-25.29)	1041.54	0.001
CPL (mm)	10.48±1.20^{c} (4.96-20.65)	7.27±0.75^{e} (4.86-10.45)	7.99±1.57^{d} (4.25-14.71)	10.82±2.79^{b} (4.42-19.32)	13.38±1.19^{a} (4.47-21.57)	663.97	0.001
CL (cm)	3.14±0.27^{d} (1.8-4.8)	2.97±0.13^{e} (2.0-3.9)	3.53±0.50^{b} (2.0-5.5)	3.45±0.51^{c} (1.6-5.4)	4.77±0.47^{a} (1.7-7.8)	916.02	0.001
DBL (cm)	7.60±0.71^{b} (4.1-11.8)	6.23±0.23^{d} (4.2-8.3)	7.32±0.80^{c} (4.4-11.1)	7.73±0.93^{b} (3.8-12.6)	9.88±0.53^{a} (4.4-15.9)	1127.34	0.001
SDL (mm)	11.17±0.80^{c} (7.06-16.23)	9.29±0.64^{e} (5.74-13.54)	10.51±1.51^{d} (6.13-17.04)	11.58±1.79^{b} (5.34-19.65)	14.68±1.51^{a} (6.46-21.33)	687.89	0.001
LDL (mm)	21.27±1.95^{b} (12.13-32.17)	16.31±0.95^{d} (11.06-22.10)	20.79±4.12^{b} (12.22-35.85)	19.75±2.55^{c} (9.45-30.36)	30.29±3.06^{a} (12.05-47.17)	1105.23	0.001
PDL (cm)	3.93±0.29^{b} (2.0-6.6)	2.94±0.14^{d} (2.0-4.1)	3.43±0.44^{c} (2.0-5.2)	3.85±0.55^{b} (1.8-6.5)	5.61±0.39^{a} (2.1-8.7)	2035.03	0.001
PVL (cm)	5.16±0.48^{b} (2.8-7.9)	3.87±0.13^{d} (2.7-5.2)	4.73±0.85^{c} (2.8-8.0)	4.82±0.65^{c} (2.4-7.9)	6.90±0.45^{a} (2.7-10.8)	1157.40	0.001
PAL (cm)	9.20±0.84^{b} (4.8-13.9)	6.84±0.25^{d} (4.6-9.2)	8.33±1.24^{c} (4.8-13.1)	9.12±1.26^{b} (4.2-15.7)	12.74±0.86^{a} (5.1-19.5)	1522.82	0.001
POH (mm)	11.40±1.03^{b} (6.32-17.12)	8.58±0.41^{cd} (5.28-11.60)	8.69±1.77^{c} (4.57-15.53)	8.37±1.39^{d} (3.95-14.15)	21.66±1.69^{a} (9.34-31.91)	5742.23	0.001
NL (mm)	12.53±1.17^{c} (7.03-19.48)	10.66±0.46^{d} (7.40-14.37)	13.51±2.59^{b} (7.60-24.08)	13.46±2.37^{b} (6.80-21.70)	20.10±2.29^{a} (6.92-32.22)	1027.10	0.001
ML (mm)	27.10±2.41^{b} (15.51-39.46)	20.64±0.71^{e} (13.90-27.41)	25.31±4.21^{d} (15.62-41.76)	26.47±3.40^{c} (13.36-43.47)	37.04±2.58^{a} (14.94-54.26)	1270.19	0.001
ED (mm)	15.48±3.04^{b} (6.15-24.78)	9.23±0.39^{e} (7.02-11.60)	10.98±2.04^{d} (6.55-18.87)	11.37±2.68^{c} (4.43-20.58)	17.27±0.84^{a} (10.95-22.16)	843.05	0.001
IOD (mm)	6.05±0.60^{c} (3.25-8.84)	5.56±026^{d} (3.54-7.84)	6.81±1.27^{b} (4.12-11.89)	6.94±1.47^{b} (3.45-12.95)	9.65±1.25^{a} (3.75-14.99)	646.45	0.001
PBL (mm)	16.01±1.33^{d} (9.36-23.47)	13.78±0.61^{e} (8.65-18.83)	16.61±2.60^{c} (9.84-27.44)	18.58±2.54^{b} (9.12-30.65)	23.46±2.69^{a} (9.69-35.05)	973.11	0.001
PPL (cm)	5.11±0.50^{b} (2.6-8.3)	3.68±0.14^{d} (2.6-4.8)	4.39±0.67^{c} (2.7-6.9)	4.48±0.60^{c} (2.3-7.8)	6.49±0.32^{a} (2.5-11.2)	1419.14	0.001
VBL (mm)	4.90±1.11^{c} (1.55-9.56)	4.46±0.23^{d} (3.10-5.81)	5.15±0.66^{b} (3.00-7.80)	5.24±0.46^{b} (1.68-8.95)	7.04±0.85^{a} (1.95-11.58)	619.24	0.001
VSL (mm)	19.01±1.24^{b} (12.39-25.88)	14.64±0.54^{e} (10.70-18.03)	17.18±2.94^{d} (10.40-27.26)	18.34±2.66^{c} (9.68-28.99)	24.57±1.92^{a} (12.68-33.59)	931.15	0.001
ABL (mm)	18.03±1.68^{d} (11.19-26.05)	16.84±0.78^{e} (12.05-21.25)	18.97±1.72^{c} (12.48-25.95)	19.68±2.42^{b} (9.58-29.54)	23.27±1.69^{a} (11.71-37.16)	593.89	0.001
SAL (mm)	8.12±0.67^{e} (5.41-11.36)	9.46±0.38^{d} (6.72-11.97)	10.46±1.04^{c} (6.43-15.43)	10.99±1.56^{b} (5.63-17.66)	12.13±1.23^{a} (5.28-18.69)	644.06	0.001
LAL (mm)	19.09±1.58^{c} (11.91-27.77)	17.41±0.65^{d} (13.11-21.63)	19.80±2.10^{b} (12.84-27.71)	19.26±2.17^{c} (10.00-27.95)	23.63±1.38^{a} (11.70-34.56)	568.49	0.001
STL (mm)	2.19±0.49^{c} (0.74-3.28)	4.32±0.33^{b} (3.21-5.90)	4.17±1.57^{b} (1.83-9.29)	11.34±2.63^{a} (4.43-20.58)	1.70±0.24^{d} (1.10-2.22)	2656.61	0.001

Table 12. – Jackknife classification matrix of the discriminant canonical analysis applied to the five *Scorpaena* species from the coastline of Turkey's four seas.

	Predicted Group Membership				
Species	*S. elongata*	*S. maderensis*	*S. notata*	*S. porcus*	*S. scrofa*
S. elongata	**98.5 (327)**	1.5 (5)	-	-	-
S. maderensis	1.8 (6)	**98.2 (320)**	-	-	
S. notata	-	-	**96.7 (414)**	3.3 (14)	
S. porcus	-	-	5.2 (24)	**94.8 (435)**	
S. scrofa					**100.0 (320)**
Overall: 97.4% of original grouped cases correctly classified.					

The correct classifications percentages and numbers are in bold; the number of individuals is given in parentheses.

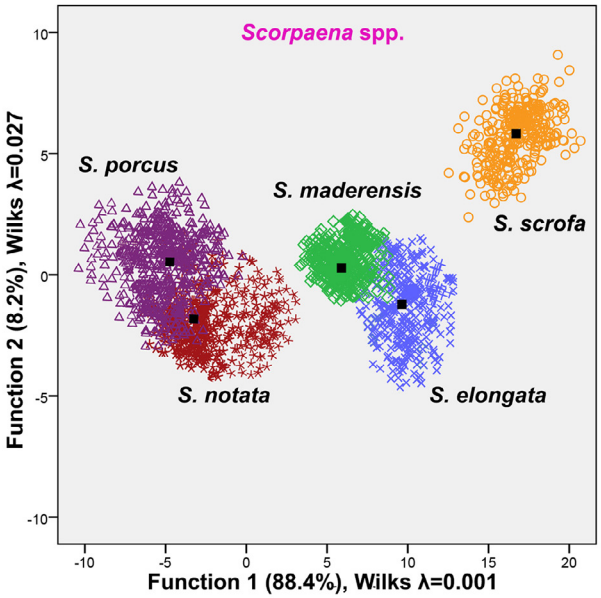

Fig. 9. – Interspecific discrimination of the five *Scorpaena* species using morphometric characters.

five *Scorpaena* species (F1[88.4%], λ=0.001, P<0.001; F2[8.2%], λ=0.027, P<0.001; F3[2.0%], λ=0.194, P<0.001; F4[1.4%], λ=0.493, P<0.001) (Fig. 9). It is determined from the CDA results that these 13 characters taken from the fish samples were quite effective for discriminating five *Scorpaena* species from each other and that they achieved 97.4% success in interspecific discrimination of these *Scorpaena* species (Table 12).

Hierarchical cluster analyses of meristic data clustered *Scorpaena* species. Three main branches were produced by UPGMA. In the first branch, *S. scrofa* was seen to be morphometrically most divergent from the other species. In the second branch, *S. notata* and *S. porcus* were the closest taxa forming the sister group to *S. elongata.* The neighbouring branch made up of *S. maderensis* was seen to be morphometrically most divergent from the other species and was branched as a third group. The third group, the neighbouring branch, included only *S. maderensis* (Fig. 4).

DISCUSSION

The genus *Scorpaena* is distributed throughout temperate and tropical seas of the world (Hureau and Litvinenko 1986, Gomon et al. 1994, Froese and Pauly 2020). It is known that *Scorpaena* species are difficult to identify at the species level using visual observation alone due to colouration similarities and overlapping morphological features in different habitats (Hureau and Livtinenko 1986, Golani et al. 2006, Akalın et al. 2011). Morphometric characters of the fish species are a strong means to measure and distinguish species and stock relations (Turan et al. 2005, Cadrin et al. 2014). In this study, the intra- and interspecific discriminations of five *Scorpaena* species inhabiting the Aegean, Black, Mediterranean and Marmara seas were successfully performed using CDA based on morphometric characters. It was determined that data obtained from *Scorpaena* species showed some differences among the species but were generally compatible with the data of Froese and Pauly (2020). The most significant measurements of five *Scorpaena* species taken into account for discrimination through the traditional analysis were body height, caudal peduncle height, caudal peduncle length, longest dorsal fin spine length, preorbital height, snout length, maxilla length, eye diameter, pectoral fin base length, anal fin base length, longest anal fin spine length, supraocular tentacle length and ventral fin spine length. As a result of CDA analysis, it was determined that morphometric characters are also effective for intraspecific discrimination of five *Scorpaena* species. For example, the highest intraspecific discrimination was determined for *S. notata* populations (96.7 %), followed by *S. porcus* (96.5 %), *S. elongata* (94.6 %), *S. scrofa* (92.2 %) and *S. maderensis* (90.5 %). The intraspecific morphological variations of five *Scorpaena* species may be due to variation in body shape but not to the total length effect because it was normalized successfully using the Elliott et al. (1995) method. Cadrin (2000) indicated that is difficult to explain the causes of morphological differences between fish populations. However, it is assumed that these differences may be related to genetic factors or may also be related to environmental factors such as feeding, habitat, pH, turbidity and temperature (Wimberger 1992).

Pothin et al. (2006) indicated that the Wilks' lambda (λ) value varies between 0 and 1. The discriminating power of CDA is best when Wilks' lambda (λ) is close to 0. In the current study, the Wilks' lambda (λ) values for intraspecific discriminations were 0.008 for *S. elongata*, 0.110 for *S. maderensis*, 0.003 for *S. notata*, 0.002 for *S. porcus* and 0.055 for *S. scrofa*. The Wilks' lambda (λ) value was determined as 0.001 for interspecific discrimination of the five *Scorpaena* species. CDA results show that morphological measurements of the five *Scorpaena* species produce good discrimination within each species and among the species. These lambda values also support the high accuracy of CDA for morphometric measurements in the present study. Using the morphometric measurements of *Scorpaena* species, the actual separation rate in CDA was determined to be high (Table 12). Body morphometric traits were reported to provide a moderate level of discrimination in many species and genera from marine and freshwater habitats such as *Trachurus mediterraneus* in the Aegean, Black, and Mediterranean seas (Turan 2004), *Eugerres* spp. in the eastern Pacific (González-Acosta et al. 2005), *Megalaspis cordyla* from the Indian coast (Sajina et al. 2011), the genus *Labeo* in Assam, India (Choudhury and Dutta 2012), *Channa punctatus* from Indian rivers (Khan et al. 2013), the genus *Nemipterus* in Malaysia and its surrounding seas (Imtiaz and Naim 2018), *Ompok pabo* from Bangladeshi freshwaters (Mahfuj et al. 2019b) and mullet species in Aceh, Indonesia (Yulianto et al. 2020).

La Mesa (2005) revised the description of *S. maderensis* sampled from the southeastern coasts of Sicily using the metric and meristic characteristics and reported that most of the morphometric characters of *S. maderensis* evaluated in this study overlap with the

S. porcus data, causing some problems in species distinction. The same author reported that supraocular tentacle length and anal fin spine length were the most effective characters for distinguishing *S. maderensis* and *S. porcus* species. Similarly, in the present study, it was determined that the supraocular tentacle length, shortest anal fin spine length and longest anal fin spine length were the most effective characters for distinguishing between *S. maderensis* and *S. porcus* species. Turan et al. (2009) compared *S. elongata, S. maderensis, S. notata, S. porcus,* and *S. scrofa* from Iskenderun Bay (Mediterranean Sea) based on the number of spines and soft rays on anal, ventral and dorsal fins, the number of soft rays on the pectoral and caudal fins, the number of scales on the lateral line, and the number of gill spines and vertebrae. They concluded that caudal fin rays, pectoral fin rays, vertebrae numbers and lateral scale numbers are important for species differentiation.

Ferri et al. (2010) evaluated 18 morphometric characteristics of *S. porcus* sampled from the eastern Adriatic Sea. They reported that these characters did not differ statistically between male and female individuals (P>0.05). Similarly, in the present study, 26 morphometric characters were evaluated for *S. porcus* from the Aegean, Black, Mediterranean seas and Marmara seas, and it was determined that metric characters showed no statistical difference between female and male individuals (P>0.05). Thus, this study contributes to the literature by supporting the data of previous studies over new samples obtained from different stations in different habitats. Akalın et al. (2011) compared 19 metric and 7 meristic characteristics in *S. porcus* and *S. notata* sampled from the Aegean Sea. Although they stated that the black spot on the dorsal fin and supraocular tentacle are effective characters for differentiating these two species, there were problems in distinguishing juvenile individuals. Therefore, they stated that a detailed morphometric comparison was needed for *Scorpaena* species. They found statistical differences between the two species in supraocular tentacle length, upper jaw length, pectoral fin length, caudal peduncle height, eye diameter, longest dorsal fin spine length, pelvic fin spine length, shortest anal fin spine length and longest anal fin spine length. Our study also revealed that morphometric characters may differ statistically among fish species (Table 11). Manilo and Peskov (2016) evaluated 20 morphometric characteristics of *S. porcus* sampled from the south coast of Crimea and the eastern part of the Adriatic Sea. They compared the male and female individuals in both regions separately. As a result of this comparison, they reported that the 13 morphometric characteristics were statistically different between these two regions. Similar results were obtained in the present study, and the PCA indicated that 13 morphometric measurements were important for the intraspecific discrimination of five *S. porcus* from four seas. We also achieved a success rate of 96.5% in the intraspecific separation of *S. porcus* sampled from different seas using these morphometric data (Table 8). As explained above in the literature review, although there are some intra- and interspecific morphometric-based studies for the genus *Scorpaena*, no studies based on morphometric measurements of these five *Scorpaena* species had been carried out in such wide geographic areas. Therefore, this is the first study based on morphometric data to perform intra- and interspecific discrimination of the five *Scorpaena* species sampled from eight stations in four seas.

In many studies, the characters are considered one of the simplest, most cost-effective and most commonly used tools to distinguish between fish populations (Khan et al. 2013, Siddik et al. 2015), to determine the structure of fish assemblages (Cheng et al. 2005) and to identify fish stocks (Cadrin et al. 2014, Siddik et al. 2016). However, in some cases these morphometric characters may not be suitable for identifying or discriminating every fish species and population. Therefore, the determination of these characters is important for fish biology and fisheries management.

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SUPPLEMENTARY MATERIAL

The following supplementary material is available through the online version of this article and at the following link: http://scimar.icm.csic.es/scimar/supplm/sm05185esm.pdf

Table S1. – Ranges of selected morphometric variables of S. elongata populations.

Table S2. – Ranges of selected morphometric variables of S. maderensis populations.

Table S3. – Ranges of selected morphometric variables of S. notata populations.

Table S4. - Ranges of selected morphometric variables of S. porcus populations.

Table S5. – Ranges of selected morphometric variables of S. scrofa populations.

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Intra- and interspecific discrimination of *Scorpaena* species from the Aegean, Black, Mediterranean and Marmara seas

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Supplementary material

Table S1. – Ranges of selected morphometric variables of *S. elongata* populations.

Morphometric Variables	Antalya	Hatay	İzmir
BL/SL	0.293-0.365	0.296-0.325	0.324-0.346
LDL/SL	0.170-0.194	0.164-0.171	0.162-0.168
PAL/SL	0.667-0.735	0.732-0.746	0.730-0.733
POH/SL	0.088-0.091	0.089-0.092	0.092-0.096
NL/SL	0.098-0.103	0.098-0.099	0.097-0.101
ML/SL	0.209-0.215	0.213-0.228	0.211-0.230
ED/SL	0.131-0.161	0.136-0.175	0.081-0.083
PBL/SL	0.124-0.130	0.122-0.133	0.121-0.147
VBL/SL	0.022-0.044	0.028-0.046	0.023-0.051
VSL/SL	0.137-0.172	0.146-0.180	0.136-0.167
ABL/SL	0.138-0.155	0.136-0.155	0.137-0.156
LAL/SL	0.147-0.167	0.136-0.168	0.145-0.180

Standard length (SL), body height (BL), longest dorsal fin spine length (LDL), preanal length (PAL), preorbital height (POH), snout length (NL), maxilla length (ML), eye diameter (ED), pectoral fin base length (PBL), ventral fin base length (VBL), ventral fin spine length (VSL), anal fin base length (ABL) and longest anal fin spine length (LAL).

Table S2. – Ranges of selected morphometric variables of *S. maderensis* populations.

Morphometric Variables	Antalya	Balıkesir	İzmir
BL/SL	0.362-0.370	0.361-0.375	0.336-0.347
LDL/SL	0.165-0.169	0.172-0.181	0.155-0.165
PAL/SL	0.697-0.724	0.701-0.703	0.667-0.676
POH/SL	0.088-0.091	0.088-0.091	0.078-0.088
ML/SL	0.207-0.210	0.214-0.227	0.204-0.210
CPH/SL	0.107-0.110	0.096-0.103	0.10 4-0.106
CPL/SL	0.082-0.089	0.062-0.073	0.070-0.073
PBL/SL	0.142-0.146	0.140-0.147	0.128-0.138
ABL/SL	0.164-0.180	0.166-0.189	0.165-0.180
LAL/SL	0.169-0.196	0.169-0.202	0.158-0.196

Standard length (SL), body height (BL), caudal peduncle height (CPH), caudal peduncle length (CPL), longest dorsal fin spine length (LDL), preanal length (PAL), preorbital height (POH), maxilla length (ML), pectoral fin base length (PBL), anal fin base length (ABL) and longest anal fin spine length (LAL).

Table S3. – Ranges of selected morphometric variables of *S. notata* populations.

Morphometric Variables	Hatay	İzmir	Marmara Ereğlisi	Şile
BL/SL	0.337-0.362	0.356-0.362	0.357-0.361	0.349-0.356
LDL/SL	0.175-0.193	0.159-0.203	0.160-0.174	0.150-0.170
POH/SL	0.069-0.078	0.054-0.088	0.063-0.071	0.070-0.073
NL/SL	0.109-0.130	0.108-0.136	0.109-0.116	0.106-0.117
ML/SL	0.221-0.236	0.204-0.236	0.201-0.225	0.208-0.217
ED/SL	0.089-0.104	0.089-0.107	0.080-0.098	0.082-0.094
PBL/SL	0.136-0.155	0.140-0.154	0.134-0.137	0.137-0.141
CPH/SL	0.102-0.110	0.096-0.109	0.096-0.099	0.093-0.101
CPL/SL	0.064-0.081	0.059-0.083	0.062-0.069	0.059-0.071
ABL/SL	0.145-0.183	0.147-0.176	0.147-0.179	0.152-0.173
LAL/SL	0.157-0.197	0.154-0.182	0.145-0.178	0.155-0.192
VSL/SL	0.147-0.154	0.154-0.156	0.128-0.144	0.127-0.150
STL/SL	0.025-0.032	0.037-0.052	0.039-0.042	0.025-0.027

Standard length (SL), body height (BL), caudal peduncle height (CPH), caudal peduncle length (CPL), longest dorsal fin spine length (LDL), preorbital height (POH), snout length (NL), maxilla length (ML), eye diameter (ED), pectoral fin base length (PBL), ventral fin spine length (VSL), anal fin base length (ABL), longest anal fin spine length (LAL) and supraocular tentacle length (STL).

Table S4. - Ranges of selected morphometric variables of *S. porcus* populations.

Morphometric Variables	Hatay	İzmir	Marmara Ereğlisi	Ordu
BL/SL	0.352-0.394	0.357-0.456	0.347-0.403	0.354-0.385
SDL/SL	0.082-0.101	0.089-0.092	0.085-0.089	0.085-0.095
LDL/SL	0.149-0.179	0.153-0.179	0.141-0.157	0.150-0.185
NL/SL	0.104-0.110	0.100-0.110	0.102-0.109	0.107-0.113
ML/SL	0.212-0.216	0.196-0.220	0.208-0.212	0.219-0.227
ED/SL	0.077-0.105	0.088-0.104	0.066-0.077	0.082-0.110
PBL/SL	0.139-0.142	0.141-0.155	0.149-0.163	0.145-0.155
CPH/SL	0.095-0.117	0.081-0.108	0.087-0.107	0.097-0.108
CPL/SL	0.080-0.086	0.078-0.098	0.066-0.083	0.080-0.082
ABL/SL	0.150-0.176	0.149-0.176	0.143-0.152	0.149-0.182
LAL/SL	0.139-0.193	0.136-0.195	0.149-0.151	0.140-0.201
VSL/SL	0.137-0.153	0.146-0.160	0.144-0.149	0.135-0.157
STL/SL	0.078-0.099	0.088-0.104	0.066-0.077	0.085-0.102

Standard length (SL), body height (BL), caudal peduncle height (CPH), caudal peduncle length (CPL), shortest dorsal fin spine length (SDL), longest dorsal fin spine length (LDL), snout length (NL), maxilla length (ML), eye diameter (ED), pectoral fin base length (PBL), ventral fin spine length (VSL), anal fin base length (ABL), longest anal fin spine length (LAL) and supraocular tentacle length (STL).

Table S5. – Ranges of selected morphometric variables of *S. scrofa* populations.

Morphometric Variables	Çanakkale	Hatay	İzmir
BL/SL	0.310-0.329	0.292-0.324	0.312-0.338
SDL/SL	0.092-0.094	0.075-0.098	0.089-0.091
LDL/SL	0.178-0.204	0.171-0.185	0.170-0.187
POH/SL	0.126-0.136	0.123-0.125	0.132-0.140
NL/SL	0.092-0.131	0.091-0.126	0.127-0.129
ML/SL	0.226-0.228	0.212-0.219	0.210-0.234
PBL/SL	0.130-0.149	0.133-0.137	0.149-0.166
CPH/SL	0.088-0.109	0.092-0.097	0.102-0.109
ABL/SL	0.148-0.156	0.145-0.153	0.138-0.177
VSL/SL	0.145-0.171	0.127-0.163	0.144-0.215

Standard length (SL), body height (BL), caudal peduncle height (CPH), shortest dorsal fin spine length (SDL), longest dorsal fin spine length (LDL), preorbital height (POH), snout length (NL), maxilla length (ML), pectoral fin base length (PBL), ventral fin spine length (VSL) and anal fin base length (ABL).