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# Morphological Variation among Atlantic Horse Mackerel, *Trachurus trachurus* Populations from Turkish Coastal Waters

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**Abstract:** Morphological variation among Turkish populations of the Atlantic horse mackerel *Trachurus trachurus* (Carangidae) was examined for 150 specimens at five different sampling localities (Sea of Marmara (Istanbul and Canakkale), Aegean (Izmir) and Northeastern mediterranean (Antalya and Iskenderun) seas) in Turkey by discriminant function analysis of eleven morphometric and five meristic characters. The results of discriminant function analysis showed that there is limited gene flow among *T. trachurus* populations in Turkish coastal waters. The Marmara Sea sample was similar to the Aegean Sea samples for both morphometric and meristic data. Morphometric and meristic data showed the heterogeneity between Aegean and Mediterranean mackerel samples. The Mediterranean samples separated from all others and indicate 2 local populations (Iskenderun and Antalya) for morphometric data, unlike meristic data that revealed no significant differentiation between 2 Mediterranean localities. Discriminant function analyses indicated that morphometric differentiation between the samples was largely due to differences in the head characters of fish. It is confirmed that metric characters are much less effective for discriminating between *T. trachurus* populations than morphometric characters, which is expressed higher distances between samples. The results indicate a small degree of spatial separation in morphology in *T. trachurus* among the studied localities.

**Key words:** Atlantic horse mackerel, *Trachurus trachurus*, morphometrics, meristic, multivariate analysis, population structure

## INTRODUCTION

The species of the genus *Trachurus* are widely distributed along the coasts and throughout oceanic waters of temperate, tropical and subtropical seas (Eschmeyer, 2003). The species of the genus *Trachurus* are pelagic fishes of economic importance. Although, numerous studies have focused on morphological and ecological variability among species of *Trachurus*, the taxonomy and phylogenetic relationships among species remain controversial (Shaboneyev, 1981; Kijima *et al*., 1988; Ben Salem, 1995). The genus *Trachurus*, which was first described its taxonomies by Nichols (1920), is represented by 3 species in Turkish waters. The horse mackerel *T. trachurus*, which is one of the these species, has a global distribution extending from the eastern Atlantic including the Mediterranean Sea, Black Sea and the Sea of Marmara, to western Atlantic and also, to western Pacific and the Indian Oceans (Fish base online).

Morphometric and meristic studies have provided useful results for identifying marine fish stocks and describing their spatial distributions (Ihssen *et al*., 1981) and multivariate analysis of a set of morphometric and meristic characters has been widely used as a powerful technique for the determination of morphological relationships between the populations of a species (Corti and Crosetti, 1996; Vidalis *et al*., 1997; Mamuris *et al*., 1998; Cadrin, 2000; Murta, 2000; Pakkasmaa and Piironen, 2001; Palma and Andrade, 2002).

Some morphometric and meristic characters of Atlantic horse mackerel in the Northeast Atlantic were previously analysed for stock identification and morphometric characteristics were showed considerably greater discriminatory power to distinguish individuals from different areas than did the meristic characters (Murta, 2000). Turan (2004) studied morphologic differentiation among stocks of Mediterranean horse mackerel, *Trachurus mediterraneus*, throughout the Black, Marmara, Aegean and Northeastern Mediterranean

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Seas from coasts of the Turkish waters, but have not yet been studied for *T. trachurus* species. Recently, intraspecific and interspecific genetic and phylogenetic relationships in the genus *Trachurus*, including also *T. trachurus* in Turkish coastal waters were investigated using mtDNA cyt b gene and control region sequences by Bektas and Belduz (2008).

The aims of this study are to assess and describe intraspecies variation in morphological and meristic characters of *T. trachurus* from different Turkey coastal locations; identify the best set of characters for group separation, with the use of the multivariate analysis technique.

## MATERIALS AND METHODS

**Sampling:** A total of 150 specimens were collected from five different locations in the Aegean Sea, Sea of Marmara and Northeastern Mediterranean Sea (Fig. 1). All specimens were directly fixed in 10% formalin and were preserved in 70% ethanol after fixation and deposited in the Zoology Laboratory, Faculty of Fisheries, Rize University.

**Morphometric and meristic studies:** Measurements and counts were taken from 30 individuals/population, comprising 11 morphometric and 5 meristic characters (Fig. 2). Morphometric characters were based on Murta (2000): Total Length (TL), Standard Length (SL), Lengths of Second Dorsal (SDFL), Pectoral (PFL) Anal (AL), First Dorsal Fins (FDFL), Lateral Line (LL), Pre-anal (PrAL) lengths, maximum Body Heights (BH) and minimum body heights (CPH), Head Length (HL), Eye Diameter (ED). Meristic characters included number of branched rays in First Dorsal (FDFR), Second Dorsal (SDFR), Pelvic (PFR), Anal (AFR) and number of pectoral rays (PFR) and number of scales on the lateral line (LS). The morphometric measurements were measured to the nearest 0.01 mm. Standard length was expressed as a percentage of the total length. Others metric measurements were expressed as percentages of the standard length. Eye Diameter (ED) was expressed as percentages of the head length (ED/HL) and the minimum body height was expressed as a percentage of the maximum body height (CPH/BH). All variables used for morphometric and meristic analysis were measured under a binocular microscope.

**Data and statistical analysis:** To determine intraspecific variations in the *T. trachurus*, morphometric and meristic characters were used separately in multivariate analyses since their allocation abilities are different statistically (Ihssen *et al*., 1981; Hair *et al*., 1996). Because of the variation in size of fish from different areas, morphometric and meristic data were statistically adjusted to permit comparative analysis in terms of shape and counts independently of size (Thorpe, 1976). Accordingly, comparison of morphometric data among different

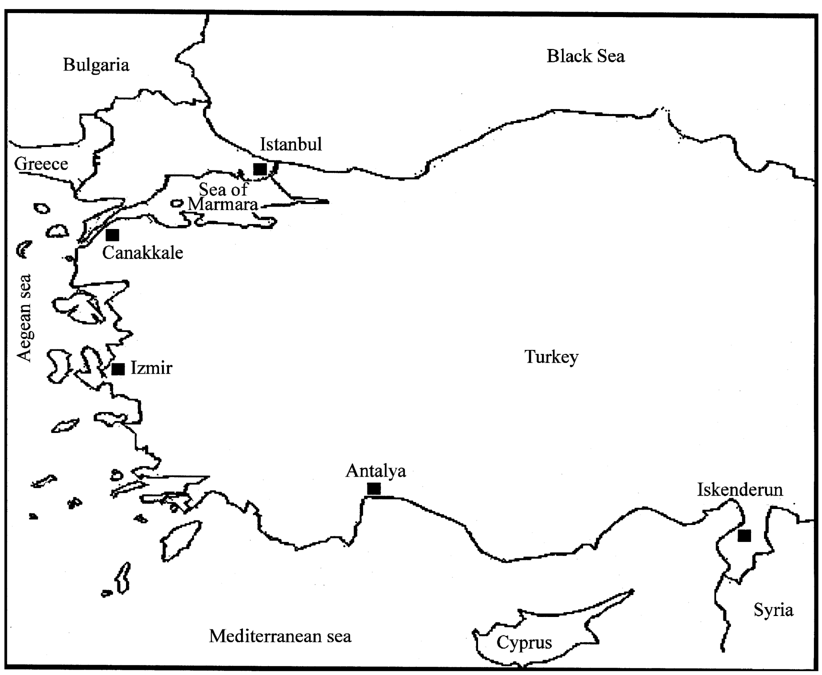
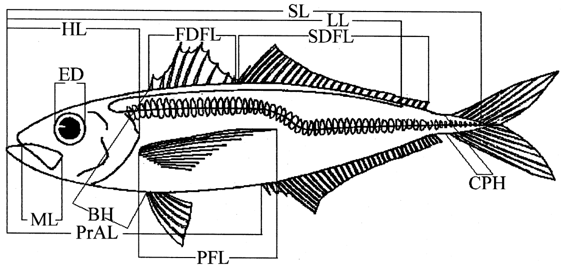



Fig. 1: Map showing the collection localities of *Trachurus trachurus*




| | | | |
|---|---|---|---|
| SL | : Standart Length | HL | : Head Length |
| LL | : Length of Lateral Line | ML | : Maxilla Lenght |
| PrAL | : Preanal Length | BH | : Maximum Body Height |
| PFL | : Pectoral Fin Length | ED | : Eye Diameter |
| FDFL | : First Dorsal Fin Length | CPH | : Minimum Body Height |
| SDFL | : Second Dorsal Fin Length | | |

Fig. 2: Measurements on the body of atlantic horse mackerel (Murta, 2000)

populations should be preceded by a suitable correction to remove size-effect. Carangid fishes show allometric growth (Santic *et al*., 2002). All individual morphometric data were thus corrected, using the following equation (Elliott *et al*., 1995).

$$M_S = M\,(L_O/L_S)^b$$

Working formula for each specimen for a given morphometric character is,

$$\log_{10} M_S = \log_{10} M + b \log_{10} L_S - b \log_{10} L_S$$

where:

- $M_S$ = The standardized character measurement
- $M$ = The observed character measurement
- $L_S$ = The mean standard length for all fish from 5 locations
- $L_O$ = The standard length of the specimen and b is the slope of the regression of $\log_{10} M$ on $\log_{10} L_S$ for all fish

The standardized data were rechecked by correlation against size to see whether the size dependence had been removed and were used in all statistical analysis.

Discriminant Function Analysis (DFA) on morphometrics and meristics were performed to identify the characteristics that were important in distinguishing population groups in the pooled sample. The importance of each character for discriminating among populations was evaluated by a correlation between individual scores of canonical variates and the values of characters for each individual (Strauss, 1985). Classification functions from those morphometric measures and meristic count were formulated for each location to determine the group, to which each case most likely belonged. To investigate the phenotypic relationships between populations a dendrogram was constructed based on Mahalanobis distances using UPGMA cluster analysis of arithmetic averages (Sneath and Sokal, 1973). All data and statistical analyses were carried out using the software package Statistica version 7.0 (Statsoft, USA).

## RESULTS AND DISCUSSION

Overall, 150 specimens of *T. trachurus* were examined for meristic and morphometric data. The mean standard length of *Trachurus trachurus*, covering a wide size-range (range from 107.0-262.0 mm Standart Length (SL)), across all populations amounted to 169.37±42.337 mm.

Derived discriminant functions in DFA using 11 of the size-corrected morphometric characters identified Eye Diameter (ED) as significant contributors that were found to be useful in population differentiation, in order of importance (Wilk's Lambda = 0.10, approx. F (44.135) = 3.115, $p<0.0001$), while, the rest of characters were not significant (Table 1). The Wilks' lambda tests indicated a small difference between the 5 population groups when their morphometric characters were compared by means of discriminant analysis (Table 1). Although, there is a noticeable overlap of individuals, particularly of fish from the Marmara and Aegean, the individuals of the Northeastern Mediterranean (Antalya and Iskenderun) are fairly distinct from those. Different populations from the Northeastern Mediterranean also, showed much higher heterogeneity than the Marmara and Aegean. This heterogeneity is likely to have arisen from the great phenotypic plasticity of fishes in response to changes in environmental factors such as temperature, salinity and food abundance. The mean percentage of specimens correctly classified to original populations was relatively high (87.5%). The plot of the canonical variables 1 and 2 shows a poor discrimination of specimen scores in 5 main groups along CV1 (Fig. 2). As revealed by the respective eigen-values, the first 2 Canonic Variates (CV) were able to explain 92.47% of the total variation existing in the original data. The first Canonical Variate (CV1) was responsible for 71.5% of the variation among-groups, the second (CV2) for 20.9% (Table 2). Examination of the correlations revealed that ED and HL contributed mostly to CV1 and hence, accounted mostly for the variance in the data, whereas BH contributed mostly to CV2. These 3 characteristics also, showed the highest values of correlation with the first and second canonical variables of the discriminant analysis (Table 2), which is useful for discriminating *T. trachurus* populations. The rest of the morphometrics also, contributed significantly to heterogeneity but were not good identifiers of individual populations.

Analyses of the meristic characters revealed no significant differences between the 3 areas. Derived discriminant functions in DFA using 5 meristi.c characters identified SDFR and AFR as significant contributors, in order of importance (Wilk's Lambda = 0.38, approx. $F(20.150) = 3.63$, $p<0.0001$), while Pectoral Fin Ray (PFR), FDFR and number of scale on lateral line (LS) were not significant (Table 1). Wilk's lambda tests showed a small differences among the 5 populations when their meristic characters were compared with morphometrics. Moreover, the stepwise analysis revealed that only 2 meristic characters contributed significantly to the multivariate discrimination of the 5 groups of fish (Table 2). Among the 5 characters that were found to be useful in population differentiation, AFR was the most significant contributor. In this case, the plot of the first two canonical variates (Fig. 3), which account for 53.9 and 26.2% of total variation (Table 2), shows a very high degree of overlap between individuals from all locations and even the centroids for each group are very close to each other. According to these findings, 2 meristic characters (SDFR and AFR) showed significant heterogeneity in *T. trachurus*. These results are in agreement with results obtained for *T. mediterraneus*, which indicate that differences among samples seemed to be associated with the anterior part of the body (Turan, 2004) and coexist within the study area.

To investigate the phenotypic relationships between the examined populations a dendrogram was constructed based on Mahalanobis distances, using UPGMA cluster analysis (Sneath and Sokal, 1973). For both morphometric and meristic characters, the dendrogram obtained by UPGMA cluster analysis was revealed 2 major groups, one containing the populations of the Northeastern Mediterranean (Antalya and Iskenderun) and the other containing the populations of the Aegean (Izmir) and Marmara (Istanbul and Canakkale) localities (Fig. 3). Contribution of each morphometric character to discriminant function were examined and the measurements ED, HL, ML, LL and CPH dominantly contributed to 1st and 2nd DFs, respectively (Fig. 4), implying that these characters are the most important in the description of population characteristics. For the meristics, SDFR and AFR were the most effective characters.

The plots derived from both discriminant function analyses (Fig. 5) also confirmed that morphometric characters are much more effective for discriminating between *T. trachurus* populations than meristic characters, which is expressed lower distances between samples.

Lack of large phenotypic differences among populations as revealed in the present study, indicate that migration among Turkish horse mackerel populations may be limited. The results of DFA show at least 2 phenotypically distinct local populations. The results indicate that no significant heterogeneity in morphology exist among all the populations studied. Morphological variation within species may have occurred due to environmental factors such as temperature such as differentiation related to predation pressures, salinity,

Table 1: Summary of the discriminant function analysis for morphometric and meristic characters

| Characters | Wilks' Lambda | F-remove | P-level | Toler. |
|---|---|---|---|---|
| **Morphometric variables** | | | | |
| HL | 0.078 | 1.102 | 0.370 | 0.252 |
| LL | 0.097 | 3.553 | 0.015 | 0.474 |
| FDFL | 0.072 | 0.446 | 0.773 | 0.579 |
| D2L | 0.073 | 0.519 | 0.721 | 0.792 |
| PrAL | 0.087 | 2.341 | 0.074 | 0.327 |
| BH | 0.090 | 2.700 | 0.046 | 0.252 |
| ED | 0.100 | 3.880 | 0 | 0.284 |
| AL | 0.072 | 0.383 | 0.818 | 0.792 |
| PL | 0.094 | 3.129 | 0.026 | 0.822 |
| CPH | 0.096 | 3.366 | 0.019 | 0.295 |
| ML | 0.094 | 3.142 | 0.026 | 0.428 |
| | | F (44.135) = 3.115 | | |
| Total | 0.069 | | | |
| | | p<0.0001 | | |
| **Meristic variables** | | | | |
| PFR | 0.287 | 0.726 | 0.578 | 0.953 |
| FDFR | 0.274 | 0.204 | 0.934 | 0.972 |
| SDFR | 0.383 | 4.740 | 0 | 0.870 |
| AFR | 0.383 | 4.714 | 0 | 0.855 |
| LS | 0.305 | 1.491 | 0.22 | 0.966 |
| | | F (20.150) = 3.6342 | | |
| Total | 0.27 | | | |
| | | p<0.0001 | | |

Table 2: Structure matrix of discriminant loadings for each of morphometric and meristic variable selected by the backward stepwise Discriminant Function Analysis (DFA)

| Characters | CV 1 | CV 2 | CV 3 |
|---|---|---|---|
| **Morphometric analysis** | | | |
| HL | 0.4284 | 0.0709 | 0.5508 |
| LL | 0.1299 | 0.3508 | -0.7081 |
| FDFL | -0.1936 | 0.0318 | 0.2585 |
| D2L | -0.0856 | -0.3387 | 0.0434 |
| PrAL | 0.0234 | 0.2131 | -0.0136 |
| BH | 0.2937 | 0.9315 | 0.3209 |
| ED | 0.7880 | -0.3234 | -0.2223 |
| AL | 0.2343 | 0.0057 | -0.3842 |
| PL | -0.2402 | -0.3782 | 0.4238 |
| CPH | 0.2787 | -0.4488 | -0.2127 |
| ML | 0.1238 | -0.5128 | -0.1498 |
| Eigenvalue | 4.4230 | 0.9228 | 0.2869 |
| Cum. prop | 0.7254 | 0.8768 | 0.9238 |
| **Meristic analysis** | | | |
| PFR | -0.2606 | -0.2901 | 0.0260 |
| FDFR | -0.0779 | 0.1113 | -0.4227 |
| SDFR | -0.5922 | -0.7270 | 0.4471 |
| AFR | -0.6128 | 0.6813 | -0.5302 |
| LS | 0.1637 | -0.6733 | -0.6791 |
| Eigenvalue | 1.8432 | 0.2543 | 0.0262 |
| Cum. Prop | 0.8631 | 0.9822 | 0.9945 |

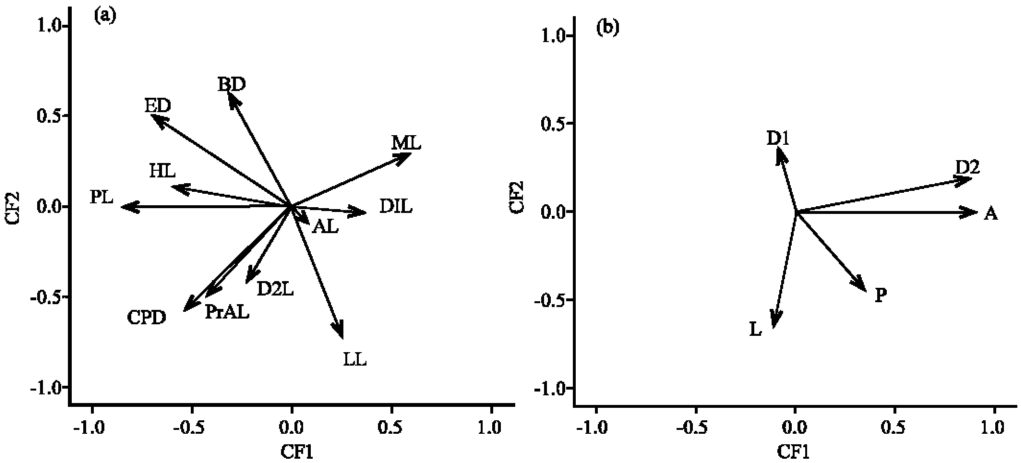



Fig. 3: Contribution of morphometric (a) and meristic (b) characters to the discriminant functions. Vectors indicate the loadings of the scores for each variable on the first and second discriminant functions

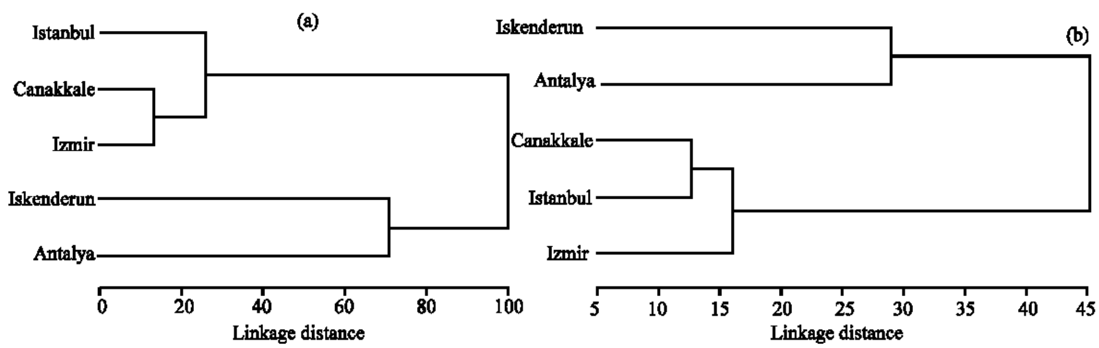



Fig. 4: UPGMA cluster analysis based on mahalanobis D2 distances between the morphometric (a) and meristic (b) characters

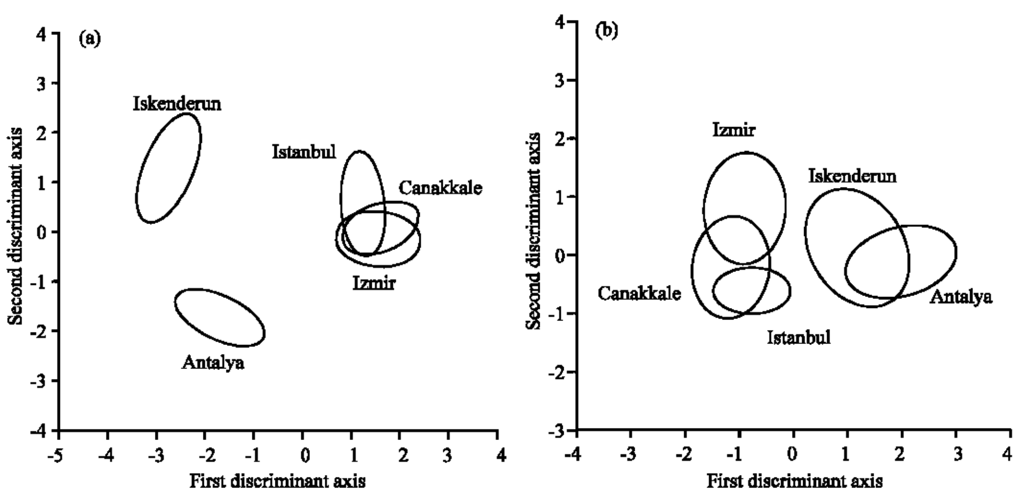



Fig. 5: Scatterplots of the Discriminant Function Analysis (DFA) scores along the 1st and 2nd root for the 5 collection sites of *T. trachurus*, based on the morphometric (a) and meristic (b) characters with 95% confidence ellipses

temperature, food availability (Scapini *et al*., 1999; Maltagliati *et al*., 2003) and there may be enough mixing among these locations to prevent differentiation. Bektas and Belduz (2008) already presented that a few genetic differences have been found among populations of *T. trachurus*. Hence, this heterogeneity among populations is attributed to phenotypic plasticity resulting from environmental variability. The Marmara Sea sample was similar to the Aegean Sea samples for both morphometric and meristic data, which may be attributable to possible inadvertent sampling of migratory horse mackerel in the Marmara Sea. On the other hand, morphometric and meristic data showed the heterogeneity between Aegean and Mediterranean mackerel samples. The Mediterranean samples separated from all others and indicate 2 local populations (Iskenderun and Antalya) for morphometric data, unlike meristic data that revealed no significant differentiation between 2 Mediterranean localities. The dissimilarity between morphometric and meristic data showed that unlike meristic characters, which are fixed early in life, morphometric characters typically show ontogenetic changes associated with allometric growth (Gould, 1966) and may be labile to environmental influences throughout life (Wainwright *et al*., 1991). Besides, there may be some migration between these areas and the meristic data are more sensitive to detect low number of migrants between the areas (Fahy, 1983; Lindsey, 1988; Hulme, 1995). Discriminant function analyses indicated that morphometric and meristic differentiation between the samples was largely due to differences in the head characters of fish, which may reflect differential habitat use.

## CONCLUSION

The results indicate a small degree of spatial separation in morphology in *T. trachurus* among the studied localities. Consequently, *T. trachurus* has been evaluated as a single stock in Turkish coastal waters.

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