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Morphologic structuring between populations of chub mackerel *Scomber japonicus* in the Black, Marmara, Aegean, and northeastern Mediterranean Seas

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Abstract Morphometric and meristic analyses of chub mackerel *Scomber japonicus* were used to discriminate stocks throughout the Black, Marmara, Aegean, and northeastern Mediterranean Seas. Morphometric and meristic analyses showed a similar pattern of differentiation between *S. japonicus* stocks and revealed a clear discreteness of two groups, northeastern Mediterranean (Antalya Bay–Iskenderun Bay) and the northern group, including the Aegean, Marmara, and Black Seas. Univariate analysis of variance showed significant differences between means of the samples for most morphometric and meristic descriptors. The contribution of each variable in distinguishing between the stocks for the first discriminant function revealed high contribution from head size measurements for morphometrics, and first and second dorsal fin rays for meristics. Plotting all specimens on the first two discriminant functions accounted for 76% of total variance for morphometric and 69% of total variance for meristic analyses, and both plots resulted in two main groupings. The overall random assignment of individuals to their original group was higher in morphometric than in meristic analysis.

Keywords Meristics · Morphometrics · *Scomber japonicus* · Stock identification

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Introduction

Chub mackerel, *Scomber japonicus* Houttuyn, 1782 is a broadly exploited pelagic fish species and has a cosmopolitan distribution along warm and temperate waters of the Atlantic, Indian, Pacific Oceans, and in the Mediterranean Sea and the southern part of the Black Sea [1]. Chub mackerel *S. japonicus* is commonly found in Turkish Seas and distinguished from *Scomber scombrus* by bigger eye diameter, absence of swim bladder, and no spots on the abdomen. As a consequence of its broad distribution and the existence of oceanographical barriers, the species may be composed of multiple disjunct stocks. There have been a number of stock structure analyses of chub mackerel species delineated in Atlantic and Pacific waters which report phenotypic and genetic differences between stocks [2–6]. This species is one of the most important commercial fishing species in the Mediterranean Sea. Nevertheless, there is limited information available on the biology, migration, and distribution of chub mackerel in the waters of Turkey. Large purse seiner is the main fishing gear for chub mackerels in offshore waters of Turkey. This species was caught at very high level during the 1980s. However, this decreased very dramatically after 1995 [7]. Total landing amount of this species in the northeastern Mediterranean, Aegean, Marmara, and Black Seas was 9,000 tonnes in 2000 and 1,480 tonnes in 2003 [8, 9]. Landing amount is always highest in the Aegean Sea (approximately 50% of total catch).

For rational and effective fishery management of resources it is necessary and important to know the stock structure of an explored species, as each stock must be managed separately to optimize their yield [10]. Poor understanding of fish and fishery management can lead to

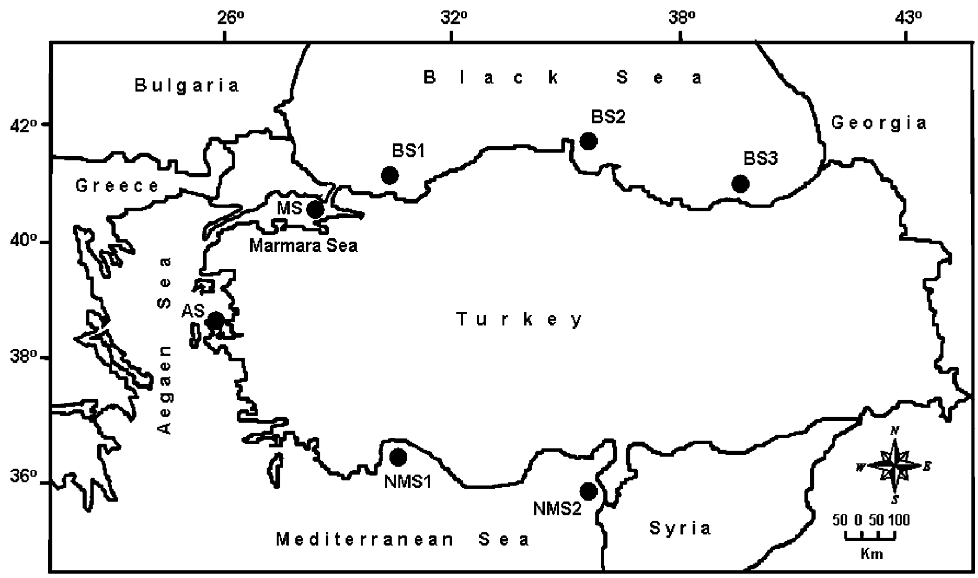

Fig. 1 Sampling locations (*filled circle*) of *S. japonicus*

dramatic changes in the biological attributes and productivity of a species [11–13].

Morphometrics and meristics are the two types of morphologic characteristics that have been most frequently employed to delineate stocks of fish. Morphometrics are continuous characteristics describing aspects of body shape. Meristic characteristics are the number of discrete, serially repeated, countable structures that are fixed in embryos or larvae. Variation in such characteristics was assumed to be entirely genetic in early studies [14–16], but is now known to have both environmental and genetic components [17–19]. Therefore, stocks having the same morphometric and meristic characteristics are often assumed to constitute a single stock. Morphometric and meristic variation between stocks can provide a basis for stock structure, and may be more applicable for studying short-term, environmentally induced variation, perhaps more applicable for fisheries management in comparison with genetic markers [20].

There is currently no knowledge of *S. japonicus* stock structure among fishing areas of Turkish territorial waters. Therefore, this study aims to investigate stock structure of *S. japonicus* based on morphometric characteristics using truss network system and meristic characteristics throughout the Black, Marmara, Aegean, and northeastern Mediterranean Seas.

Materials and methods

Sample collection

Chub mackerel were collected from the northeastern Mediterranean, Aegean, Marmara, and Black Seas (Fig. 1). All samples were collected from commercial vessels, and sampling details are given in Table 1. Samples were frozen soon after collection and defrosted for digital image analysis, which took place about 2 months later to ensure that all fish were analyzed following a similar period of freezing. Taxonomic identification of the samples were carried out according to Whitehead et al. [1] and Turan [21], and the range of observed characteristics of *S. japonicus* was in agreement with the description of Whitehead et al. [1] and Turan [21].

Morphometrics

The truss network system described for fish body morphometrics [22] was used to make a network on fish body; 13 landmarks determining 27 distances were produced and measured, as illustrated in Fig. 2. Images of fish were acquired from a fixed distance with a digital camera, and analyzed using MorFISH [23], an image processing program specially developed for morphometric measurements and analysis of fish populations. The user-friendly interface of the software allows the practitioner to precisely mark and record the *X*–*Y* coordinates of the positions of each landmark to build the truss network. The MorFISH automates the measurements of the distances and accumulates them in a project file for each stock and is capable of carrying out the statistical analysis for allometric eliminations [24]. Additional morphometric measurements, such as eye diameter (ED) and head width (HW) were manually measured. Only undamaged fish were included in the analyses.

Meristics

Meristic characteristics commonly used to distinguish *Scomber* species [21, 25] were analyzed using the number

Table 1 Sampling details of *S. japonicus* used in this study

Sampling site	Abbreviation	Sample size	Date of capture	Sampling method	RSL	MSL ± SD
N. Mediterranean (Antalya Bay)	NMS1	33	Feb. 14, 2007	Purse seiner	142–216	164.33 (8.24)
N. Mediterranean (Iskenderun Bay)	NMS2	35	Feb. 08, 2007	Trawler	154–202	165.06 (11.03)
Aegean Sea	AS	41	Jan 17, 2007	Purse seiner	136–235	166.76 (10.73)
Marmara Sea	MS	35	Feb. 02, 2007	Purse seiner	151–237	173.11 (11.42)
Western Black Sea (Sile)	BS1	33	Feb. 18, 2007	Purse seiner	144–225	165.18 (4.16)
Middle Black Sea (Sinop)	BS2	30	Feb. 24, 2007	Purse seiner	146–248	176.63 (12.23)
Eastern Black Sea (Trabzon)	BS3	36	Feb. 26, 2007	Purse seiner	143–251	174.44 (3.89)

Standard deviation of MSL is given in brackets

RSL Range of standard length (mm); *MSL* Mean standard length

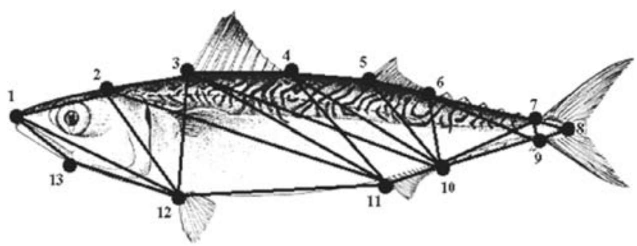

Fig. 2 Locations of the 13 landmarks for constructing the truss network on fish (*filled circle*) and morphometric lengths between dots. Landmarks refer to: (1) anterior tip of snout at upper jaw, (2) most posterior aspect of neurocranium (beginning of scaled nape), (3) origin of dorsal fin, (4) insertion of dorsal fin, (5) origin of second dorsal fin, (6) insertion of second dorsal fin, (7) anterior attachment of dorsal membrane from caudal fin, (8) posterior end of vertebrae column, (9) anterior attachment of ventral membrane from caudal fin, (10) insertion of anal fin, (11) origin of anal fin, (12) insertion of pelvic fin, and (13) posteriormost point of maxillary

of dorsal fin rays (DFR1, DFR2), ventral fin rays (VFR), anal fin rays (AFR), pectoral fin rays (PFR), gill rakers (GR), and caudal fin rays (CFR) under a binocular microscope. Vertebrate numbers (VN) were counted after taking X-ray films of fish.

Multivariate analyses

One-way analysis of variance (ANOVA) was performed to assess the statistical significance of each character for between-stock differentiations. Morphometric and meristic characteristics were used separately in multivariate analyses since these variables are different both statistically (the former are continuous while the latter are discrete) and biologically (the latter are fixed early in development, while the former are more susceptible to the environment) [26].

Most of the variability in a set of multivariate characters is due to size [27]. Thus, shape analysis should be free from the effect of size to avoid misinterpretation of the results [28]. No significant correlations were observed between meristic characteristics and standard length of samples. However, significant correlations were observed between size and morphometric characteristics between the samples. Therefore, transformation of absolute measurements to size-independent shape variables was the first step of the analyses. In order to eliminate any variation resulting from allometric growth, all morphometric measurements were standardized according to Elliott et al. [24].

$$M_{\mathrm{adj}} = M(L_{\mathrm{s}}/L_{\mathrm{o}})^{b},$$

where M is the original morphometric measurement, M_{adj} is the size-adjusted measurement, L_{o} is the standard length of fish, and L_{s} is the overall mean of standard length for all fish from all samples for each variable. The parameter b was estimated for each character from the observed data as the slope of the regression of log M on log L_{o}, using all specimens. Correlation coefficients between transformed variables and standard length were calculated to check if the data transformation was effective in removing the effect of size from the data. The standardized truss measurements showed no significant correlation with standard length. Therefore, the size effect had been successfully removed with the allometric transformation.

Classification functions were derived from stepwise discriminant function analysis (DFA) to assign individual specimens to putative stocks. Centroids with 95% confidence ellipses derived from the DFA were used to show segregation between the stocks. The classification success rate was evaluated based on percentage of individuals correctly assigned into original sample. All statistical analyses were performed using SPSSv12 and SYSTAT v10.

Results

Morphometrics

There was no significant correlation ($P > 0.05$) between standardized truss measurements and standard length,

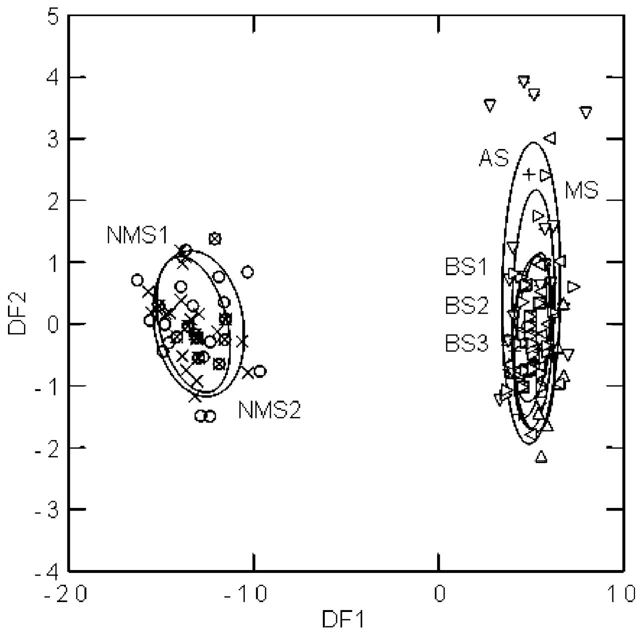

Fig. 3 Plot of first two discriminant functions and 95% confidence ellipses of DFA scores for morphometric analysis

Table 2 Percentage of individuals reallocated in each sample in the validation of the discriminant function analyses for morphometric and meristic data

Sample	NMS1	NMS2	AS	MS	BS1	BS2	BS3
Morphometric							
NMS1	**70**	30	0	0	0	0	0
NMS2	28	**72**	0	0	0	0	0
AS	0	0	**43**	15	12	7	23
MS	0	0	25	**42**	6	6	21
BS1	0	0	19	18	**39**	9	15
BS2	0	0	9	12	13	**43**	23
BS3	0	0	21	17	6	11	**45**
Meristic							
NMS1	**59**	41	0	0	0	0	0
NMS2	38	**62**	0	0	0	0	0
AS	0	0	**41**	22	10	12	15
MS	0	0	29	**42**	3	6	20
BS1	0	0	15	21	**39**	10	15
BS2	0	0	20	23	3	**40**	14
BS3	0	0	8	16	9	24	**43**

indicating that the size effect was successfully removed with the allometric transformation. Univariate analysis of variance (ANOVA) revealed significant differences ($P < 0.001$) between means of the seven samples for 26 out of 30 standardized morphometric measurements (only 7_9, 10_9, 6_9, and 7_10 were not significantly different, $P > 0.05$).

Plotting all specimens on the first two discriminant functions accounted for 76% of total variance and resulted in two main groups: the first group included samples from the northeastern Mediterranean (NMS1 and NMS2); the second group included the sample from the waters of the Aegean, Marmara, and Black Seas (Fig. 3). The overall random assignment of individuals into their original sample was low (51%) (Table 2). The proportion of correctly classified individuals into their original samples revealed high intermingling between the Aegean (43%), Marmara (42%), and Black Sea (39–45%) samples.

The primary morphometric descriptors that dominantly contributed to first DF were from the measurements on the head, 2_12, HW, and 2_13 (Table 3). The DF2 was dominated by the variables 13_12, 1_13, and 4_5.

Meristics

Univariate analysis of variance (ANOVA) revealed significant differences between means of the seven samples for three out of seven standardized morphometric measurements (only GR, VN, and CFR were not significantly different, $P > 0.05$).

In discriminant function analysis, six discriminant functions (DFs) were produced, and the first canonical function accounted for the largest amount of between-stock variability (46%), the second and third accounted for 23% and 12%, respectively. Plotting DF1 and DF2 explained 69% of the between stock variation and revealed stock differentiation (Fig. 4). The 95% confidence ellipses of the two northeastern Mediterranean samples (NMS1 and NMS2) overlapped and were clearly distinct from other samples (0% of individuals were classified into these two samples). The other samples from the waters of the Aegean, Marmara, and Black Seas overlapped each other and formed a stock. The overall random assignment of individuals into their original sample was low (47%) (Table 2). The proportion of correctly classified individuals into their original sample was highest in the Iskenderun Bay sample (55%) and lowest in the Sile (39%) sample.

The characteristics of primary importance in distinguishing between the stocks for the first and second discriminant functions were DFR1, DFR2 and PFR, GR, respectively (Table 3).

Discussion

The morphologic data reveal the clear existence of two groups, northeastern Mediterranean (Antalya Bay–Iskenderun Bay) and northern group, including the Aegean, Marmara, and Black Seas. Both morphometric and meristic methods indicated that chub mackerels from the

Table 3 Contribution of morphometric and meristic variables to the canonical functions

Characters	Function					
	DF1	DF2	DF3	DF4	DF5	DF6
Morphometrics						
2_12	0.216*	0.108	−0.074	0.085	−0.162	0.090
HW	0.207*	−0.048	−0.030	0.081	−0.140	0.127
2_13	0.155*	0.029	0.044	−0.061	0.017	0.181
13_12	0.005	0.278*	0.148	−0.270	−0.091	0.149
1_13	−0.004	−0.172*	0.322*	−0.145	−0.167	0.091
4_5	0.096	0.118*	0.284*	−0.070	−0.084	−0.043
12_11	0.113	−0.092	0.241*	0.150	−0.214	0.103
7_8	0.030	0.106	0.213*	0.013	−0.065	0.045
6_11	0.107	0.041	0.155*	−0.003	−0.085	0.024
3_12	0.079	0.213	0.045	−0.286*	0.150	0.209
4_11	0.116	−0.059	0.009	−0.242*	−0.191	−0.110
6_10	0.035	0.143	0.077	−0.186*	−0.037	0.140
ED	0.023	−0.013	0.028	−0.179*	−0.121	0.083
11_10	0.075	0.058	0.065	−0.177*	−0.053	0.001
5_11	0.090	0.115	0.167	−0.068	−0.301*	0.046
V.U	0.174	−0.146	−0.172	−0.012	−0.269*	0.238
2_3	−0.068	0.014	−0.050	−0.025	−0.117*	0.095
7_10	0.018	0.186	0.249	0.162	−0.047	0.476*
1_12	0.043	0.007	−0.030	0.006	−0.136	0.463*
10_9	0.009	0.421	0.125	0.029	−0.163	0.456*
6_9	−0.010	0.043	0.129	−0.088	0.018	0.378*
6_7	−0.008	−0.061	0.036	0.193	−0.043	0.339*
7_9	−0.020	0.186	0.225	−0.050	0.153	0.319*
4_12	0.033	0.240	0.181	−0.039	0.203	0.316*
1_2	0.134	0.313	0.136	−0.158	−0.131	0.314*
3_11	0.072	0.081	−0.007	−0.001	−0.043	0.306*
3_4	−0.020	0.233	0.120	0.123	0.018	0.287*
9_8	0.227	0.225	0.070	−0.201	0.063	0.272*
5_6	−0.004	0.025	−0.024	−0.068	−0.146	0.210*
5_10	0.077	−0.099	−0.137	−0.013	−0.142	0.156*
Meristic						
DFR2	0.817*	0.276	0.229	−0.105	0.221	0.210
DFR1	−0.588*	−0.174	0.247	0.083	0.305	0.247
PFR	−0.317	0.738*	0.188	0.304	0.363	0.073
GR	0.049	−0.112	0.662*	−0.162	−0.171	0.546
VN	0.089	−0.062	0.025	0.826*	−0.452	0.318
AFR	0.197	−0.473	−0.045	0.331	0.672*	0.189
CFR	0.026	−0.149	0.480	0.281	0.051	−0.809*

Variables ordered by absolute size of correlation within function. * Largest absolute correlation between each variable and any discriminant function

northeastern Mediterranean (Antalya Bay–Iskenderun Bay) had a morphotype distinct from the remaining areas. Discrimination of the two morphotypes was confirmed statistically by the significant difference between population centroids and by the percentage of reallocation.

In the first discriminant function, morphometric characters on the head played an important role in differentiation between the samples examined. The northeastern Mediterranean chub mackerels had a larger head and smaller mouth size than the chub mackerels from the

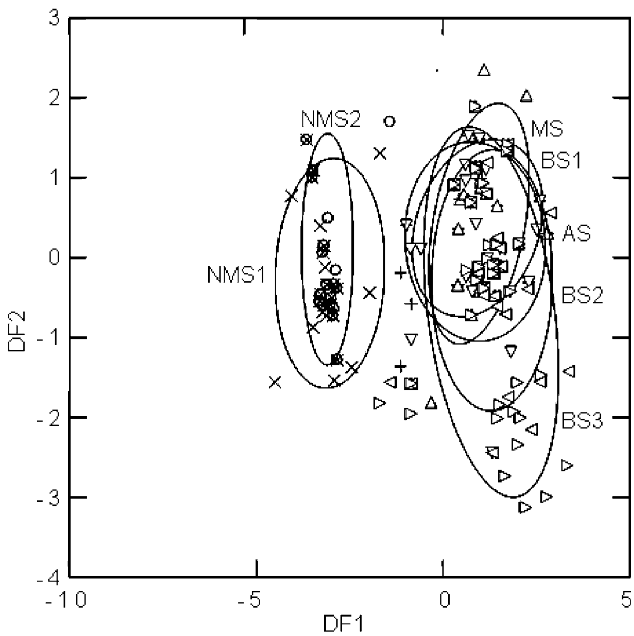

Fig. 4 Plot of the first two discriminant functions and 95% confidence ellipses of DFA scores for meristic analysis

northern group (Aegean, Marmara, and Black Seas), perhaps attributable to growth responses to the differing habitats arising from oceanographical and ecological conditions. The greater zooplankton productivity of the Aegean, Marmara, and Blacks Seas could account for the adaptive trend towards the development of a larger head and mouth to enhance feeding activity. These differences reinforce the results of a recent multivariate study of chub mackerel morphometry in the southwest Atlantic Ocean that reported that greater head length but lower mouth width and interorbital length were the primary characteristic difference between the stocks [4]. Perrotta et al. [29] also reported that increase in the length of the body of chub mackerel correlates with decreasing head size, which is related to a migration feeding strategy.

Meristic methods also support that chub mackerels from northeastern Mediterranean are distinct from the remaining areas. First and second dorsal fin rays in the first discriminant function had highest loadings to differentiate stocks. Environmental differences which isolate stocks and cause limited intermingling between the areas may contribute the detected differentiation; for example, southern Turkish waters (northeastern Mediterranean) have higher temperature than northern Turkish waters (Aegean, Marmara, and Black Seas). Fahy [30] reported temperature effect on the number of dorsal fin rays developing in *Fundulus majalis*.

Morphometric studies have proved to provide an insight into discrimination of marine stocks [15]. However, it is now commonly accepted that morphological variation has both environmental and genetic components. Thus, morphometric differences may reflect genetic differences between the stocks and/or environmental differences between localities. Therefore, stock identification based on morphological characters must be confirmed by genetic evidence to verify that the phenotypic differences reflect some degree of reproductive isolation rather than simply environmental differences. On the other hand, stock discrimination by morphologic markers might be appropriate for fisheries management even if this phenotypic divergence is not reflected by genetic differentiation [31, 32].

In conclusion, there are two groups of chub mackerel in the waters off Turkey, northeastern Mediterranean group and northern group, including the Aegean, Marmara, and Black Seas. Although environmental factors may govern to some degree the potential morphological differentiation of chub mackerel aggregations, the detected pattern of differences at least shows that there is some restriction to intermingling between stocks. Further understanding of differentiation must await broader samplings throughout the species range, collections of molecular genetic data such as microsatellites, and physical tagging programs designed to measure long-distance movements of chub mackerel.

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