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Geographic and Sex-Based Morphometric Variation in Horse Mackerel (*Trachurus trachurus* Linnaeus, 1758) from Eastern, Central, and Western Algeria: Implications for Stock Identification

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ABSTRACT

The variability of thirty-one morphometric and eight meristic characters of *Tracharus tracharus* L., collected between 2018 and 2020 from three stations along the Algerian coast (East, Centre, and West), was examined using 905 specimens ranging in total length from 9 to 24 cm. The results revealed that individuals of indeterminate sex constituted the majority of the sample (55.42%), with the highest proportion recorded in Oran (69%). Geographic region proved to be the main discriminating factor (P = 0.000), more influential than sex (P = 0.280). Specimens from Annaba exhibited a more robust morphology compared to those from Algiers. Morphometric characteristics were significantly more effective than meristic traits in distinguishing individuals from the three studied regions, whereas meristic characters did not allow for clear differentiation among sampling sites. Although sexual dimorphism was moderate at the national scale, it was more pronounced in Algiers. The observed differences mainly involved greater development of the dorsal and anal fins in males and increased posterior body length in females. The clear separation into three geographic groups in the discriminant analysis supports the existence of distinct stocks (East, Centre, and West), highlighting the need for region-specific fisheries management strategies.

INTRODUCTION

Due to its semi-enclosed nature, its east–west orientation, and its geological history, the Mediterranean Sea is considered a hotspot of marine biodiversity (**Boudouresque, 2004; Cuttelod *et al*., 2009**). There are 16,848 species (**Dauvin *et al*., 2013**). Although it covers less than 1% of the world's oceans, it is home to nearly 18% of macroscopic marine species, around 30% of which are endemic (**Coll *et al*., 2012**). However, the overexploitation of fishery resources is well documented: it affects 35% of stocks worldwide (**FAO, 2022**), but reaches 91% in the Mediterranean, where 59% of pelagic species are affected (**Dahel &

Djebbar, 2024). In Algeria, small pelagic species account for around 80% of the potential of this fishery, with horse mackerel representing 17% (**MPPH, 2023**).

The common horse mackerel (*Trachurus trachurus*) (Pisces: Carangidae) is classified as a vulnerable species worldwide (**Smith-Vaniz *et al*., 2015**). Its distribution covers the Atlantic and extends into the Mediterranean Sea (**Abaunza *et al*., 2004**). It is a major pelagic resource for many fisheries around the world (**FAO, 2010; Costa *et al*., 2017**) and also plays a central role in marine ecosystems due to its position in the food web: it serves as prey for large pelagic species while feeding on other species of fisheries interest, notably anchovies (**Milisenda *et al*., 2018**). Although the biology of this species (morphology, reproduction, physiology, growth, etc.) has been widely studied in the Mediterranean (**Murta, 2000; Van Beveren *et al*., 2016; Ferreri *et al*., 2019; Rodríguez-Castañeda *et al*., 2024**), studies conducted in Algeria have also addressed these aspects, both in the western part of the country (**Ichalal *et al*., 2015; Gherram *et al*., 2018; Ichalal *et al*., 2019; Rahmani *et al*., 2020a; Rahmani *et al*., 2020b; Rahmani *et al*., 2021**) and in the east (**Ichalal *et al*., 2016; Azzouz *et al*., 2019; Dahel & Djebbar, 2024**). Finally, a comprehensive review (**Nasri *et al*., 2024**) compiled and analyzed all available knowledge on this species.

Algeria's geographical position, influenced by currents from the Atlantic Ocean, results in high hydrological variability at the mesoscale, providing access to significant fishery resources (**Dahel & Djebbar, 2024**). According to **Millot (1985)**, the instability of the Algerian Current creates temperature and salinity gradients between different regions (**Mallil *et al*., 2022**) that are likely to induce phenotypic variations within the studied fish population (**Mounir *et al*., 2019; Houeto *et al*., 2024**). These variations include morphometric and meristic characteristics and can be influenced by sex, food availability, predator–prey interactions, and other factors. They are valuable tools for identifying fish stocks (**Jawad *et al*., 2018; Labidi *et al*., 2021; Rodríguez-Castañeda *et al*., 2024**).

Despite previous studies, the stock of *Trachurus trachurus* along the 1,200 km of Algerian coastline remains poorly understood. The study conducted by **Azzouz (2018)**, although it addressed morphological differences between regions, was limited by a small sample size of 30 individuals per region and did not consider the effect of sex.

This study aims to analyze the morphometric variations observed in the common horse mackerel (*Trachurus trachurus*) across three distinct areas (East, Centre, and West). Two hypotheses are examined: (i) the populations studied exhibit sexual dimorphism; and (ii) morphometric traits differ according to geographical location. The results could help better define regional stocks and support the development of appropriate exploitation strategies for each region.

MATERIALS AND METHODS

Study area

The Algerian basin is generally divided into three main areas: a western area, extending from the Algerian–Moroccan border in the west to Ténès in the east; an eastern area, stretching from Dellys in the west to the Algerian–Tunisian border in the east; and a central area (**Hemida, 2005**). Sampling was carried out at three Algerian ports (Fig. 1), approximately 400 km apart in a straight line: the port of Annaba (located at the eastern end of the eastern basin; 36°54′06.15″ N, 7°46′23.54″ E), the port of Algiers (in the centre of the central basin; 36°46′30.67″ N, 3°04′05.73″ E), and the port of Oran (at the western end of the western basin; 35°42′39.96″ N, 0°38′40.30″ E).

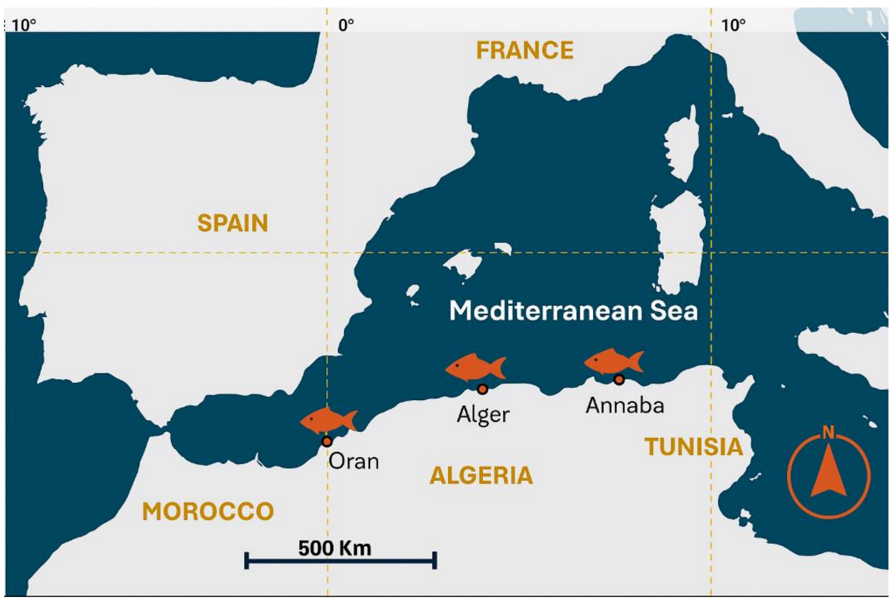

Fig. 1. Location of the study area and stations (: study station)

Sampling and treatment

Samples of horse mackerel (*Trachurus trachurus*) were collected from commercial fishing landings in the three ports mentioned above. A total of 905 fish were collected at random to cover all size classes: 400 in Annaba (October 2018), 255 in Algiers (January 2019) and 250 in Oran (January 2020). The samples were transported in a cooler and then stored frozen until analysis.

Measured parameters

A total of 39 morphometric parameters were selected and measured using an ichthyometer. The measurements included the following parameters: Total Length (TL), Fork

Length (FL), Standard Length (SL), Head Length (HL), Orbital Diameter (OD), Pre-Orbital Distance (PrOD), Post-Orbital Distance (PoOD), Maxillary Length (ML), Pre-Dorsal Length (PDL), Pre-Pectoral Length (PPL), Pre-Pelvic Length (PPvL), Pre-Anal Length (PAL), Pectoral Fin Length (PFL), First Dorsal Fin Height (1DFH), Second Dorsal Fin Height (2DFH), Pelvic Fin Height (PvFH), Anal Fin Height (AFH), First Dorsal Fin Base Length (1DFB), Second Dorsal Fin Base Length (2DFB), Anal Fin Base Length (AFB), Inter-Dorsal Space (IDS), Dorsal/Pectoral Distance (D/Pc), Dorsal/Pelvic Distance (D/Pv), Dorsal/Anal Distance (D/A), Dorsal/Caudal Distance (D/C), Pectoral/Pelvic Distance (Pc/Pv), Pelvic/Anal Distance (Pv/A), Body Depth (BD), Caudal Peduncle Height (CPH), Body Thickness (BT), Interorbital Space (IO), and using an electronic balance (Scout Pro) with 0.01g precision for the total weight (TW).

Eight (8) meristic parameters were recorded using the naked eye or a binocular magnifier: number of spines on the first dorsal fin (NSD1), number of soft rays on the second dorsal fin (NSRD2), number of spines on the anal fin (NSA), number of soft rays on the anal fin (NSRA), number of lower gill rakers (NLgr), number of upper gill rakers (NUgr), number of scales on the lateral line (NSLL), and number of vertebrae (NV). A total of ten (10) individuals from each population were selected for these counts. Sex was determined by dissection.

Data analysis

The analyses were performed separately for morphometric (continuous) and meristic (discrete) characters. Meristic characters are fixed early in development (**Allendorf *et al*., 1987; Murta, 2000**). Descriptive statistics (mean, standard deviation, and mode) were calculated for each site.

Body measurements were expressed relative to total length (TL) or head length (HL) using the least squares method (reduced major axis), based on the regression equation recommended by **Teissier (1948)**. The normality of data distribution was assessed using the Shapiro–Wilk test ($P < 0.05$). A Box–Cox transformation was applied to normalize the data prior to performing a one-way analysis of variance (ANOVA). When significant differences were detected, a Tukey post hoc test was conducted. Finally, Linear Discriminant Analysis (LDA) was performed to identify the most discriminating factors among populations.
All statistical analyses were carried out using R (version 4.4.3) and Minitab.

RESULTS

Variation in TL in both sexes at the three study stations

Fig. (2) shows the variation in total length according to sex. The total length (n = 905 individuals) of the samples ranged from a minimum of 9 cm in Annaba to a maximum of 24.7 cm in Oran. Females were slightly larger than males, and both sexes were significantly larger than indeterminate individuals, which constituted 55.42% of the total sample, compared to 29.31% females and 15.26% males.

The sex ratio favored males in specimens from Annaba and Algiers, whereas it was reversed in Oran. A high proportion of indeterminate individuals was observed at all sites, accounting for 56% in Algiers, 47% in Annaba, and 69% in Oran.

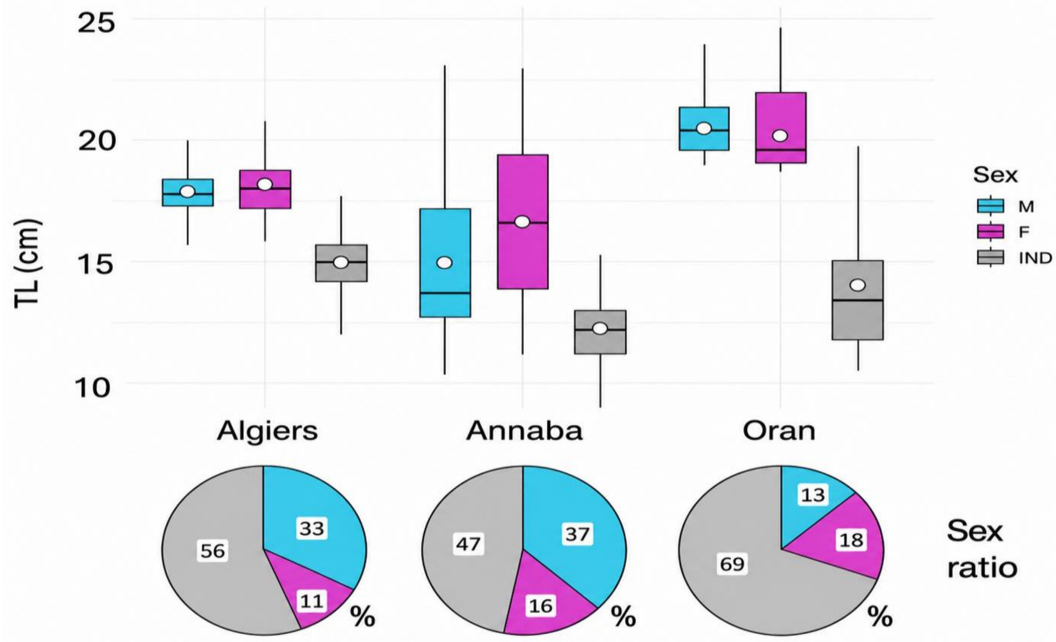

Fig. 2. Variation in total length of individuals according to sex and sex ratio at the three study stations.

Numerical parameters

Statistical analysis (Table 1) revealed a highly significant difference ($P < 0.001$) in all parameters counted and between the three stations, except for the number of anal spines, which was always equal to 2. The 30 individuals selected (10 per population) had almost the same number of vertebrae, with a mode of 23 vertebrae for Annaba and Oran, and a mode of 22 for Algiers.

Table 1. Descriptive statistics (mean ± standard deviation and mode) for the different characteristics studied in the populations of Annaba (An), Algiers (Al) and Oran (Or)

Character	**Region**	NSD1	NSRD2	NSA	NSRA	NLgr	NUgr	NSLL
Mode	An	7	33	2	29	44	17	69
	Al	8	33	2	30	47	16	72
	Or	9	32	2	30	39	15	76
Average	An	7 ± 0	32 ± 1.81	2 ± 0	28.79 ± 1.27	43.79 ± 2.01	17 ± 0	67.76 ± 3.15
	Al	8 ± 0.06	33.51 ± 1.26	2 ± 0	29.73 ± 1.23	45.54 ± 1.74	16.33 ± 0.88	72.11 ± 3.43
	Or	8.8 ± 0.49	32.61 ± 1.65	2.01 ± 0.11	29.31 ± 1.31	40.47 ± 3.04	15.05 ± 1.27	73.76 ± 5.3
Tukey test	An	a	a	a	a	a	a	a
	Al	b	b	a	b	b	b	b
	Or	c	c	b	c	c	c	c

The letters from Tukey's test (a, b, c) indicate statistically identical groups: a letter common to two populations means there is no significant difference between them.

Metric parameters

a. Discriminant analysis

Linear discriminant analysis, based on 31 parameters measured in the three regions and for each gender (Fig. 3), shows that the most discriminating factor is the region (Algiers, Annaba, Oran) with a value of P = 0.000, which is highly significant, compared to the gender factor, whose value of P = 0.280 is not statistically significant. The Algiers region, according to the LD2 axis, shows more marked sexual dimorphism than the populations of Annaba and Oran, which show partial overlap.

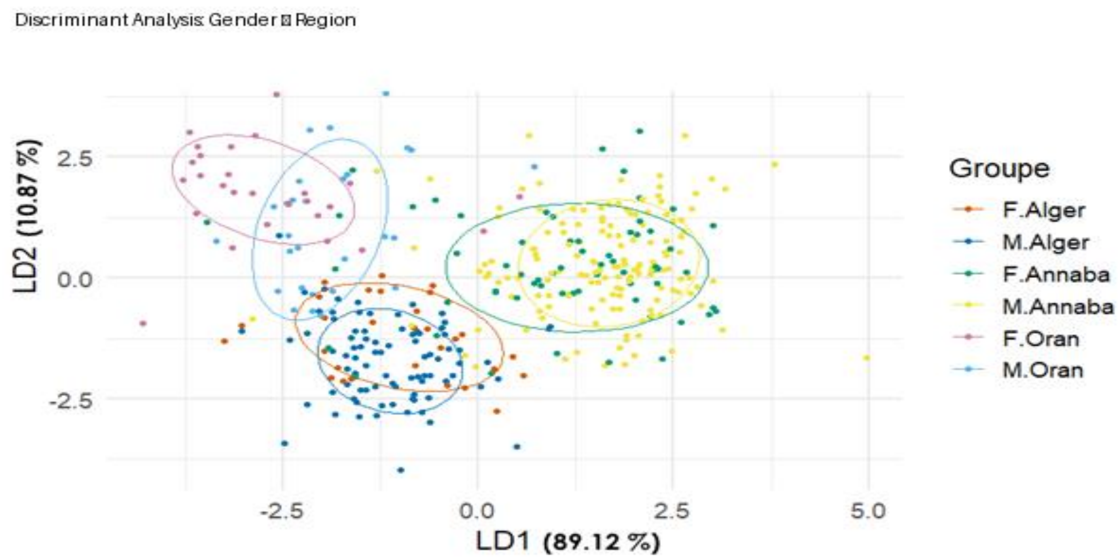

Fig. 3. Linear discriminant analysis (LDA) based on metric parameters

b. Parameter variation

Fig. (4) summarises the mean values and standard deviation of the percentages of the 30 parameters measured separately for the male and female populations according to region and type of allometry.

Relative growth analysis reveals that 50% of parameters exhibit positive allometry (+), while 44% follow isometry (=) and 6% negative allometry (-) with a significant correlation ($0.71 \leq r \leq 0.98$).

Individuals from the same region evolve in the same way, whereas a clear difference is observed between individuals from different regions. The most discriminating parameters are: PDL, PAL, PFL, 1DFB, 2DFB, D/Pv, D/A, D/C, BD, BT, CPH, PoOD, ML, et IO.

Sexual dimorphism is moderate and is expressed in only a limited number of parameters, reflecting relatively small morphological differences between males and females. It mainly involves the dorsal and anal fins, as well as certain trunk-related ratios, including PFL, 1DFB, 2DFB, D/Pv, D/A, D/C, AFB, and PvFH. In general, males exhibit more developed dorsal and anal fins, whereas females display a proportionally longer posterior body length. Overall, the observed sexual dimorphism is moderate but evident, primarily associated with the morphology of the dorsal and pectoral fins and specific trunk morphometric ratios.

Morphometric diversity among the three sampling stations is particularly pronounced, with significant differences observed for most characteristics, including PDL, PAL, PFL, 1DFB, 2DFB, D/Pv, D/A, D/C, BD, BT, CPH, PoOD, ML, and IO. These results indicate clear interpopulation morphometric variation. Individuals from Annaba generally exhibit the highest values for most of these parameters, whereas those from Algiers tend to show the lowest values. Specimens from Oran often occupy an intermediate position, sometimes comparable to Annaba, particularly for dorsal and anal fin lengths.

The characteristics showing the least variation among stations are mainly those related to standard length, total length, and certain head measurements, indicating an overall morphological stability in general body shape.

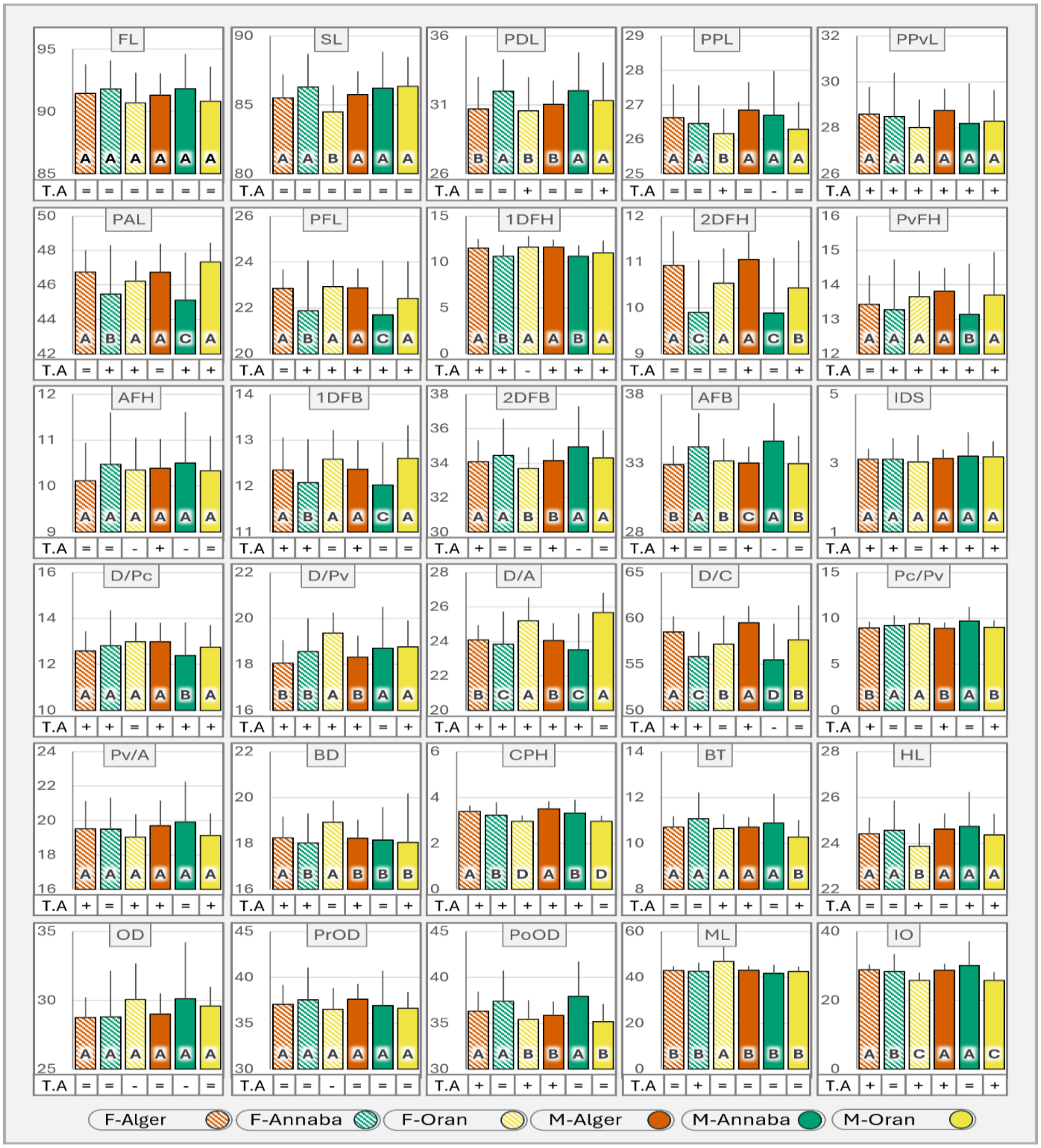

Fig. 4. Comparison of metric parameter averages. The letters A, B, C, and D from Tukey's test indicate that groups sharing the same letters do not differ significantly. The type of allometry is represented by + (upward allometry), - (downward allometry), and = (isometric growth). (Fork Length (FL), Standard Length (SL), Pre-Dorsal Length (PDL), Pre-Pectoral Length (PPL), , Pre-Pelvic Length (PPvL), Pre-Anal Length (PAL), Pectoral Fin Length (PFL), First Dorsal Fin Height (1DFH), Second Dorsal Fin Height (2DFH), Pelvic Fin Height (PvFH), Anal Fin Height (AFH), First Dorsal Fin Base Length (1DFB), Second Dorsal Fin Base Length (2DFB), Anal Fin Base Length (AFB), Inter-Dorsal Space (IDS), Dorsal/Pectoral Distance (D/Pc), Dorsal/Pelvic Distance (D/Pv), Dorsal/Anal Distance (D/A), Dorsal/Caudal Distance (D/C), Pectoral/Pelvic Distance (Pc/Pv), Pelvic/Anal Distance (Pv/A), Body Depth (BD), Caudal Peduncle Height (CPH), Body Thickness (BT), Head Length (HL), Orbital Diameter (OD), Pre-Orbital Distance (PrOD), Post-Orbital Distance (PoOD), Maxillary Length (ML) , Interorbital Space (IO).

DISCUSSION

In light of the results, morphometric and meristic measurements reveal significant phenotypic heterogeneity among *Trachurus trachurus* specimens sampled along the Algerian coastline. Furthermore, discriminant analysis (LDA) highlights three local populations that are clearly differentiated in terms of phenotype.

The study of total length in *T. trachurus* revealed a size range of 9 to 24.7 cm (based on 905 individuals). Compared with results reported by other researchers in Algeria, these values fall within the ranges currently observed along the Algerian coastline: from 6.4 to 30.5 cm on the eastern coast (**Dahel & Djebbar, 2024**), around 18 cm (**Gherram *et al*., 2018**), and from 10.2 to 34.4 cm for males and from 9.1 to 35.1 cm for females on the western coast (Oran/Béni Saf) (**Rahmani *et al*., 2020**).

In other Mediterranean regions, the maximum size reported for *T. trachurus* reaches 60 cm in the northwestern Mediterranean Sea (**Lloris & Moreno, 1995**). However, several studies report lower size ranges: from 3.5 to 35.5 cm in the western Mediterranean (**Rodríguez-Castañeda *et al*., 2024**), from 7.8 to 33.8 cm along the Moroccan coast (**Nasri *et al*., 2024**), and an average length of 12.4 cm (7.9–19.02 cm) in Turkey (**Aydin & Karadurmus, 2012**). Individuals measuring between 16 and 25 cm have also been reported, with variations linked to season and study area (**Abaunza *et al*., 2003**).

Several factors influence the distribution of length classes within a population, including growth, mortality, fishing gear selectivity, and, above all, sampling strategy (**Rahmani, 2020**). These findings may also be explained by differences in ecological conditions (temperature, salinity, food availability), fishing pressure on stocks (**DIE, 2001; Aydin & Karadurmus, 2012; Dahel & Djebbar, 2024**), or adaptive phenotypic responses. Such responses may result in changes in size at first maturity, fecundity, condition factor, and age structure, likely driven by both exploitation and environmental conditions (**Rodríguez-Castañeda *et al*., 2024**). According to **Ouled-Cheikh *et al*. (2022)**, individuals exposed to unfavorable environments allocate more energy to adaptation, increasing their vulnerability to external stressors.

According to **Abaunza *et al*. (2003)**, one biological characteristic of Carangidae is that females generally attain slightly larger sizes than males, possibly due to differences in reproductive investment. In this study, indeterminate individuals constituted the majority (55.42%), with regional variation: 56% in Algiers, 47% in Annaba, and 69% in Oran. This high proportion of indeterminate specimens may indicate that Algerian coastal waters serve as important nursery and spawning grounds for horse mackerel, consistent with observations by **Basilone *et al*. (2023)**.

Variations in sex ratio among stations may result from spatial segregation related to differing trophic or reproductive requirements between males and females (**Abaunza *et al*., 2003**), or from size-selective fishing. Our findings differ from those of **Gherram *et***

***al*. (2018)**, who reported no significant difference between male and female proportions. However, they are consistent with **Azzouz *et al*. (2019)**, who reported a slight male predominance (49.98%), also observed in Annaba and Algiers. In Oran, the pattern is reversed, possibly due to the sampling period (January), which overlaps with the breeding season (December to April) (**Azzouz *et al*., 2019**). Additionally, this variability may be linked to physiological factors and diet (**Dahel & Djebbar, 2024**). According to **Abaunza *et al*. (1995)**, sex ratios may vary depending on population structure and breeding season, and males may be more vulnerable to fishing gear.

Regarding meristic characters, the number of vertebrae remains relatively constant, with values of 22 in Algiers and 23 in Annaba and Oran. However, a clear geographical pattern emerges: all measured traits, except for anal spines (consistently numbering two), show highly significant differences (iP < 0.001) among the three Algerian sites. This suggests potential stock differentiation; otherwise, individuals from different sites would exhibit similar averages.

The presence of highly significant differences may indicate limited gene flow or geographic isolation among populations (**Turan, 2004**). **Abaunza *et al*. (2008a)** reported that variability in meristic traits in *T. trachurus* reflects local environmental conditions, particularly temperature and salinity during early development. However, **Murta (2000)** noted that these traits alone are insufficient to clearly distinguish geographic populations.
Despite observed differences, meristic values in this study are consistent with those reported by the **FAO (1987)**. The number of upper gill rakers ranges from 15 to 18, and lower gill rakers from 41 to 48. The first dorsal fin has eight spines, while the second has one spine and 29–33 soft rays. The anal fin has two detached spines, followed by one spine and 24–29 soft rays. The lateral line comprises 66–75 scales. These characteristics confirm species identification.

In terms of morphometric variability, the results show a clear separation of populations according to geographic origin, confirmed by discriminant analysis (P = 0.000). Individuals from Annaba exhibit a more robust morphology and more developed fins (PDL, PAL, PFL, 1DFB, 2DFB) than those from Algiers.

These phenotypic differences, reflected in body shape, highlight the high plasticity of horse mackerel in response to local environmental conditions such as primary productivity and temperature (**Winton *et al*., 2014; Ferreri *et al*., 2019**). Similarly, **Basilone *et al*. (2023)** showed that variations in body shape and condition reflect adaptive responses to hydrodynamic conditions.
Although the effect of sex is not statistically significant (P = 0.280), sexual dimorphism remains observable, particularly in dorsal, pectoral, and anal fin morphology (PFL, 1DFB, 2DFB, AFB). This dimorphism is more pronounced in Algiers, suggesting that selective pressures vary along the Algerian coast. This local variation may result from ecological or sexual selection pressures specific to the central region.

According to **Abaunza *et al*. (2008b)**, *T. trachurus* exhibits regional morphological variability, and dimorphism may fluctuate depending on hydrodynamic isolation. The instability of the Algerian Current generates gradients in temperature and salinity (**Millot, 1985; Mallil *et al*., 2022**), which may drive phenotypic variation (**Mounir *et al*., 2019; Houeto *et al*., 2024**). Growth patterns observed in this study include 50% positive allometry, 44% isometry, and 6% negative allometry, reflecting substantial growth plasticity (**Murta, 2000**).

In conclusion, *T. trachurus* exhibits both spatial and sex-related morphological variability along the Algerian coast. Rather than a single homogeneous stock, the species appears to consist of several distinct populations distributed across the region. These findings support the existence of three morphological stocks (East, Centre, and West) and highlight the need for region-specific fisheries management strategies to ensure sustainable exploitation of this resource in Algeria.

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