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**ARAŞTIRMA MAKALESİ** **RESEARCH PAPER**

# An Empirical Comparison of Sex Ratio, Condition Factor, and Length–Weight Relationships in Commercial Catch of Mediterranean Horse Mackerel from the Sea of Marmara, the Middle and Eastern Black Sea

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**Abstract:** Fish length–weight relationships are essential for estimating biomass and assessing fish population health, typically showing low variation within and between neighbouring stocks. This study investigates the length–weight relationships of Mediterranean horse mackerel (*Trachurus mediterraneus*) collected from the Sea of Marmara, the Middle Black Sea, and the Eastern Black Sea during 2022. In addition, the study assessed the sex ratio and Fulton's condition factor (*kc*) of Mediterranean horse mackerel at each station, alongside an examination of length-frequency samples, providing a comprehensive analysis. The one-way ANCOVA analysis showed no significant differences in length–weight regression between the sexes. However, it identified a considerable area effect, with samples from the Sea of Marmara significantly differing from those in the Middle Black Sea and Eastern Black Sea. The fish samples from the latter areas displayed moderate length–weight variation, which was close to the significance threshold with a *P*-value of 0.069. The growth pattern of Mediterranean horse mackerel consistently exhibited negative allometry across all sampled areas for both males and females, except for female Mediterranean horse mackerel from the Middle Black Sea, which tended to follow an isometric growth pattern. This study revealed consistent results within neighbouring areas (Middle Black Sea and Eastern Black Sea) and significant variations when comparing the Black Sea and Sea of Marmara Mediterranean horse mackerel, highlighting notable large-scale spatial trends.

**Keywords:** Growth, pelagic fish, simple power function, stock identification, Türkiye.

# Marmara Denizi, Orta Karadeniz ve Doğu Karadeniz'den ticari av kompozisyonundan örneklenen istavrit balığı (*Trachurus mediterraneus*)'nın Cinsiyet Oranı, Kondisyon Faktörü ve Boy–Ağırlık İlişkisinin Ampirik Karşılaştırması

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**Öz:** Balıklarda boy–ağırlık ilişkileri balık popülasyonlarının değerlendirilmesi ve biyokütle tahmininde kullanılan bir parametre olup, genellikle yakın bölgelerde yaşayan balık stokları arasında düşük varyasyon gösterir. Bu çalışma, 2022 yılında Türkiye'den Marmara Denizi, Orta Karadeniz ve Doğu Karadeniz'den avlanan istavrit (*Trachurus mediterraneus*) örneklerinin boy-ağırlık ilişkilerini incelenmiştir. Ayrıca, bu çalışma, her istasyondaki istavrit balığının cinsiyet oranını ve kondisyon faktörünü değerlendirerek boy-frekans analizleri yapılmıştır. Tek yönlü ANCOVA analizi, cinsiyetler arasında boy-ağırlık regresyonunda anlamlı farklılıklar olmadığını göstermiştir. Ancak, bu çalışmada Marmara Denizi'nden alınan örneklerin Orta Karadeniz ve Doğu Karadeniz'den alınan örneklere göre farklı olduğu tespit edilmiştir. İkincil bölgelerden alınan balık örnekleri, anlamlılık eşiğine yakın olan 0,069 ile orta düzeyde boy–ağırlık varyasyonu sergilemiştir. İstavrit balığının büyüme deseni, erkekler ve dişiler için tüm örnek bölgelerinde tutarlı bir şekilde negatif alometrik olduğu tespit edilmiştir. Ancak Orta Karadeniz'den avlanan dişi örnekler izometrik bir büyüme tipinde olduğu belirlenmiştir. Bu çalışma, komşu bölgelerde (Orta Karadeniz ve Doğu Karadeniz) tutarlı sonuçlar ortaya koyarken, Karadeniz ve Marmara Denizi istavritleri karşılaştırıldığında önemli farklılıklar olduğunu göstermiş ve kayda değer büyük ölçekli mekânsal eğilimleri vurgulamıştır.

**Anahtar kelimeler:** Basit üssi fonksiyon, büyüme, pelajik balık, stok belirleme, Türkiye.

## INTRODUCTION

Deoxygenation, the reduction of oxygen levels in the marine environment, directly affects the survival, growth, and reproduction of aquatic organisms, posing significant challenges to their long-term sustainability (Brander, 2010; Cheung et al., 2013; Poloczanska et al., 2016; Froese et al., 2022). This alarming global pattern, involving a 2% decline in oceanic oxygen levels since the mid-20th century (Schmidtko et al., 2017), is expected to persist over the coming centuries, with potential adverse consequences for marine organisms and ecosystem dynamics (Bopp et al., 2013; Oschlies, 2021; Kim et al., 2023). Likewise, within Turkish marine waters, there has been a noticeable warming trend in surface temperatures in recent decades. This trend encompasses various regions, including the Mediterranean, Aegean, Marmara, and Black Seas (Bricaud et al., 2002; Ginzburg et al., 2004; Mel'nikova et al., 2023), indicating the widespread impact of rising temperatures in these waters. The Black Sea experienced particularly pronounced warming between 1980 and 2000, with temperatures increasing at a rate of 0.09° C per year (Ginzburg et al., 2004). Furthermore, a massive marine mucilage outbreak in the Sea of Marmara from November 2020 to July 2021 led to oxygen depletion, resulting in widespread mortality events including fish and invertebrates (Karadurmuş, 2022; Karadurmuş & Sari, 2022).

Several studies have emphasised the importance of determining length–weight relationships in fish, providing valuable insights into various aspects of fish biology, not only about the general health of fish but also provide information about the morphological characteristics of the fish, growth pattern, habitat conditions, life history, and fish fatness and condition (Schneider et al., 2000; Froese, 2006; Gerritsen & McGrath, 2007; Cilbiz & Yabim, 2017). This concept derives from the empirical observation that fish inhabiting more favourable ecological conditions tend to exhibit higher body weights relative to their length measurements (Froese, 2006; Nguyen et al., 2023). The Fulton's condition factor (*kc*) can also assess fish health and growth, where high values indicate good health and ample food, whereas low values indicate stress or competition for resources (Cren, 1951; Froese, 2006). The length–weight relationship of fish has exhibited minimal variation within or between neighbouring stocks (Gerritsen & McGrath, 2007), and hence occasionally leads to the use of data from nearby stocks when data on length–weight relationship for a specific fish stock are sparse (ICES, 2004). However, several studies have demonstrated that fish length–weight relationships and condition indices vary significantly across large-scale spatial distances (Brodziak & Mikus, 2000; Gerritsen & McGrath, 2007).

Mediterranean horse mackerel (Carangidae: *Trachurus mediterraneus*, Steindachner, 1868) is a commercially important migratory semi-pelagic carnivorous fish with a wide distribution encompassing the Eastern Central and Northeastern regions of the Atlantic Ocean, the Black Sea, the Sea of Marmara, and the Mediterranean (Wheeler, 1987; Yankova, 2011; FAO, 2023). Türkiye accounted for up to 63% of the global yield of this fish from the Black Sea and Mediterranean Sea, followed by Spain with a contribution of around 11% (FAO, 2023). The highest Turkish landing of Mediterranean horse mackerel in the last decade was reported at 24,625 tonnes in 2012 (TurkStat, 2022; FAO, 2023). Türkiye reported its lowest catches of Mediterranean horse mackerel in 2020 at 7,495 tonnes, although it saw a significant increase to 19,590 tonnes next year (TurkStat, 2022).

Several studies have parameterised the length–weight relationships of Mediterranean horse mackerel using a simple power function (Kasapoğlu, 2006; Bostanci, 2009; Özdemir et al., 2010; Samsun et al., 2018; Koç & Erdoğan, 2019; Şahin & Ceylan, 2023). However, previous studies have generally focussed on obtaining Mediterranean horse mackerel from a single study area, and none of them have investigated the length–weight relationships of Mediterranean horse mackerel from various locations within Turkish marine waters during the same period. Consequently, the main objectives of this study were to determine the length–weight relationships and Fulton's condition factor (*kc*) for Mediterranean horse mackerel acquired from the Sea of Marmara, Middle Black Sea, and Eastern Black Sea during the same period. Secondly, the study investigated the assumption that the length–weight relationship and Fulton's condition factor (*kc*) exhibit minimal variation between neighbouring stocks (e.g., Middle Black Sea vs. Eastern Black Sea), and that this variation becomes more pronounced as the spatial distance increases (e.g., Black Sea vs. Sea of Marmara). Thirdly, this study aimed to assess the utility of the length–weight relationship as a potential marker for fish stock identification.

## MATERIAL AND METHOD

***Fish acquisition:*** Specimens of Mediterranean horse mackerel from the Sea of Marmara, the Middle and Eastern Black Sea were obtained directly from local fishing vessels from September 12 to 22, 2022 (Figure 1). The specimens were then transferred to the laboratory in well-insulated Styrofoam containers, which were maintained under ice cover during transport. In the laboratory, the total length ($L_T$) of each individual fish was measured to the nearest 0.1 cm, and their total weight ($T_W$) was recorded to the nearest 0.01 g. Subsequently, the fish were dissected to

determine its sex through the examination of gonads with the naked eye (Anna et al., 2022).


**Figure 1.** Study area map with sampling locations marked as solid circles (Sources: Esri, HERE, Garmin, FAO, NOAA, USGS).

***Length–weight relationship:*** The relationship between length and weight was established by applying a simple power function (Mazlum & Turan, 2018).

$$T_W = \alpha {L_T}^{\beta} \quad (1)$$

In this equation, $\alpha$ denotes the intercept, while $\beta$ represents the slope. The slope value $\beta$ is an indicative of the fish's growth pattern:

- When $\beta$ equals 3, it signifies isometric fish growth.
- $\beta$ values below 3 denote negative allometric growth, where fish become slimmer as they grow.
- Conversely, $\beta$ values exceeding 3 suggest positive allometric growth, indicating that fish become heavier relative to their length, generally reflecting optimal growth conditions.

***Fulton's condition factor* (*kc*):** The Fulton's condition factor (*kc*) was determined using the following equation (Fulton, 1911):

$$C_F = \frac{W \cdot 100}{{L_T}^3} \quad (2)$$

***Statistical analysis:*** The chi-square test ($\chi^2$) was used to evaluate the sex ratio and determine whether it deviated from the hypothetical distribution of 1:1 ratio. The size–frequency distributions of males and females were compared in each sampling area using a two-sample Kolmogorov-Smirnov test. In addition, this test was used to assess variations in length–frequency distributions within pairs of stations.

To assess fish isometry, Student's *t*-test was used to measure the deviation of $\beta$ from the isometric value of 3.0. The one-way analysis of covariance (ANCOVA) was used to examine how gender (male and female) and sampling stations affect the length–weight relationships of Mediterranean horse mackerel. In this analysis, fish weight served as the response variable.

The non-parametric Kruskal-Wallis test was used to evaluate significant differences in the Fulton's condition factor (*kc*) of Mediterranean horse mackerel among the Sea of Marmara, the Middle Black Sea, and the Eastern Black Sea. Sexual dimorphism in Fulton's condition factor (*kc*) for each station was assessed using the Mann–Whitney U test. All statistical analyses were performed using R, version 4.2 (R Core Team, 2020) with the inclusion of packages like 'FSA,' 'ggplot2,' 'HH,' 'SP,' and 'Tidyverse'.

## RESULTS

***Sex ratio and length-frequency distribution:*** The sex ratio was (M:F) 1.0:1.0 for the Mediterranean horse mackerel sample from the Sea of Marmara, 1.0:1.1 for the Middle Black Sea, and 1.0:1.0 for the Eastern Black Sea. These ratios did not significantly deviate from the hypothetical distribution of 1:1 ($\chi^2$ =0.010, $P$ = 0.922 for the Sea of Marmara; $\chi^2$ = 0.155, $P$ = 0.694 for the Middle Black Sea; $\chi^2$ = 0.003, $P$ = 0.960 for the Eastern Black Sea.

The length-frequency distribution of male and female Mediterranean horse mackerel did not differ significantly at each sampling area (2-sample Kolmogorov–Smirnov test, $Z$ = 1.191, $P$ = 0.117 for the Sea of Marmara; $Z$ = 1.065, $P$ = 0.206 for the Middle Black Sea; $Z$ = 0.569, $P$ = 0.902 for the Eastern Black Sea). However, the length–frequency distributions between pairs of stations exhibited significant differences (2-sample Kolmogorov–Smirnov test, $Z$ = 4.286, $P$ < 0.001 for the Sea of Marmara vs. the Middle Black Sea; $Z$ = 7.795, $P$ < 0.001 for the Sea of Marmara vs. the Eastern Black Sea; $Z$ = 3.111, $P$ < 0.001 for the Eastern Black Sea vs. the Middle Black Sea). The dominant size classes of Mediterranean horse mackerel from the Sea of Marmara were 11.0–11.5 cm and 11.5–12.0 cm, followed by 10.5–11.0 cm. In the Middle Black Sea, the dominant size classes were 13.0–13.5 cm and 13.5–14.0 cm, followed by 11.0–11.5 cm, whereas in the Eastern Black Sea, the dominant size classes were 13.0–13.5 cm and 12.5–13.0 cm, followed by 13.5–14.0 cm (Figure 2).

***Length–weight relationship:*** The minimum and maximum total lengths of the Mediterranean horse mackerel from the Sea of Marmara were 9.2 cm and 13.4 cm, respectively. In the Middle Black Sea, these measurements ranged from 9.6 cm to 16.5 cm, whereas in the Eastern Black Sea, they varied between 8.0 cm and 14.8 cm. The estimated $\beta$ values of $W = \alpha {L_T}^{\beta}$ were 2.5 for females and 2.9 for male Mediterranean horse mackerel from the Sea of Marmara. In the Middle Black Sea, the estimates were 3.0 for females and 2.9 for males, whereas in the Eastern Black Sea, females had an estimated value of 2.7, and males had an estimated value of 2.7 (Table 1). The growth pattern of Mediterranean horse mackerel consistently displayed negative allometry across all sampled areas for both males and females, except for female Mediterranean horse mackerel from the Middle Black Sea, which tended to follow an isometric growth pattern.

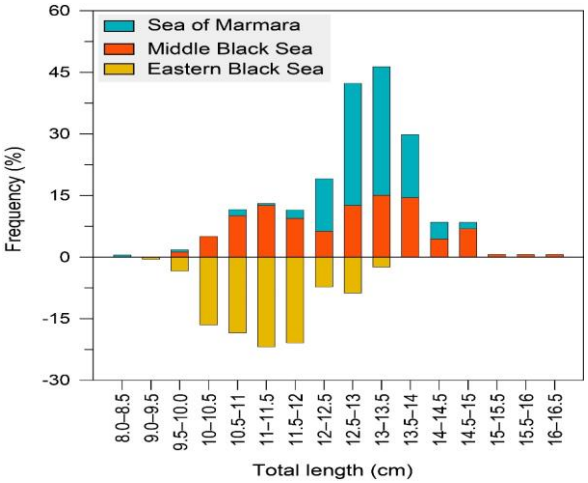


**Figure 2.** Length–frequency distribution of the Mediterranean horse mackerel (*Trachurus mediterraneus*) from the Sea of Marmara, the Middle Black Sea, and the Eastern Black Sea.

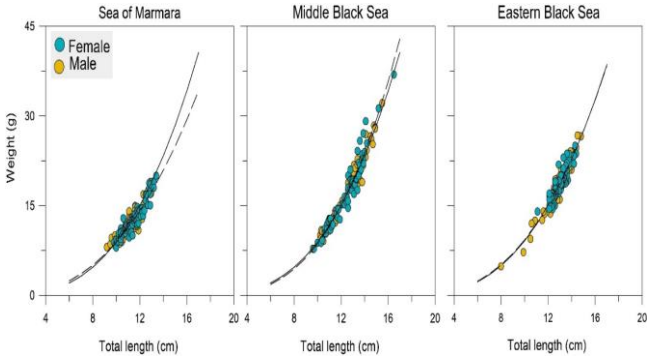


**Figure 3.** Length–weight relationships for the Mediterranean horse mackerel (*Trachurus mediterraneus*) sampled from the Sea of Marmara, Middle Black Sea, and Eastern Black Sea. The solid lines depict the curve for male fish, whereas the dashed lines represent the curve for female fish. These curves were obtained using a simple power function with the estimated values provided in Table 1..

**Table 1.** Summary statistics (mean ± 95% CI) of length–weight relationships $T_W = \alpha L_T^{\beta *}$ for Mediterranean horse mackerel (*Trachurus mediterraneus*) sampled from the Sea of Marmara, Middle Black Sea, and Eastern Black Sea.

| | | Length (cm) | | Total weight (g) $T_w$ | Length-Total Weight Relationship | | | Student's *t*-test for $\beta$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *n* | Min – Max | $L_T$ | | $\alpha$ | $\beta$ | Adj. $R^2$ | *t* | *P* | Growth |
| **SEA OF MARMARA** | | | | | | | | | | |
| Overall | 206 | 9.2 ± 13.4 | 11.3 ± 0.1 | 12.2 ± 0.3 | 0.027 ± 0.009 | 2.521 ± 0.142 | 0.851 | -6.624 | <0.001 | Negative allometric |
| Female | 104 | 9.8 ± 13.4 | 11.4 ± 0.2 | 12.6 ± 0.5 | 0.025 ± 0.012 | 2.544 ± 0.190 | 0.867 | -4.709 | <0.001 | Negative allometric |
| Male | 102 | 9.2 ± 13.0 | 11.1 ± 0.2 | 11.9 ± 0.5 | 0.012 ± 0.004 | 2.860 ± 0.125 | 0.968 | -2.203 | 0.029 | Negative allometric |
| **MIDDLE BLACK SEA** | | | | | | | | | | |
| Overall | 159 | 9.6 ± 16.5 | 12.5 ± 0.2 | 17.5 ± 0.9 | 0.010 ± 0.003 | 2.930 ± 0.108 | 0.951 | -1.281 | 0.201 | Isometric |
| Female | 83 | 9.7 ± 16.5 | 12.5 ± 0.3 | 17.5 ± 1.2 | 0.008 ± 0.004 | 3.022 ± 0.176 | 0.934 | 0.242 | 0.809 | Isometric |
| Male | 76 | 9.6 ± 15.5 | 12.5 ± 0.3 | 17.5 ± 1.4 | 0.012 ± 0.004 | 2.860 ± 0.125 | 0.968 | -2.203 | 0.029 | Negative allometric |
| **EASTERN BLACK SEA** | | | | | | | | | | |
| Overall | 195 | 8.0 ± 14.8 | 13.0 ± 0.1 | 18.6 ± 0.4 | 0.018 ± 0.007 | 2.698 ± 0.155 | 0.878 | -3.820 | <0.001 | Negative allometric |
| Female | 97 | 11.1 ± 14.4 | 13.0 ± 0.1 | 18.9 ± 0.5 | 0.020 ± 0.013 | 2.677 ± 0.265 | 0.804 | -2.389 | 0.018 | Negative allometric |
| Male | 98 | 8.0 ± 14.8 | 12.9 ± 0.2 | 18.5 ± 0.7 | 0.018 ± 0.008 | 2.717 ± 0.187 | 0.917 | -2.972 | <0.001 | Negative allometric |

The one-way ANCOVA analysis revealed no significant sexual dimorphism in the length–weight relationships of Mediterranean horse mackerel as determined for the Sea of Marmara, Middle Black Sea, and Eastern Black Sea (Table 2). However, it is worth noting that in the case of Mediterranean horse mackerel sampled from the Middle Black Sea, the absence of sexual dimorphism in the length–weight relationships was found to be marginally significant, with a *P*-value of 0.07, approaching the conventional threshold for significance. In addition, Student's *t*-test revealed evidence of sexual dimorphism in the growth patterns of Mediterranean horse mackerel sampled from the Middle Black Sea. This suggests that although the one-way ANCOVA analysis did not find significant differences in length–weight relationships, there may still be distinctions in growth between male and female Mediterranean horse mackerel from the Middle Black Sea.

In contrast to the absence of sexual dimorphism, one-way ANCOVA revealed a significant regional effect, particularly distinguishing samples from the Sea of Marmara from those collected in the Middle and Eastern Black Sea (Table 3). The length–weight relationships for Mediterranean horse mackerel samples from the Middle and Eastern Black Sea were notably similar. This resemblance between the Middle and Eastern Black Sea samples was supported by a *P*-value of 0.07, which closely approached the conventional significance threshold.

**Table 2.** One-way analysis of covariance (ANCOVA) results testing the effects of gender on (log-transformed) length–weight relationships of Mediterranean horse mackerel (*Trachurus mediterraneus*) from the Sea of Marmara, Middle Black Sea, and Eastern Black Sea, with fish weight (g) as the response variable.

| Source of variation | Df | Sum Sq | Mean Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| **SEA OF MARMARA** | | | | | |
| Total length (cm) | 1 | 1.26 | 1.26 | 1082.88 | <0.001 |
| Sex | 1 | 0.00 | 0.00 | 0.67 | 0.410 |
| Total length:Sex | 1 | 0.00 | 0.00 | 0.14 | 0.710 |
| Residuals | 202 | 0.24 | 0.00 | | |
| **MIDDLE BLACK SEA** | | | | | |
| Total length (cm) | 1 | 3.16 | 3.16 | 3666.10 | <0.001 |
| Sex | 1 | 0.00 | 0.00 | 0.00 | 0.970 |
| Total length:Sex | 1 | 0.00 | 0.00 | 3.22 | 0.070 |
| Residuals | 155 | 0.13 | 0.00 | | |
| **EASTERN BLACK SEA** | | | | | |
| Total length (cm) | 1 | 1.20 | 1.20 | 1825.95 | <0.001 |
| Sex | 1 | 0.00 | 0.00 | 1.37 | 0.240 |
| Total length:Sex | 1 | 0.00 | 0.00 | 0.82 | 0.370 |
| Residuals | 191 | 0.13 | 0.00 | | |

**Table 3.** One-way analysis of covariance (ANCOVA) results analysing the effect of sampling stations on (log-transformed) length–weight relationships of Mediterranean horse mackerel (*Trachurus mediterraneus*) in the Sea of Marmara, Middle Black Sea, and Eastern Black Sea.

| Source of variation | Df | Sum Sq | Mean Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| **SEA OF MARMARA vs. MIDDLE BLACK SEA** | | | | | |
| Total length (cm) | 1 | 6.12 | 6.12 | 5923.91 | <0.001 |
| Station | 1 | 0.03 | 0.03 | 32.49 | <0.001 |
| Total length:Station | 1 | 0.04 | 0.04 | 37.55 | <0.001 |
| Residuals | 361 | 0.37 | 0.00 | | |
| **SEA OF MARMARA vs. EASTERN BLACK SEA** | | | | | |
| Total length (cm) | 1 | 5.81 | 5.81 | 6334.17 | <0.001 |
| Station | 1 | 0.05 | 0.05 | 49.52 | <0.001 |
| Total length:Station | 1 | 0.01 | 0.01 | 14.33 | <0.001 |
| Residuals | 397 | 0.36 | 0.00 | | |
| **MIDDLE BLACK SEA vs. EASTERN BLACK SEA** | | | | | |
| Total length (cm) | 1 | 4.53 | 4.53 | 6009.49 | <0.001 |
| Station | 1 | 0.00 | 0.00 | 3.04 | 0.082 |
| Total length:Station | 1 | 0.00 | 0.00 | 3.34 | 0.069 |
| Residuals | 350 | 0.26 | 0.00 | | |

*Fish weight (g) as the response variable.

***Fulton's condition factor* (*kc*):** The estimated minimum and maximum Fulton's condition factor (*kc*) of Mediterranean horse mackerel in the Sea of Marmara ranged from 0.7 to 1.1 for females and 0.6 to 1.1 for males. In the Middle Black Sea, these values were between 0.7 and 1.0 for females and 0.7 and 1.0 for males, whereas in the Eastern Black Sea, the Fulton's condition factor (*kc*) ranged from 0.8 to 1.0 for females and 0.7 to 1.0 for males (Figure 4). These Fulton's condition factor (*kc*) values were subjected to the Kruskal–Wallis test, which revealed statistically significant differences among the sampling stations ($H_5$ = 14.433, $P$ = 0.013). However, upon further analysis using Dunn's test for multiple comparisons, no significant differences were observed within the pairs of stations for Mediterranean horse mackerel.

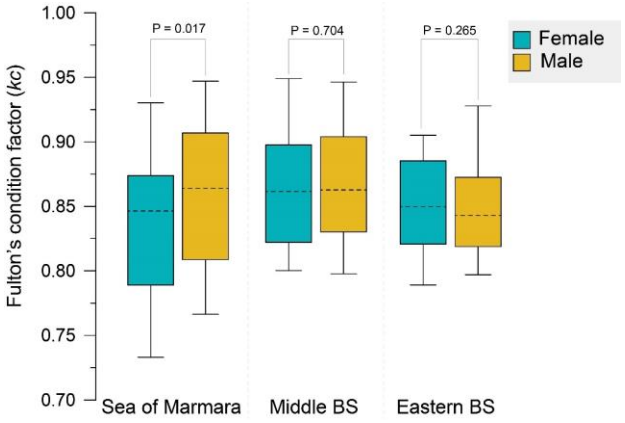


**Figure 4.** Boxplots of Fulton's condition factor (*kc*) for Mediterranean horse mackerel from the Sea of Marmara, Middle and Eastern Black Seas. Dashed lines indicate the mean values. The statistical significance of the differences between males and females was assessed using the Mann–Whitney U Test. 'BS' in the figure represents the Black Sea.

The estimated Fulton's condition factor (*kc*) for male and female Mediterranean horse mackerel from the Sea of Marmara exhibited significant variations (Mann-Whitney U Statistic= 4281.5, $P$ = 0.017). However, no such significant variations in Fulton's condition factor (*kc*) between male and female Mediterranean horse mackerel were observed in the samples from the Middle and Eastern Black Sea (Figure 4).

## DISCUSSION

This study revealed a consistent negative allometric growth pattern in Mediterranean horse mackerel across all sampled areas for both males and females, except female Mediterranean horse mackerel from the Middle Black Sea, which tended to exhibit an isometric growth pattern. The results regarding the negative allometric pattern of Mediterranean horse mackerel in the Sea of Marmara are in line with previous studies (Bostanci, 2009; Koç & Erdoğan, 2019). However, the negative allometric pattern observed in Mediterranean horse mackerel from the Middle and Eastern Black Sea is inconsistent with earlier studies that generally reported an isometric growth pattern for Mediterranean horse mackerel in the Black Sea (Table 4). Furthermore, Santic et al. (2006) demonstrated seasonal variation in the length–weight relationship of Mediterranean horse mackerel in the Eastern Adriatic Sea: positive allometric growth in late spring and summer (May, June, and July), negative allometric growth in autumn (September and October), while isometric growth in other months. The observed seasonal variation in the length–weight relationship of a fish species has been attributed to its reproductive cycle, which is correlated with the gonadosomatic index (GSI) (Santic et al., 2006; Nguyen et al., 2023).

The Fulton's condition factor (*kc*) is a commonly employed measure for assessing the overall health of fish: a Fulton's condition factor (*kc*) of 1 generally indicates good condition, while <1 suggests slimness in fish, and more than 1 indicates fatness of fish (Piper, 1972; Joergensen, 2017). In this study, the mean Fulton's condition factor (*kc*) of Mediterranean horse mackerel ranged from 0.84 to 0.87. These lower Fulton's condition factor (*kc*) values are likely the result of the fish predominantly completing their spawning activities in September, an assumption supported by Santic et al. (2006). They noted that the Fulton's condition factor (*kc*) of Mediterranean horse mackerel in the Eastern Adriatic Sea remained constant during the pre-spawning period, declined during spawning (in August), reached its lowest point in September immediately after spawning, and then increased during the gonadal recovery phase, ultimately peaking in December.

In this study, the length–weight relationship did not differ between male and female Mediterranean horse mackerel sampled from the Sea of Marmara, Middle and Eastern Black Sea (one-way ANCOVA, $P$ > 0.05), consistent with previous findings (Santic et al., 2006; Şahin & Ceylan, 2023). However, sexual dimorphism in the

length–weight relationship of the Mediterranean horse mackerel may become obvious during the summer months (e.g., June and July) when the GSI of the Mediterranean horse mackerel reaches its peak (Santic et al., 2006).

This study observed significant differences in the length–weight relationship of Mediterranean horse mackerel among the Sea of Marmara, Middle, and Eastern Black Sea (one-way ANCOVA, $P < 0.05$). The variation in the length–weight relationship increased with greater geographical distances, leading to a considerable distinction between the Mediterranean horse mackerel from the Sea of Marmara and those from the Black Sea in terms of their length–weight relationships. These results reaffirmed the general assumption of minimal variation within or between neighbouring stocks that vary significantly across large-scale spatial distances (Brodziak & Mikus, 2000; ICES, 2004; Gerritsen & McGrath, 2007). Several studies have proposed that fish populations may exhibit heightened morphological variation in response to increasing environmental diversity (Dürrani et al., 2022). This implies that as environmental heterogeneity grows, intra-population differences in body shape and size become more prominent (Griffiths et al., 2000; Lázaro-Nogal et al., 2015; Malinich, 2019; Dürrani et al., 2022). Consequently, the relatively similar environmental conditions found in the Eastern Black Sea and Middle Black Sea, compared to the Sea of Marmara, might result in less noticeable body shape variation among Mediterranean horse mackerel within the Black Sea (Durrani et al., 2022).

**Table 4.** Literature data on total length and parameters of the length–weight relationship (LWR) for Mediterranean horse mackerel (*Trachurus mediterraneus*) from the Sea of Marmara, Middle Black Sea, and Eastern Black Sea.

| | | | Length (cm) | Parameters of the LWR | | |
|---|---|---|---|---|---|---|
| **REGION** | **Sampling periods** | **n** | **Min – Max** | ***α*** | ***β*** | **REFERENCE** |
| Eastern Black Sea | Oct. 2010 - Mar. 2011 | 690 | 6.2 - 20.4 | 0.0067 | 3.165 | Kasapoğlu (2006) |
| Sea of Marmara | 01 - 28 Apr. 2006 | 158 | 7.9 - 16.5 | 0.0115 | 2.9367 | Bostanci (2009) |
| Middle Black Sea | 2008 - 2009 | 902 | 7.8 - 18.0 | 0.0074 | 3.0445 | Özdemir et al. (2010) |
| Middle Black Sea | Sep. 2016 - Mar. 2017 | 1467 | 7.1 - 20.3 | 0.0067 | 3.0848 | Samsun et al. (2018) |
| Sea of Marmara | Sep. 2013 - Dec. 2015 | 1232 | 9.7 - 17.6 | 0.0440 | 2.4700 | Koç and Erdoğan (2019) |
| Eastern Black Sea | Sep. 2019 - Aug. 2020 | 1533 | 8.5 - 18.4 | 0.0063 | 3.0980 | Şahin and Ceylan (2023) |
| Sea of Marmara | 19 Sep. 2022 | 206 | 9.2 - 13.4 | 0.0270 | 2.5210 | |
| Middle Black Sea | 22 Sep. 2022 | 159 | 9.6 - 16.5 | 0.0100 | 2.9300 | This study |
| Eastern Black Sea | 12 Sep. 2022 | 195 | 8.0 - 14.8 | 0.0180 | 2.6980 | |

## CONCLUSIONS

This study revealed considerable variations in the length–weight relationships of Mediterranean horse mackerel from the Middle and Eastern Black Sea, signifying a trend of negative allometric growth, whereas previous literature on Mediterranean horse mackerel from the Middle and Eastern Black Sea documented isometric growth. However, both the literature data and the findings of this study for Mediterranean horse mackerel from the Sea of Marmara remained consistent, showing negative allometric growth. This study further validated the general assumption of minimal variation within or between neighbouring stocks in the length-weight relationship, whereas significant differences were observed as spatial distances increased. Consequently, these findings support the potential utility of such relationships as a method for identifying fish stocks, which require further confirmation through future studies. Moreover, it is imperative for future studies to elucidate the factors contributing to the substantial difference in the Fulton's condition factor ($k_c$) between the sexes of Mediterranean horse mackerel from the Sea of Marmara. It should be noted that length–weight relationships are greatly influenced by fish reproductive activities and their surrounding habitat. Therefore, their use for stock identification should be supplemented by a secondary method to evaluate phenotypic differences between subpopulations to achieve sound conclusions.

### Declaration of Competing Interest

The author declare no conflicts of interest.

### Data availability statement

Data is available upon request from the corresponding author.

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