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Age Composition, Growth and Mortality of European Hake *Merluccius merluccius* (Linneaus, 1758) (Actinopterygii: Merlucciidae) from the Sea of Marmara, Turkey

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Abstract: This study deals with the age composition, growth and mortality of European hake *Merluccius merluccius* (L.) from the Sea of Marmara, Turkey. A total of 777 European hakes were sampled monthly from October 2014 to September 2015. Total lengths of all sampled individuals ranged from 10.4 cm to 55.3 cm. The length–weight relationship for all samples was calculated as $W = 0.9656\ L^{2.989}$. The ages of the specimens ranged from 1 to 6. Growth parameters calculated according to the von Bertalanffy Growth Equation were L_∞ = 106.358 cm, k = 0.082, t_0 = –1.097 for females, L_∞ = 102.431 cm, k = 0.091, t_0 = –0.829 for males, and L_∞ = 103.971 cm, k = 0.087, t_0 = –0.926 for all samples. According to age–structure analysis, the total, natural and fishing mortality rates were calculated as 2.01, 0.19, and 1.81, respectively. The exploitation rate, E = 0.90, indicated an over-exploitation on the European hake stocks in the Sea of Marmara.

Key words: *Merluccius merluccius*, age, growth, mortality, the Sea of Marmara

Introduction

European hake *Merluccius merluccius* (L., 1758), a member of the family Merlucciidae, is a commercially important demersal species exhibiting wide distribution in the eastern Atlantic Ocean from Norway and Iceland to Mauritania, including the Mediterranean Sea (Froese & Pauly 2016). *M. merluccius* is generally found on muddy bottoms and distributed over a wide depth range from only several meters along the coastline to 1,000 m depth (Cohen et al. 1990, Philips 2012). The species is mostly carnivorous, feeding on various food items such as fish, crustaceans, mollusks, algae and plant detritus (Philips 2012). In Western European demersal fisheries, European hake is one of the most heavily exploited fish species (Casey & Pereiro 1995). It is also an important predator of deeper shelf and upper slope Mediterranean communities (Carpentieri et al. 2005). This species is mainly caught by demersal trawls (especially by bottom and beam trawls), pelagic trawls, longlines and bottom-set gillnets. The global capture production of *M. merluccius* in 2014 was about 125,000 mt (FAO 2016). In addition, the Mediterranean hake catch in 2014 amounted at 20,377 mt (FAO 2017). On the other hand, in Turkey, the production of this species in 2015 was reported as 706 mt (TUIK 2016).

With a view to ensuring the management and sustainable exploitation of the stock, the information on age, growth and reproductive biology of this species is of great importance. In the last two decades, several authors (Morales-Nin et al. 1998, Lucio et al. 2000, Godinho et al. 2001, Piñeiro & Saínza 2003, De Pontual et al. 2006, Murua 2010, Belcaid & Ahmed 2011, Costa 2013, Khoufi et al. 2014, Philips 2014, Akalin 2014, Soykan et al. 2015) have investigated the age estimation and growth parameters of *M. merluccius*. In addition, there are also some other studies on population dy-

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namics, stock assessment and spatial distribution of European Hake have been carried out by Aldebert & Recasens (1996), Orsi-Relini et al. (2002), Lleonart & Maynou (2003), Stergiou et al. (2003), Abella et al. (2005), Gurbet et al. (2013) and Yalçin & Gurbet (2016).

In Turkish waters, the fisheries management approaches, especially for commercial species, require updating. For that reason, the information on age, growth and mortality of this species is really important. However, little information is available for European Hake in the study area. Therefore, the present study aims to determine the age composition, growth parameters and mortality rates of *M. merluccius* in the Sea of Marmara.

Materials and Methods

Totally, 777 specimens were sampled monthly from the Sea of Marmara, mostly by commercial fishermen using beam trawls (with mesh size of 32 mm) and bottom-set gillnets (with mesh size of 52 mm) between October 2014 and September 2015. The sampling depths were from 40 to 200 m. However, in some periods, especially in summer months when the beam trawlers were forbidden, the samples were obtained from the bottom trawlers (with codend mesh size of 34 mm) operating illegally and from the fishermen using various types of gillnets.

For each specimen, total length (TL, cm) and total wet weight (TW, g) were measured. The sex was macroscopically recorded. For age estimation, the sagittal otoliths of the sampled individuals were removed. The otoliths were ground on one side on two abrasive papers with 35.0 µm and 25.8 µm (Ross & Hüssy 2013). Afterwards they were cleaned in ethanol, and immersed in glycerine for the examination by using an image analysis system (Leica DFC295 stereomicroscope). The age was determined by interpreting growth rings on the otoliths. Each annual ring was defined as where the opaque zone meets the translucent zone.

The length–weight relationship (LWR) was calculated using the equation $W = a L^b$, where W is the total weight, L is the total length (TL), and *a*- and *b*-values are the parameters of the equation (Ricker 1973). Growth parameters were calculated according to the von Bertalanffy Growth Equation, $L_t = L_\infty [1 - e^{-k(t - t0)}]$ (Sparre & Venema 1992), where L_t is the total length at age t, k is the growth coefficient, L_∞ is the asymptotic length, and t_0 is the theoretical age at length zero. The growth performance index (Φ') was also estimated according to Pauly & Munro (1984). The total mortality (Z) was calculated from the age-structured catch curve formulated by Pauly et al. (1995). The natural mortality was estimated using empirical equation described by Pauly (1980):

$$\text{Log (M)} = 0.8 \text{ x } \exp(-0.0152 - 0.279 * \ln L_\infty + 0.6543 * \ln k + 0.4630 * \ln T°C)$$

According to Çolakoğlu & Tokaç (2011), the temperature (T°C) was employed as 16.2°C. In addition, the natural mortality was also estimated following Gislason (2010) method: $\ln(M) = 0.55 - 1.61 \ln(L) + 1.44 \ln(L_\infty) + \ln(K)$, using the calculation of average total length by age class, as required by this method. The fishing mortality rate (F) was es-

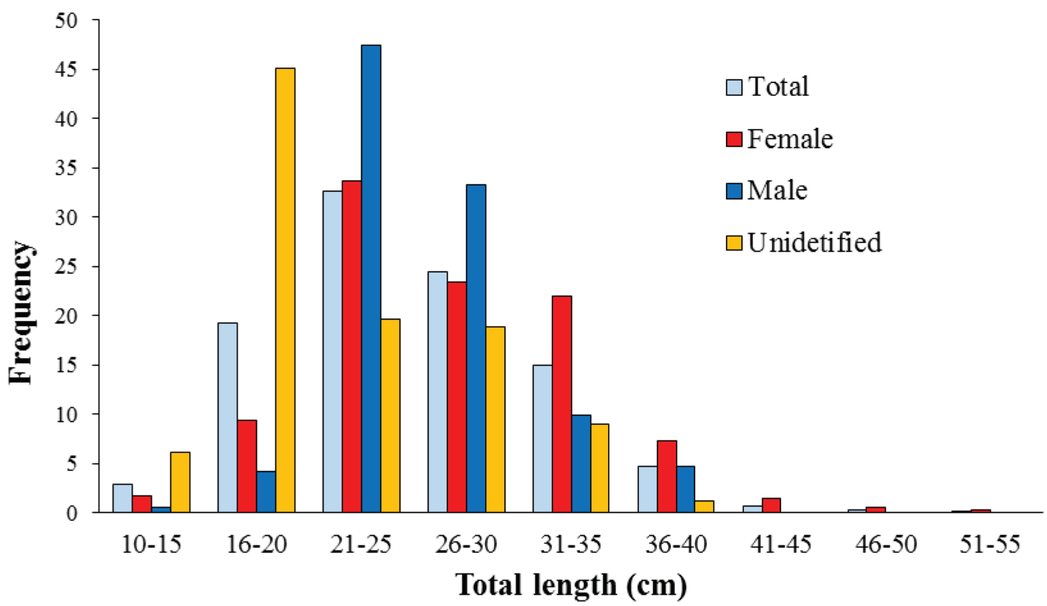

Fig. 1. Length–frequency distribution for females, males, unidentified and all samples of *Merluccius merluccius* (N = 777) from the Sea of Marmara

Table 1. Parameters of length-weight relationship (W=*a* FL^b) of *Merluccius merluccius* from the Sea of Marmara

		TL (cm)		TW (g)		Parameters of length–weight relationship (W = *a* FL^b)					
	N	Min	Max	Min	Max	*a*	*b*	SE (*b*)	CL	R^2	GT
All samples	777	10.4	55.3	10.4	1031.02	0.0079	2.9896	0.20	2.950-3.029	0.9656	Isometric
Females	341	13.4	55.3	13.75	1031.02	0.0074	3.0155	0.36	2.944-3.087	0.9527	Isometric
Males	192	15.6	40.5	27.36	441.39	0.0173	2.7429	0.42	2.660-2.826	0.9569	Isometric
Unidentified	244	10.4	40.3	10.4	454.6	0.0071	3.0231	0.32	2.960-3.086	0.9736	+ Allometric

N, number of individuals; *a* and *b*, intercept and slope of the relationship; R^2, coefficient of determination; SE (*b*), standard error of slope; CL, 95% confidence limits; GT, growth type.

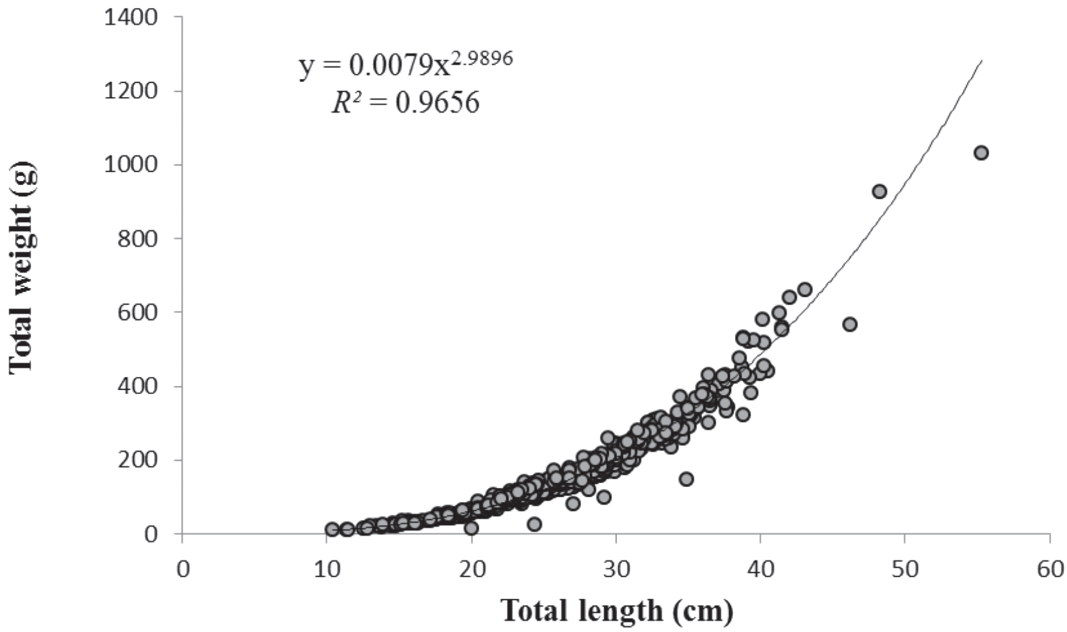

Fig. 2. Length–weight relationship for all samples of *Merluccius merluccius* (N = 777) from the Sea of Marmara

timated according to Sparre & Venema (1992): F = Z – M. The exploitation rate (E) was calculated by F / Z (Pauly 1983).

An independent sample *t*-test was used to test for possible significant difference in mean length between males and females. In addition, the parameter (*b*) of LWR was compared for significant difference between sexes by analysis of covariance, ANCOVA (Zar 1999). Statistical analyses were performed with SPSS 14.0 software package and a significance level of 0.05 was adopted.

Results

Totally, 777 European hakes were sampled monthly during the study period. The total length of all individuals ranged from 10.4 to 55.3 cm (mean length 25.9 ± 0.21 cm); the total weight was from 10.40 to 1,031.02 g (mean weight 155.63 ± 4.06 g). Furthermore, 341 females ranged from 13.4 to 55.3 cm (mean 27.8 ± 0.34 cm); 192 males from 15.6 to 40.5 cm (mean 26.5 ± 0.32 cm) and 244 unidentified specimens from 10.4 to 40.3 cm (mean 22.8 ± 0.35 cm) (Fig. 1). The results of independent samples *t*-test indicated that there were significant differences (P<0.05) in mean length between males and females.

The relationship between total length (cm) and total weight (g) values of all samples are shown in Table 1 and Fig. 2. The *a*- and *b*-values obtained from the estimated length-weight relationship (W = *a* L^b) equation were calculated as 0.9656 and 2.989, respectively. The relationship between the two variables was observed to be highly significant (P<0.001). In addition, the ANCOVA test indicated that there were significant differences between the slopes (*b*) estimated for females and males (P<0.05), and isometric growth was also observed.

Age estimation was based upon counting the number of annuli (rings) on 767 otoliths (Fig. 3); however, annuli on 10 otoliths could not be read. The length-at-age values and the number of individuals in each age class were presented in Table 2. It was found

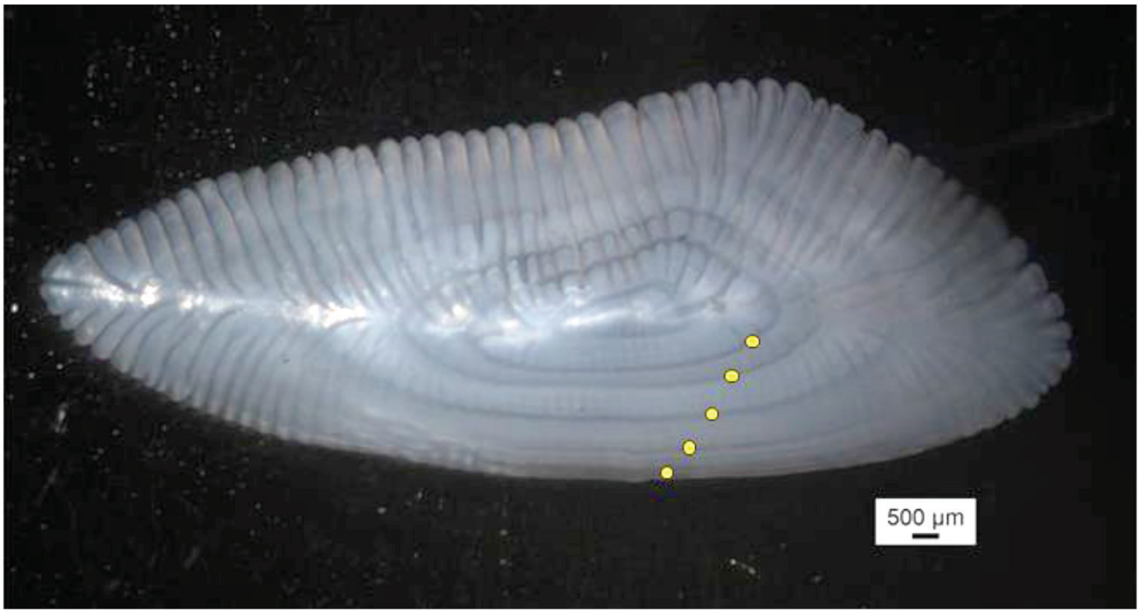

Fig. 3. Sagittal otolith of *Merluccius merluccius* showing the annuli (43.1 cm TL, age 5)

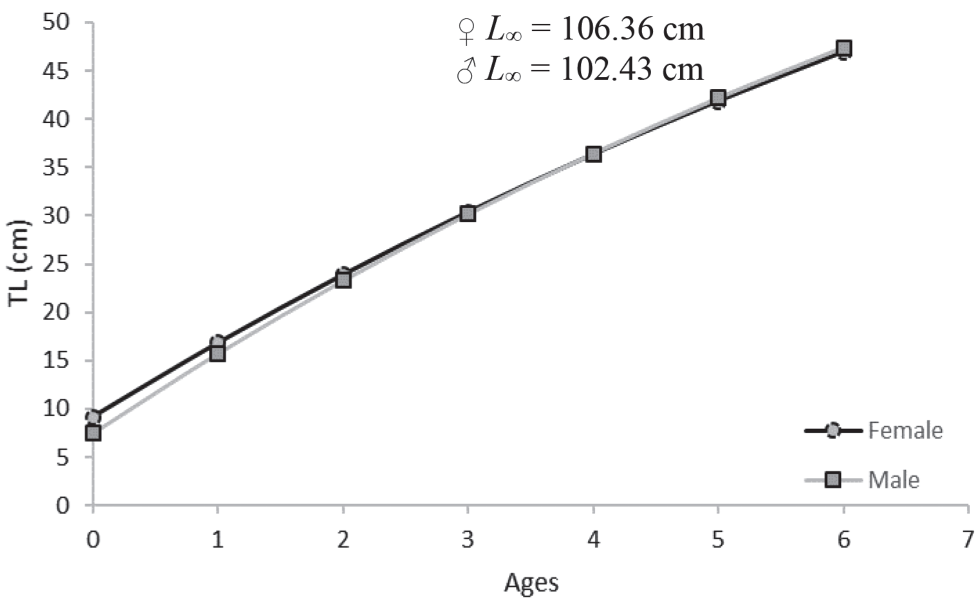

Fig. 4. The von Bertalanffy growth curve for each sex of *Merluccius merluccius* from the Sea of Marmara

that the estimated ages ranged from 1 to 6 years, with the 2nd age class (42.07 %) as the most abundant.

The von Bertalanffy growth curve (Fig. 4) demonstrates that individuals grow faster during the first year of life. The von Bertalanffy growth parameters were estimated for both sexes and overall (Table 3). It was observed that L_∞ (asymptotic length) value of females (106.36 cm) was relatively greater than the ones obtained for males (102.43 cm); therefore, females grew slightly faster than males.

The age-structure catch curve revealed that the total mortality rate (Z) was estimated as 2.01 year^{-1}. According to Pauly (1980), the natural mortality (M) was estimated as 0.19. Moreover, the method of Gislason (2010) estimated that M=1.41 for age-1, 1.33 for age-2, 0.51 for age-3, 0.37 for age-4, 0.25 for age-5 and 0.18 for age-6. On the other hand, the fishing (F) mortality rate was 1.81. In addition, the exploration ratio (E) was calculated as 0.90.

Discussion

This study represents the age composition, growth, and mortality of *M. merluccius* from the Sea of

Table 2. Length-at-age key for all samples of *Merluccius merluccius* from the Sea of Marmara

Length class (TL, cm)	1	2	3	4	5	6	Total
10 - 15	22						22
16 - 20	96	44					140
21 - 25	2	247	5				254
26 - 30		34	156				190
31 - 35		2	67	47			116
36- 40			1	36			37
41 - 45				4	1		5
46 - 50				1	1		2
51 - 55						1	1
Total	120	327	229	88	2	1	**767**

Table 3. The von Bertalanffy growth parameters calculated for *Merluccius merluccius* from the Sea of Marmara

Sex	N	k	t_0	L_∞	W_∞	Φ'
All samples	767	0.087	–0.926	103.97	8460.3	2.97
Females	341	0.082	–1.097	106.36	9548.7	2.96
Males	192	0.091	–0.829	102.43	5655.3	2.93

Marmara. The length range of specimens in our study was generally similar to those found in other studies carried out in western and eastern Mediterranean (Table 4). Accordingly, our sampling captured a representative size distribution similar to those in most of the previous studies. In addition, we found that the *a*- and *b*-values estimated in this study are generally similar to those of other studies.

The age and growth parameters from sagittal otoliths of *M. merluccius* obtained by several authors (Table 5) demonstrate that the estimated ages reported from the Western Mediterranean and Northeast Atlantic ranged from 0 to 10 years. On the other hand, the ages found in the studies especially carried out in the eastern part of the Mediterranean Sea were between 1 and 6 years. Similarly, in the present study, seven different ages (age-classes 1 – 6) were determined. Therefore, it can be concluded that European Hake stocks in the eastern Mediterranean have been over-exploited.

The growth parameters (L_∞, k, t_0, and Φ') of this study were compared with the findings of other authors (Table 5). The asymptotic length (L_∞) in our study is similar to those of the studies from Gulf of Lions (Aldebert & Recasens 1996), Bay of Biscay (Lucio et al. 2000, De Pontual et al. 2006), Gulf of Alicante (Garcia Rodriguez & Esteban 2002) and Northeast Atlantic (Godinho *et al*. 2001). However, the L_∞ parameters, especially from the Turkish coasts of Aegean Sea (Gurbet et al. 2013, Akalin 2014, Soykan et al. 2015), the Moroccan North Atlantic Sea (Belcaid & Ahmed 2011), and the Egyptian Mediterranean (Philips 2014) are lower than our findings. In addition, just like the other studies mentioned above, our L_∞ value for females (106.36 cm) was relatively greater than the value for males (102.43 cm), indicating that the females grew relatively faster than the males. As for k and t_0 values, our findings are in line with those of other studies by Aldebert & Recasens (1996), Lucio et al. (2000), Godinho et al. (2001) and Philips (2014). Finally, the growth performance index (Φ') of the present study show similarities especially with the findings of other studies carried out in Northeast Atlantic (Godinho et al. 2001), in the Egyptian Mediterranean (Philips 2014) and in Turkish coasts of Central Aegean Sea (Soykan et al. 2015). On the other hand, the Φ' values obtained from Strait of Gibraltar (Pineiro & Sainza 2003) and Gulf of Alicante (Garcia Rodriguez & Esteban 2002) are relatively greater than our result. Moreover, when compared to the above-mentioned studies, our Φ' value shows significant difference (t-test; $P<0.05$).

As widely known, the causes of observed differences in LWR, age, growth and mortality values could possibly be attributed to several factors such as environmental conditions (e.g., temperature and salinity), habitat variability, latitude effect, food availability, maturity stages, fishing season, sampling methodology, selectivity of fishing gear and genetic variations (Ricker 1969, Baganel & Tesch 1978, Recasens et al. 1998, Basilone et al. 2006, Froese 2006, Domínguez-Petit et al. 2010, Soykan et al. 2010).

The mortality rates (Z, M, and F) in this study were compared with the findings of the other studies. Gurbet et al. (2013) indicated that in the Turkish coasts of Central Aegean Sea, the mortalities (Z, M, and F) and exploitation rate (E) were calculated as 2.24 y^{-1}, 0.58 y^{-1}, 1.66 y^{-1}, and 0.74, respectively. In the same area, Soykan et al. (2015) found that these parameters were Z = 1.539 y^{-1} , M = 0.579 y^{-1}, F = 0.959 y^{-1} and E = 0.624. Accordingly, it can be inferred from the exploitation rates calculated in our study as well as the above-mentioned studies that there is a fairly high fishing pressure on the European hake stocks in Turkish waters.

During the past decade, General Fisheries Commission for the Mediterranean (GFCM) has considered that European hake stocks in the Mediterranean is overexploited (growth and danger of recruitment overexploitation) with current high fishing mortality (F) about six times higher than the limit and target reference points (GFCM 2016). Moreover, this species has been assessed as Least

Table 4. The length–weight relationships for *Merlucius merluccius* from various areas

Authors	N	L_{min} - L_{max} (TL, cm)	Length–weight relationships	Study Area
Murua & Motos (2006)	1681	37.0 – 92.0	-	Bay of Biscay
Pineiro & Sainza (2003)	1391	6.0 – 78.0	$W = 0.00733\ L^{2.981}$	Iberian Atlantic
Costa et al. (2013)	4935	7.3 – 93.3	$W = 0.0038\ L^{3.172}$	Portuguese coast
Mellon-Duval et al. (2010)	242	15.0 – 40.0	-	Gulf of Lion
Philips (2014)	229	14.0 – 43.0	-	Egypt – Mediterranean.
Moutopoulos & Stergiou (2002)	152	18.0 – 50.2	$W = 0.004\ L^{3.2}$	Greek Aegean waters
Uçkun et al. (2000)	336	13.6 – 43.5	$W = 0.005\ L^{3.194}$	Turkish Aegean coast
Ozaydin et al. (2007)	2711	2.7 – 48.8	$W = 0.981\ L^{3.189}$	Turkish Aegean coast
Gurbet et al. (2013)	1353	5.9 – 44.4		Turkish Aegean coast
Soykan et al. (2015)	2108	5.2–45.5	$W = 0.00341\ L^{3.24}$	Turkish Aegean coast
Karakulak et al. (2006)	22	19.7 – 41.1	$W = 0.005\ L^{3.103}$	Northern Aegean Sea
Ismen et al. (2007)	2041	7.9 – 66	$W = 0.004\ L^{3.150}$	Northern Aegean Sea
Akalin (2014)	2375	7.6 – 46.2	$W = 0.0067\ L^{3.307}$	Edremit Bay
Present study	777	10.4 – 53.3	$W = 0.0079\ L^{2.989}$	Sea of Marmara

Table 5. The von Bertalanffy growth parameters (L_∞: asymptotic mean length; k: growth rate; t_0: hypothetic age at zero length) and growth performance index values (*Φ'*) obtained from different areas for *Merluccius merluccius\, n\]=-09876t5reg.0k\7*

Authors	Methods	L_∞	k	t_0	Φ'	Study area
Belcaid & Ahmed (2011)	FISAT (ELEFAN)	72.45	0.28	–0.72	3.16	Moroccan North Atlantic Sea
De Pontual et al. (2006)	Otolith	89.9	0.362	-	-	Bay of Biscay
Aldebert & Recasens (1996)	Otolith (♀)	100.7	0.124	–0.350		Gulf of Lion
	Otolith (♂)	72.8	0.149	–0.383		
Piñeiro & Sainza (2003)	Otolith	80.8	0.35	–1.70	3.36	Strait of Gibraltar, Spain
Lucio et al. (2000)	Otolith	110.0	0.12	–0.452	-	Bay of Biscay
garcia rodriguez & esteban (2002)	FISAT (ELEFAN)	108.0	0.21	– 0.115	3.39	Gulf of Alicante
Godinho et al. (2001)	Otolith	110.6	0.089	–0.97	2.99	Northeast Atlantic
Gurbet et al. (2013)	Otolith	57.05	0.32	-	-	Turkish coast of Central Aegean Sea
Philips (2014)	Otolith	74.19	0.119	–0.281	2.82	Egypt – Mediterranean
Soykan et al. (2015)	Otolith	54.53	0.315	–0.223	2.97	Turkish coast of Central Aegean Sea
Akalin (2014)	Otolith (♀) Otolith (♂)	53.49 47.43	0.385 0.349	-0.078 -0.112	3.042 2.895	Edremit Bay
Present study	Otolith (♀) Otolith (♂)	106.36 102.43	0.082 0.091	-1.097 -0.829	2.96 2.93	Sea of Marmara

Concern category in IUCN Red List of Threatened Species, and subpopulations in the Mediterranean were previously assessed as "vulnerable" due to declines in abundance attributed to high fishing pressure in the region (Fernandes et al. 2016). Similarly, in Turkish waters, particularly in the Sea of Marmara, European hake populations are considered overexploited, and the excessive fishing pressure on *M. merluccius* could ultimately reduce the spawning stock below levels sufficient to maintain the population. In this case, we recommend that strict management measures should be employed immediately. It is expected that our findings will contribute to better fisheries management of European hake and will be the basis for further studies to be carried out in the future.

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