AGE COMPOSITION, GROWTH, AND MORTALITY OF EUROPEAN HAKE 
MERLUCCIUS MERLUCCIUS (ACTINOPTERYGII: GADIFORMES: MERLUCCIIDAE) 
FROM THE NORTHERN AEGEAN SEA, TURKEY

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INTRODUCTION

European hake, Merluccius merluccius (Linnaeus, 1758), is a commercially important demersal species, distributed in the eastern Atlantic Ocean from Norway and Iceland to Mauritania, and also in the Mediterranean Sea (Froese and Pauly 2018). Merluccius merluccius is generally found on muddy bottoms and distributed on a wide depth range from the coastline down to the depth of 1000 m (Cohen et al. 1990, Philips 2012). This species is mostly carnivorous, feeding on fishes, crustaceans, molluscs, algae, and plant detritus (Philips 2012). Hakes are found in a deeper zone in the daytime but move to the upper zone at night (Froese and Pauly 2018). In the west European demersal fisheries, the European hake is one of the most heavily exploited fish species (Casey and Pereiro 1995), and is also an important predator of deeper shelf-upper slope Mediterranean communities (Carpentieri et al. 2005). European hake is generally caught by demersal trawls (especially by the bottom and beam trawls), pelagic trawls, longlines, and bottom-set gillnets. The yearly global landings of the European hake was 125 000 t in 2014 (Anonymous 2016a) while the annual landings of this species in Turkey was 706 t (Anonymous 2016b). European hake has been reported as one of the most important target species for trawlers in the Ionian and Aegean Seas (Katsanevakis et al. 2010).

Background. This study is the first attempt to acquire information about growth, age composition, and mortality of European hake, Merluccius merluccius (Linnaeus, 1758), in the northern Aegean Sea. In Turkey, the hake is a very important commercial species captured with demersal trawls. Therefore the management of the hake fishery is important for the stock sustainability. The aim of this study was to determine the age composition, growth, and mortality of hake from Gökçeada Island, northern Aegean Sea, Turkey.

Materials and methods. A total of 2253 hake specimens were collected monthly in three fishing seasons off Gökçeada Island from September 2013 to April 2016 with a commercial trawler. Fish age was estimated based on otoliths. Growth parameters were calculated according to the von Bertalanffy growth equation.

Results. The total length ranged from 5.9 cm to 51.2 cm for all individuals. The length–weight relation was $W = 0.0034TL^{3.2249}$ ($R^2 = 0.9655$). The age of the fish was estimated to range from 1 to 6 years. Growth parameters were as follows, $L_\infty = 88.54$ cm, $k = 0.1088$, $t_0 = –0.9962$ for males, $L_\infty = 102.34$ cm, $k = 0.0908$, $t_0 = –1.3105$ for females, and $L_\infty = 102.66$ cm, $k = 0.0992$, $t_0 = –0.8085$ for all fish sampled. The total, natural, and fishing mortality ratio of the samples were found as 2.21, 0.57, and 1.64, respectively.

Conclusion. The exploitation ratio ($E$) of the samples was estimated to be 0.74, showing a high fishing pressure on the hake population and it will be the main argument for the need of a strict management on the hake fishery in the area studied. The other argument is the high number of juveniles in the catch composition. It is expected that the results of the presently reported study will contribute to the sustainable fishery for hake. The minimum landing size in the Turkish waters should be increased from 20 cm to 25 cm to ensure at least single breeding of Merluccius merluccius.

Keywords: Merluccius merluccius, age, growth, mortality, northern Aegean Sea


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There is a minimum landing size (MLS) of 27 cm total length (TL) in the European Union (Anonymous 2011) and 20 cm for Turkish Seas (Anonymous 2016c) in order to protect the juveniles of the species.

The information on the age, growth, and reproduction of the species has an important role in the management and sustainable exploitation of the stock. Several authors have studied the age estimation and growth parameters of hake (Morales-Nin et al. 1998, Uçkun et al. 2000, Godinho et al. 2001, Piñeiro and Sainz 2003, de Pontual et al. 2006, Ismen et al. 2010, Murua 2010, Belcaid and Ahmed 2011, Gurbet et al. 2013, Costa 2013, Khoufi et al. 2014, Philips 2014, Soykan et al. 2015). On the other hand, many studies on stock assessment, population dynamics, and spatial distribution of hake have been implemented by Aldebert and Recasens (1996), Orsi-Relini et al. (2002), Lleonart and Maynou (2003), Stergiou et al. (2003), Abella et al. (2005), Gurbet et al. (2013), Yalçın and Gurbet (2016).

Fisheries management is important for sustainable fisheries and needs updating for different fishing areas. This study aims to determine the growth parameters, age composition, and mortality rates of hake. The presently reported study is the first scientific project covering hake population dynamics in the region of Gökçeada Island, northern Aegean Sea. The result of the presently reported study is necessary for sustainable fisheries for the region.

MATERIALS AND METHODS

The European hake, *Merluccius merluccius*, is both commercially and ecologically important for Gökçeada Island where the study was conducted (Fig. 1). The fish sampled monthly by commercial trawlers, in three fishing seasons, between September 2013 and April 2016, and a total of 2253 specimens were collected. There is a fishery ban in the spring–summer months (May, June, July, and August) for trawlers. Therefore, the sampling was carried out by the same bottom trawler after obtaining a research collection permit from the competent authority (Tarım ve Orman Bakanlığı; Ministry of Agriculture and Forestry). A traditional demersal trawl gear was used during the sampling, featuring a 5.4-m codend made of knotted polyethylene with 44 mm diamond mesh size. The operation time was between the end of steel rope release and the start of haul retrieval, the hauling speed was 2.2–2.6 knots, and the hauling time changed between 1 to 5 h, thus the hauling time was calculated as 1 h.

Total length (TL) and total weight (TW) of the collected hake specimens were determined. The sex was determined macroscopically. The sagittal otoliths of the samples were removed for the age estimation. The otoliths were ground on one side with two different abrasive papers with 35.0 μm and 25.8 μm median diameters (Ross and Hüsey 2013), cleaned with ethanol, and immersed in glycerine for the examination with a microscope (Leica DFC295 stereomicroscope with Leica S8APO LAS image analysis software). The fish age was determined by interpreting the growth rings on the otoliths as translucent and opaque rings. Otoliths were assessed by two independent readers through otolith readings without referring to any information except the date of capture and size. The age estimation of some otoliths was rejected because of readings did not coincide.

The length–weight relation (LWR) was calculated using the equation

\[ W = aTL^b, \]

where *W* is the total weight, *TL* is the total length, and *a* and *b* values are the parameters of the equation (Ricker 1973). Growth parameters were calculated according to the von Bertalanffy growth equation (Sparre and Venema 1992)

\[ L_t = L_\infty [1 - e^{-kt}] \]

Fig. 1. The study area—Gökçeada Island, Turkey, northern Aegean Sea
where $L_i$ is the total length, $k$ is growth coefficient, $L_\infty$ is asymptotic length, $t_0$ is theoretical length at age zero, and $T$ is the mean water temperature.

The growth performance index ($\Phi$) formulated by Pauly and Munro (1984) was also estimated for accuracy of the growth parameters

$$\Phi' = \log k + 2 \cdot \log L_\infty.$$

The total mortality ($Z$) was calculated from the age-structured catch curve formulated by Pauly et al. (1995). The natural mortality ($M$) was estimated using the empirical equation described by Pauly (1980)

$$\log (M) = 0.8 \cdot \exp (-0.0152 - 0.279 \cdot \log L_\infty + 0.6543 \cdot \ln k + 0.4630 \cdot \ln T)$$

The fishing mortality rate ($F$) was estimated according to Sparre and Venema (1992)

$$F = Z - M$$

The exploitation rate ($E$) was calculated by $F \cdot Z^{-1}$ (Pauly 1983).

The independent sample $t$-test was used for determining the possible significant difference in mean length between males and females. Additionally, analysis of covariance ANCOVA was used for determining significant difference between sexes to compare the parameter $b$ of LWR (Zar 1999). The SPSS 21.0 software package was used for statistical analyses and a significance level of 0.05 was adopted.

RESULTS

A total of 2253 European hake individuals were sampled monthly during the study period. The females constituted 31% ($n = 708$), males constituted 50% ($n = 1126$), and the immature specimens constituted 18% ($n = 419$) of the total catch. The total length of all individuals ranged from 5.9 cm to 51.2 cm (mean ± standard deviation: 25.4 ± 11.1 cm); the total weight was from 3.48 to 1162.89 g (160.29 ± 2.99 g). Furthermore, the TL of females was in between 19.1 and 51.2 cm (31.8 ± 1.64 cm), males from 18.9 to 42.6 cm (30.5 ± 1.47 cm) (Fig. 2), and immature specimens from 5.9 to 22.1 cm. The results of $t$-test indicated that there were significant differences ($P < 0.05$) in mean length between males and females.

The relation between total weight (g) and total length (cm) values of male, female, and all fish are shown in Table 1 and Fig. 3. The $a$ and $b$ values, obtained from the estimated length–weight relation equation were calculated as 0.0034 and 3.224, respectively and positive allometry growth was observed. The relation between the two variables was found to be insignificant ($P > 0.001$). In addition, the ANCOVA test showed that there were insignificant differences between the slopes ($b$) estimated for females and males ($P > 0.05$).

The otolith structure of the European hake involves some false rings in the first year of growth. The false rings are larval rings which occur after the nucleus, hyaline rings occur in pelagic period and the rings occur when the fish got down to demersal zone (Godinho et al. 2001).

As shown in Fig. 4, the age estimation was based upon counting the number of annuli (rings) on 2253 otoliths. The length-at-age values and the number of individuals in each age class were presented in Table 2. Six age cohorts have been found from 1 to 6 years (Fig. 5). The most abundant age class was the 2nd, representing 45.05% of the fish, followed by the 3rd age class (27.90%), the 1st age class (25.44%), the 4th age class (1.48%), the 5th age class (0.09%), and the 6th age class (0.04%) (Figs. 6, 7).

The von Bertalanffy growth curve, shown in Fig. 8, represents all samples. In Table 3, the von Bertalanffy growth parameters were estimated for all sexes. It was visible that $L_\infty$ (asymptotic length) value of females (102.34 cm) was relatively greater than that of males (88.54 cm); therefore, it is evident that the males grew slightly faster than the females.

The age-structured catch curve revealed that the total mortality rate ($Z$) was estimated as 2.21 year$^{-1}$. The natural ($M$) and fishing ($F$) mortality rates were found to be 0.57 and 1.64, respectively. In addition, the exploration ratio ($E$) was calculated as 0.74.

![Length–frequency distribution for females, males, and immature specimens of Merluccius merluccius from northern Aegean Sea, Turkey, studied within 2013–2016](image)

**Fig. 2.** Length–frequency distribution for females, males, and immature specimens of *Merluccius merluccius* from northern Aegean Sea, Turkey, studied within 2013–2016

<table>
<thead>
<tr>
<th>Sex</th>
<th>Regression factors</th>
<th>Confidence limits of $b$</th>
<th>Growth type</th>
<th>$r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$a$</td>
<td>$b$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>0.0041</td>
<td>3.1733</td>
<td>3.11–3.23</td>
<td>+ Allometry</td>
</tr>
<tr>
<td>Male</td>
<td>0.0043</td>
<td>3.1454</td>
<td>3.09–3.19</td>
<td>+ Allometry</td>
</tr>
<tr>
<td>All samples</td>
<td>0.0034</td>
<td>3.2249</td>
<td>3.20–3.25</td>
<td>+ Allometry</td>
</tr>
</tbody>
</table>

$a =$ intercept, $b =$ slope of the relation; $r^2 =$ coefficient of determination.

Table 1

Length–weight relation parameters of *Merluccius merluccius* for all samples and their sexes from northern Aegean Sea, Turkey, studied within 2013–2016
DISCUSSION

This study is the first attempt on age composition, growth, and mortality of *Merluccius merluccius* from Gökçeada Island, northern Aegean Sea. As given in Table 4, the length range of specimens in this study was generally similar to those of other studies. In addition, the $a$ and $b$ values of the LWR in the study were generally similar to those of other studies.

The age and growth parameters of *M. merluccius* are presented by several authors (Table 5). The parameters of the studies could show variations according to the sampling period, study area, and environmental conditions.

![Length–weight relation for male, female, and all samples of *Merluccius merluccius* from northern Aegean Sea, Turkey, studied within 2013–2016](image)

**Fig. 3.** Length–weight relation for male, female, and all samples of *Merluccius merluccius* from northern Aegean Sea, Turkey, studied within 2013–2016

![Sagittal otolith of *Merluccius merluccius* showing the rings; N = nucleus, L = larval ring, P = hyaline ring, D = demersal ring](image)

**Fig. 4.** Sagittal otolith of *Merluccius merluccius* showing the rings; N = nucleus, L = larval ring, P = hyaline ring, D = demersal ring

![The age cohort of *Merluccius merluccius* from northern Aegean Sea, Turkey, studied within 2013–2016](image)

**Fig. 5.** The age cohort of *Merluccius merluccius* from northern Aegean Sea, Turkey, studied within 2013–2016

![Age frequency distribution of *Merluccius merluccius* from northern Aegean Sea, Turkey, studied within 2013–2016](image)

**Fig. 6.** Age frequency distribution of *Merluccius merluccius* from northern Aegean Sea, Turkey, studied within 2013–2016

![The sex-specific age distribution of *Merluccius merluccius* from northern Aegean Sea, Turkey, studied within 2013–2016](image)

**Fig. 7.** The sex-specific age distribution of *Merluccius merluccius* from northern Aegean Sea, Turkey, studied within 2013–2016
Several researchers have evaluated the von Bertalanffy growth parameters according to different seasons and areas as well (Table 5). The growth parameters varied respectively to the environmental and ecological factors. The differences in the growth parameters in fish are affected by the genetic structure, temperature, nutrition, and diseases (Pauly 1994, Wootton 1998). In addition, the population parameters can be affected and changed year by year with the recruitment and environment factors (Burton et al. 2012). The growth variation (k) of the European hake in the presently reported study was between 0.09 and 0.10.

The growth parameters (L∞, k, and t0) were compared with the other authors (Table 5). The asymptotic length (L∞) is similar to the studies from the Gulf of Lions (Aldebert and Recasens 1996), North-east Atlantic (Godinho et al. 2001), Alicante Bay (García-Rodríguez and Esteban 2002), and the Sea of Marmara (Kahraman et al. 2017). However, the lower L∞ values than those in the presently reported study were from Bay of Biscay (de Pontual et al. 2006), the Moroccan North Atlantic Ocean (Belcaid and Ahmed 2011), the Egyptian Mediterranean (Philips 2014), and the Turkish coasts of the central Aegean Sea (Gurbet et al. 2013, Soykan et al. 2015). The value of L∞ for males (88.54 cm) was lower than the value for females (102.34 cm), showing that the growth of the females was faster than the males. As for k and t0 values, the results of this study are in line with those of the other studies (Godinho et al. 2001, Kahraman et al. 2017). At the end, the growth performance index (Φ′) show similarities and greater from the other studies, show lower values than the study in the Egyptian Mediterranean (Philips 2014). Furthermore, according to the mentioned studies, the Φ′ value shows a significant difference (t-test; P < 0.05) (Table 5).


Gurbet et al. (2013) reported that the mortality rates (Z, M, and F) and exploitation ratio (E) were calculated.
Table 4

<table>
<thead>
<tr>
<th>Study area</th>
<th>n</th>
<th>Total length [cm]</th>
<th>a</th>
<th>b</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aegean Sea, central, Turkey</td>
<td>336</td>
<td>13.6–43.5</td>
<td>0.005</td>
<td>3.194</td>
<td>Uçkun et al. 2000</td>
</tr>
<tr>
<td>Aegean Sea, central, Turkey</td>
<td>2711</td>
<td>2.7–48.8</td>
<td>0.981</td>
<td>3.189</td>
<td>Özaydin et al. 2007</td>
</tr>
<tr>
<td>Aegean Sea, central, Turkey</td>
<td>1353</td>
<td>5.9–44.4</td>
<td>—</td>
<td>—</td>
<td>Gurbet et al. 2013</td>
</tr>
<tr>
<td>Aegean Sea, Greece</td>
<td>2108</td>
<td>5.2–45.5</td>
<td>0.00341</td>
<td>3.24</td>
<td>Soykan et al. 2015</td>
</tr>
<tr>
<td>Aegean Sea, northern, Turkey</td>
<td>152</td>
<td>18.0–50.2</td>
<td>0.004</td>
<td>3.2</td>
<td>Moutopoulos and Stergiou 2002</td>
</tr>
<tr>
<td>Aegean Sea, northern, Turkey</td>
<td>22</td>
<td>19.7–41.1</td>
<td>0.005</td>
<td>3.103</td>
<td>Karakulak et al. 2006</td>
</tr>
<tr>
<td>Aegean Sea, northern, Turkey</td>
<td>2041</td>
<td>7.9–66.0</td>
<td>0.004</td>
<td>3.150</td>
<td>Ismen et al. 2007</td>
</tr>
<tr>
<td>Aegean Sea, northern, Turkey</td>
<td>2253</td>
<td>5.9–51.2</td>
<td>0.0034</td>
<td>3.224</td>
<td>This study</td>
</tr>
<tr>
<td>Atlantic, Bay of Biscay</td>
<td>1681</td>
<td>37.0–92.0</td>
<td>—</td>
<td>—</td>
<td>Murua and Motos 2006</td>
</tr>
<tr>
<td>Atlantic, Portugal</td>
<td>4935</td>
<td>7.3–93.3</td>
<td>0.0038</td>
<td>3.172</td>
<td>Costa 2013</td>
</tr>
<tr>
<td>Atlantic, Spain, Portugal</td>
<td>1391</td>
<td>6.0–78.0</td>
<td>0.00733</td>
<td>2.981</td>
<td>Piñeiro and Sainza 2003</td>
</tr>
<tr>
<td>Mediterranean, Egypt</td>
<td>229</td>
<td>14.0–43.0</td>
<td>—</td>
<td>—</td>
<td>Philips 2014</td>
</tr>
<tr>
<td>Mediterranean, Gulf of Lions</td>
<td>777</td>
<td>10.4–53.3</td>
<td>—</td>
<td>—</td>
<td>Mellon-Duval et al. 2010</td>
</tr>
</tbody>
</table>

$a$ = intercept, $b$ = slope of the relation.

Table 5

<table>
<thead>
<tr>
<th>Study area</th>
<th>Method</th>
<th>Sex</th>
<th>$L_n$</th>
<th>$k$</th>
<th>$t_0$</th>
<th>$\Phi'$</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aegean Sea, central, Turkey</td>
<td>Otolith</td>
<td>♂ + ♀</td>
<td>57.05</td>
<td>0.320</td>
<td>—</td>
<td>—</td>
<td>Gurbet et al. 2013</td>
</tr>
<tr>
<td>Aegean Sea, central, Turkey</td>
<td>Otolith</td>
<td>♂ + ♀</td>
<td>54.53</td>
<td>0.315</td>
<td>–0.223</td>
<td>2.97</td>
<td>Soykan et al. 2015</td>
</tr>
<tr>
<td>Aegean Sea, northern, Turkey</td>
<td>Otolith</td>
<td>♂ + ♀</td>
<td>102.66</td>
<td>0.099</td>
<td>–0.808</td>
<td>3.01</td>
<td>This study</td>
</tr>
<tr>
<td>Atlantic–Med, Strait of Gibraltar</td>
<td>Otolith</td>
<td>♂ + ♀</td>
<td>80.80</td>
<td>0.350</td>
<td>–1.700</td>
<td>3.36</td>
<td>Piñeiro and Sainza 2003</td>
</tr>
<tr>
<td>Atlantic, Bay of Biscay</td>
<td>Otolith</td>
<td>♂ + ♀</td>
<td>89.90</td>
<td>0.362</td>
<td>—</td>
<td>—</td>
<td>de Pontual et al. 2006</td>
</tr>
<tr>
<td>Atlantic, North-east</td>
<td>Otolith</td>
<td>♂ + ♀</td>
<td>110.60</td>
<td>0.089</td>
<td>–0.970</td>
<td>2.99</td>
<td>Godinho et al. 2001</td>
</tr>
<tr>
<td>Atlantic, North, Morocco</td>
<td>FISAT (ELEFAN)</td>
<td>♂ + ♀</td>
<td>72.45</td>
<td>0.280</td>
<td>–0.720</td>
<td>3.16</td>
<td>Belcaid and Ahmed 2011</td>
</tr>
<tr>
<td>Mediterranean, Alicante Bay, Spain</td>
<td>FISAT (ELEFAN)</td>
<td>♂ + ♀</td>
<td>108.00</td>
<td>0.210</td>
<td>–0.115</td>
<td>3.39</td>
<td>Garcia-Rodriguez and Esteban 2002</td>
</tr>
<tr>
<td>Mediterranean, Egypt</td>
<td>Otolith</td>
<td>♂ + ♀</td>
<td>74.19</td>
<td>0.119</td>
<td>–0.281</td>
<td>2.82</td>
<td>Philips 2014</td>
</tr>
<tr>
<td>Mediterranean, Gulf of Lions</td>
<td>Otolith</td>
<td>♂</td>
<td>100.70</td>
<td>0.124</td>
<td>–0.350</td>
<td>—</td>
<td>Aldebert and Recasens 1996</td>
</tr>
<tr>
<td>Mediterranean, Gulf of Lions</td>
<td>Otolith</td>
<td>♀</td>
<td>72.80</td>
<td>0.149</td>
<td>–0.383</td>
<td>—</td>
<td>Aldebert and Recasens 1996</td>
</tr>
<tr>
<td>Sea of Marmara, Turkey</td>
<td>Otolith</td>
<td>♂ + ♀</td>
<td>103.97</td>
<td>0.087</td>
<td>–0.926</td>
<td>2.97</td>
<td>Kahraman et al. 2017</td>
</tr>
</tbody>
</table>

$L_n$ = asymptotic mean length, $k$ = growth rate, $t_0$ = hypothetic age at zero length, $\Phi'$ = growth performance index values.

The von Bertalanffy growth parameters and growth performance index values obtained from different areas for *Merluccius merluccius* as 2.24 $y^{-1}$, 0.58 $y^{-1}$, 1.66 $y^{-1}$, and 0.74, respectively in the Turkish coasts of the central Aegean Sea, while the mortality rates ($Z$, $M$, and $F$) were calculated as were $Z = 1.539 y^{-1}$, $M = 0.579 y^{-1}$, $F = 0.959 y^{-1}$, and $E = 0.624$ in the same area (Soykan et al. 2015). High fishing pressure was determined due to the mortality rates of the presently reported study and the most abundant individuals being two years old in the catch composition.

The General Fisheries Commission for the Mediterranean (GFCM) has considered that European hake stocks in the Mediterranean are overexploited (growth and danger of recruitment overexploitation) with current fishing mortality ($F$) which is about six times higher than the limit and target reference points (Anonymous 2016a). In addition, this species has been assessed as Least 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). Implementing the first minimum landing size (MLS) of the *M. merluccius* in the Turkish seas was in 1997 and the MLS for this species was 25 cm total length. Although there is no quota implementation in Turkey, the minimum landing size of the European hake was reduced from 25 cm to 20 cm total length by fishery legislation authority in 2016 for four years period (2016 to 2020) (Anonymous 2016c). Philips (2014) indicated that if it is needed, European hake to breed at least once, the minimum landing size must be 25 cm total length. The minimum landing size is 20 cm total length in the other Mediterranean European countries while for Atlantic regions, the MLS for European hake is 27 cm of total length and there is an annual quota for the total allowable catch. Under the lights of our findings, the European hake stock has to be investigated in the Turkish coast of Aegean Sea and management strategy must be
changed into the quota system (TAC) as in the European Union countries.

The goal of the presently reported study was to investigate the length distribution, weight–weight relation, age, growth and mortality of European hake in the north Aegean Sea and compare the findings with the other studies. Fishing fleets have been targeting European hake for a long time in the Mediterranean. As demonstrated in the presently reported study, there is high fishing pressure on this species and it is therefore recommended that strict management measures should be employed. Being a shared stock, European hake cooperation would be in progress between Turkey and Greece in the Aegean Sea for this commercially valuable species. In this case, further studies must be carried out in the future and it is expected that the results of the presently reported study will contribute to better fisheries management for European hake.

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