Age, growth and exploitation rate of European hake, *Merluccius merluccius*, from the Moroccan Mediterranean coastline

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Abstract. Improved biological and fisheries studies are needed for the management, conservation and sustainability of marine resources. This research represents age and growth characteristics of European hake, *Merluccius merluccius* (Linneaus, 1758), one of the most exploited demersal resources in the Moroccan Mediterranean coastline. Growth parameters, mortality, and exploitation of 6223 specimens were estimated, collected monthly from March 2015 to April 2019 from commercial catches landed in Beni Ensar's port-Nador. The length-weight relationships (LWR) were $TW=0.0067\ TL^{3.0208}$ ($R^2=0.97$) for females, $TW=0.0098\ TL^{2.895}$ ($R^2=0.95$) for males and $TW=0.0054\ TL^{3.079}$ ($R^2=0.97$) for combined sexes. Besides, it showed negative allometry growth for males, however, isometrical growth for females and combined sexes was noted (b=2.89, 3.02 and 3.07 respectively). Age was determined using the Bhatacharya's method showing the presence of 7 year classes. The asymptotic length (L_∞), growth rate (K) and (t0) were estimated as 76.65 cm, 0.11 year^{-1} and -1.21 year, respectively, for combined sexes. The growth performance index Φ was calculated as 2.81. The instantaneous total mortality (Z) and natural mortality (M) were determined: 0.65 and 0.28 year^{-1}, respectively. The instantaneous fishing mortality rate (F=0.37 year^{-1}) exceeded both the optimum fishing mortality rate (F_{opt}=0.112 year^{-1}) and the limiting fishing mortality (F_{limit}=0.186 year^{-1}). Furthermore, the exploitation rate ($E_{current}$=0.57 year^{-1}) was higher than the estimated sustainable exploitation level (E_{50}=0.30 year^{-1}) and matched the estimated maximum allowable exploitation point (E_{max}=0.55 year^{-1}) indicating that *M. merluccius* exploitation is at its maximum sustainable yield and experiences overfishing. Therefore, urgent management interventions are required to protect the *M. merluccius* stock from possible collapse in the future.
Key Words: Mediterranean Sea, length at age, mortality, stock assessment.

Introduction. The European hake, *Merluccius merluccius* (Linneaus, 1758), is a demersal fish of the Merlucidae family, widely distributed throughout the Mediterranean Sea including the southern coast of the Black Sea and the eastern Atlantic coasts from Norway and Iceland to southward to Mauritanian coast (Carpentieri et al 2005). This species inhabits muddy substrats but could be occasionally found on muddy-sandy and sandy bottoms as well, at depths ranging from 50 to 510 m (GFCM 2019). This species is carnivorous, feeds mainly on fish (pelagic and demersal) and crustaceans (Guichet 1995; Du Buit 1996; Bozzano et al 1997; Velaso & Olaso 1998; Carpentieri et al 2005; Mahe et al 2007; Ferraton et al 2007; Cartes et al 2008; Stagioni et al 2011; Philips 2012; Abdellaoui et al 2014; Mellon-Duval et al 2017; Carrozzi et al 2019; Giulia et al 2020). However, Mollusca (Mahe et al 2007; Fanelli et al 2018; Carrozzi et al 2019), algae and plant detritus could also be part of its diet (Philips 2012).

M. merluccius is one of the most commercially important demersal species in the Moroccan Mediterranean Sea, accounting for a major portion of the landings at numerous fishing ports in the region. However, this resource is witnessing a high fishing pressure. Landings of *M. merluccius* have been declined from 390 tons in 2009 to 87 tons in 2020 (ONP 2020). Overfishing of this species might actually lead to a depletion of the stock. As a result, it is advised to ensure both scientific monitoring and to employ effective management measures, avoiding the decline in economic gains of those dependent on the fishing sector and the deterioration of social conditions of fishermen.

Due to its market value, age, growth and mortality of, hake has been the topic of various research at different locations in Mediterranean Sea (Mellon-Duval et al 2010; Belhoucine 2012; Demirel & Dalkara 2012; Khoufi et al 2014 ; Philips 2014; Soykan et al 2015; Betatache-Alik 2015; Kahraman et al 2017; Khoukh & Maynou 2018; Uzer et al 2019; Adamidou et al 2020; Boudjadji & Rachedi 2021). No biological research on its growth have been conducted in the Moroccan Mediterranean region as far as we know. Because of its ecological role, abundance and commercial interest, the current study's goal was to provide information on length–weight relation, growth characteristics, age composition, mortality and exploitation of *M. merluccius* from the Moroccan Mediterranean Sea. It is expected that the present study will contribute to better fisheries management for European hake.

Material and Method

Fish collection. Samples of *M. merluccius* were collected from the Mediterranean coastline of Morocco (Figure 1), which extends from Jebha in the west to Saidia in the east (at the Algerian border) mostly by commercial fishermen using bottom trawlers, at depths of 50-510 m. The sampling period was at monthly intervals from March 2015 through April 2019. The collected specimens were directly taken to the laboratory of the National Institute of Fisheries Research (INRH).

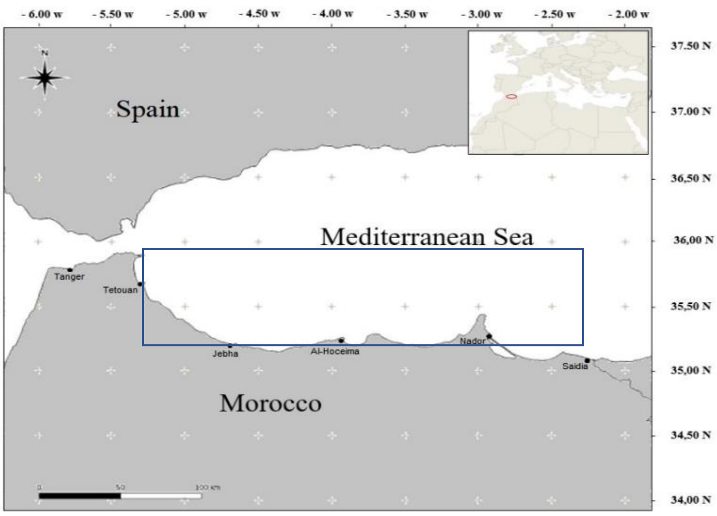

Figure 1. The location of studied site in the Mediterranean.

Fish measurements. Measurements for total length (TL, cm) and total body weight (TW, g) were recorded at the nearest 1 mm and 0.1 g, respectively, for each specimen. The determination of sex and maturity stages were carried out by macroscopic analysis of the gonads. Measurements gonad weight (Wg) were made and sex was recorded. Maturation stages were designated using Gunderson's (1993) classification system as 5 stage classification schemes:

I = immature, II = resting, III = developing, IV = ripe and V = spent.

Sampling analysis

Length-weight relationship. The parameters of length-weight relationship (TL-TW) were obtained using the equation of Ricker (1975):

$$TW = a\,TL^b$$

Where:
TL - total length (cm);
TW - total weight (g);
a - constant;
b - slope.

Growth type was identified by the student's t-test and the determination coefficient (R^2) was used to determine the degree of association between variables TL and TW.

Aging and growth estimation. The growth parameters (L_∞, K and t_0) were calculated using the equation of Von Bertallanfy (1938):

$$Lt = L\infty\,(1 - e^{-k(t-t0)})$$

Where:
Lt - total length at age t;
L_∞- asymptotic length;
K - the growth coefficient;
t_0- the theoretical age at length zero.

The FiSAT II program was used to calculate L_∞ and K (Gayanilo et al 2005), while theoretical age at length zero t_0 and growth performance index Φ were obtained according to the following equations (Pauly 1979; Munro & Pauly 1984):

$$Log\,(-t0) = -0.3922 - 0.2752\,Log\,L\infty - 1.038\,Log\,K$$
$$\Phi = log\,K + 2\,log\,L\infty$$

Age was determined using FISAT II by applying Bhattacharya's method (1967) depending on the length frequency data (Gayanilo et al 2005).

Instantaneous mortality rates and exploitation ratio. Instantaneous natural mortality (M) was achieved using the following empirical equation (Pauly 1983):

$$log\,M = -0.0066 - 0.279 \times (log\,L\infty) + 0.6543 \times (log\,K) + 0.4634 \times (log\,T)$$

Where:
L_∞ and K - growth parameters of Von Bertalanffy;
T - mean ambient temperature of the water at the sampling site, considered equal to 20ºC;
M and T - input parameters to determine the total instantaneous mortality (Z) applying the length-converted catch curve proposed by Pauly et al (1995).

The following formula was used to compute the instantaneous fishing mortality rate (F) (Beverton & Holt 1957):

$$F = Z - M$$

Where:
Z - total mortality;
M - natural mortality.

The current exploitation rate ($E_{current}$) was estimated as F/Z according to (Gulland 1970). Maximum fishing effort (F_{max}), precautionary limit reference point (F_{limit}) and optimum fishing rate (F_{opt}) were estimated using the expressions (Hoggarth et al 2006; Patterson 1992; Pauly 1983):

$$\boldsymbol{F}\,\mathbf{max} = \mathbf{0.67}\,\boldsymbol{K}/\mathbf{0.67} - \boldsymbol{Lc}$$

Where:
$L_c = \frac{LC50}{L\infty}$: Lc_{50} = length at first capture

$$Flimit = \frac{2}{3}\ x\ M$$
$$F\ opt = 0.4\ x\ M$$

Length at 1st capture (Lc_{50}) and length at first maturity (Lm_{50}). The probabilities of capture were calculated using FiSAT II Tool by plotting the cumulative probability of capture against the mid-length (Gayanilo et al 2005). The lengths at which 25, 50 and 75% of the stock is captured were then matched against the cumulative probability at 25, 50 and 75%, respectively. The cumulative probability at 50% was taken as corresponding to the length at first capture (Lc_{50}). The length at first sexual maturity (Lm_{50}), defined as the size at which 50% of individuals were close to spawning (King 1996), was estimated as following (Piñeiro & Saínza 2003):

$$P(l) = \frac{1}{1 + e^{(a+bl)}}$$

Where:
P (l) - the proportion of mature fish in each length class (%);
l - the fish length (cm);
a and b - the parameters of the logistic equation.

Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R). Knife edge option was used to calculate E_{max}: maximum exploitation rate, $E_{0.1}$: exploitation rate does not exceed 10% of its virgin stock and $E_{0.5}$: exploitation rate under which the stock is reduced to half of its virgin biomass.

Results

Length frequency distribution. A total of 6,223 specimens of *M. merluccius* were analyzed during this study. Figure 2 shows the length frequency distribution for the assessed fish species. The class size of 21-22 cm showed the highest frequency distribution, followed by the length classes of 23-24 and 25-26 cm. The highest length recorded throughout the study period was 73.8 cm. The total length (TL) and body total weights (TW) of males and females were significantly different (Mann–Whitney U test; P<0.001). TL of males ranged from 16.9–46.3 cm and TL of females ranged 15.7–73.8 cm.

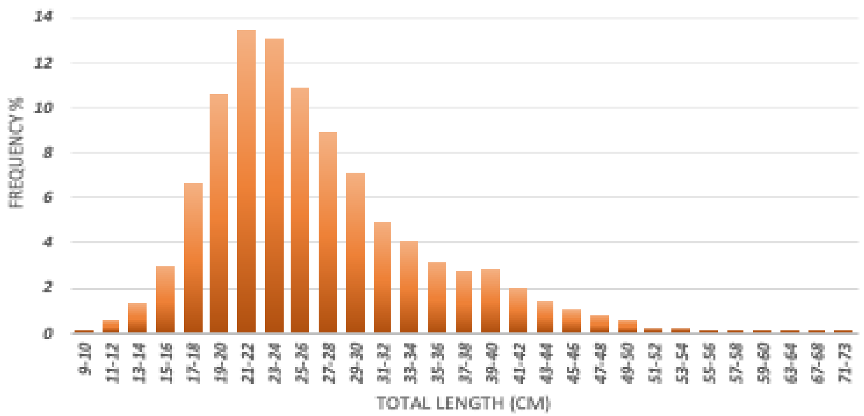

Figure 2. Length frequency distribution of *Merluccius merluccius* from the Mediterranean coastal area of Morocco.

Length-weight relationship. The relationship between total length (cm) and total weight (g) values of all samples are shown in Table 1 and Figure 3. A high determination coefficient

(R^2) was obtained between TL and TW: 0.97 in pooled sexes and 0.96 in males and females. According to Student's t-test, the regression between TL and TW for males, females and combined sexes was observed to be highly significant ($P<0.001$). In addition, it showed a sharp negative allometric growth in males as the value of b was significantly inferior to the isometric value (3; $p<0.05$), but an isometrical growth was observed for females and combined sexes.

Table 1
Length-weight relationship of *Merluccius merluccius* from the Mediterranean coastal area of Morocco

Sex	*Length - weight relationship*	*Correlation coefficient*
Combined sexes	$TW = 0.0054\ TL^{3.0792}$	$R^2 = 0.97$
Females	$TW = 0.0067\ TL^{3.0208}$	$R^2 = 0.97$
Males	$TW = 0.0098\ TL^{2.895}$	$R^2 = 0.95$

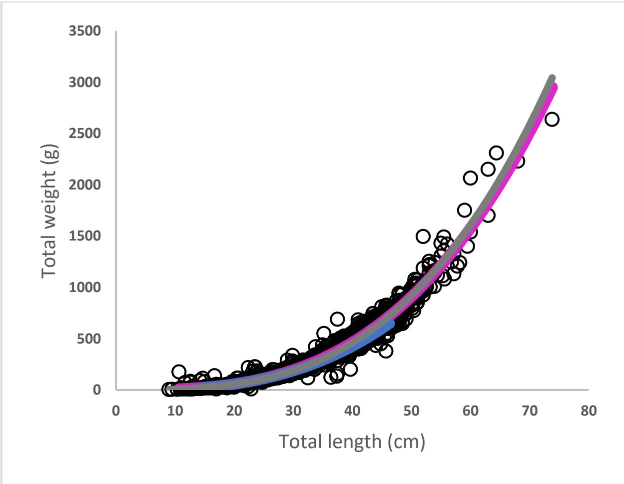

Figure 3. Length-weight relationship of *Merluccius merluccius* from the Mediterranean coastal area of Morocco (---: combined sexes, ---: females, ---: males).

Aging and growth. The length frequency data of European hake was analyzed by Bhattacharya (1967) method using the FiSAT II software for combined sexes. Seven modal length classes (year classes) were determined (Table 2, Figure 4). These modal length classes for *M. merluccius* were: 15.31, 21.24, 28.34, 39.23, 47.08, 56.06 and 61.00 cm, with a separation index greater to 1.5 (Figure 4). Table 2 summarizes the results of aging. 46.67% and 33.96% of the catches were specimens aged of 2 and 3 years, respectively. The minimum catch was observed in 7 years old individuals (0.04%).

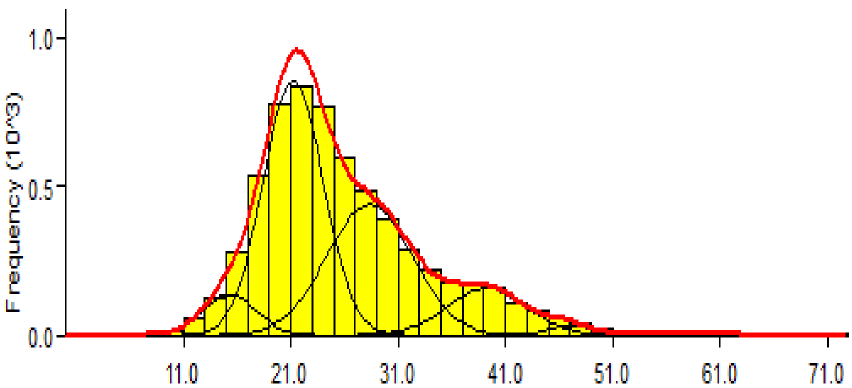

Figure 4. Length frequency of *Merluccius merluccius* separated into normally distributed components using Bhattacharya's method.

Table 2
Mean length, standard deviation (SD) and separation index (S.I.) for each age group of *Merluccius merluccius* obtained by Bhattacharya's method

Age (Years)	*Mean length (cm)*	*S.D.*	*Population (Individuals)*		*S.I.*
			N	*%*	
1	15.31	2.490	420.00	6.53	n.a.
2	21.24	2.800	3002.00	46.67	2.240
3	28.34	3.970	2184.00	33.96	2.100
4	39.23	3.680	726.00	11.29	2.850
5	47.08	1.960	78.00	1.21	2.780
6	56.06	2.910	19.00	0.30	3.690
7	61.00	3.040	3.00	0.04	1.660

The growth parameters were obtained using ELEFAN I method. The results showed that L_∞ for the pooled sex category was 76.65 cm, and the values of annual growth rate k was 0.11 $year^{-1}$, while t_0 was calculated at -1.21 $year^{-1}$. The parameters of Von Bertalanffy's model aided to construct the absolute linear growth equation as follows (Von Bertalanffy 1938):

$$Lt = 76.65\ (1 - \ e^{-0.11(t+1.21)})$$

The growth performance index (φ) was estimated as 2.81.

Table 3
The Von Bertalanffy (1938) growth parameters are calculated for *Merluccius merluccius* from the Mediterranean coastal area of Morocco

Parameters	*L_∞ (cm)*	*K ($year^{-1}$)*	*t_0 (year)*	*Φ*
Combined sexes	76.65	0.11	-1.21	2.81

Instantaneous mortality rates and exploitation ratio. The catch curve analysis based on length distributions (Pauly 1984) was applied and the total mortality coefficient was Z=0.65 $year^{-1}$, with R^2=0.95 (Figure 5). By using Pauly formula (1983), the natural mortality (M) was obtained as M=0.28 $year^{-1}$. The fishing mortality (F) was estimated at 0.37 $year^{-1}$. In addition, the exploitation rate was estimated at 0.57. This exploitation rate is greater than 0.5. The optimum fishing rate (F_{opt}), maximum fishing limit (F_{max}) and the precautionary fishing limit (F_{limit}) were 0.112 $year^{-1}$, 0.198 $year^{-1}$ and 0.186 $year^{-1}$ respectively.

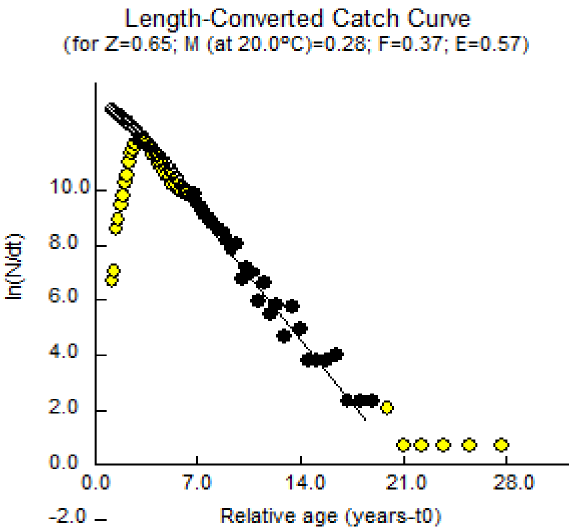

Figure 5. FiSAT II output of linearized length-converted catch curve for *Merluccius merluccius* in the Moroccan Mediterranean coast.

Lengths at 1st capture and length at first maturity. The selection length of Lc_{25} (25%) was 19.06 cm, Lc_{50} (50%) was 22.97 cm and Lc_{75} (75%) was 26.88 cm (Figure 6A), which provides a clear indication of the estimated real size of fish in the fishing area. Therefore, the length at first capture (L_{c50}) is calculated as 22.97 cm. The mean size at first sexual maturity in 50% of the individuals was calculated to be 21.1 cm TL for males, 32.5 cm for females and 24.8 cm for combined sexes (Figure 6B).

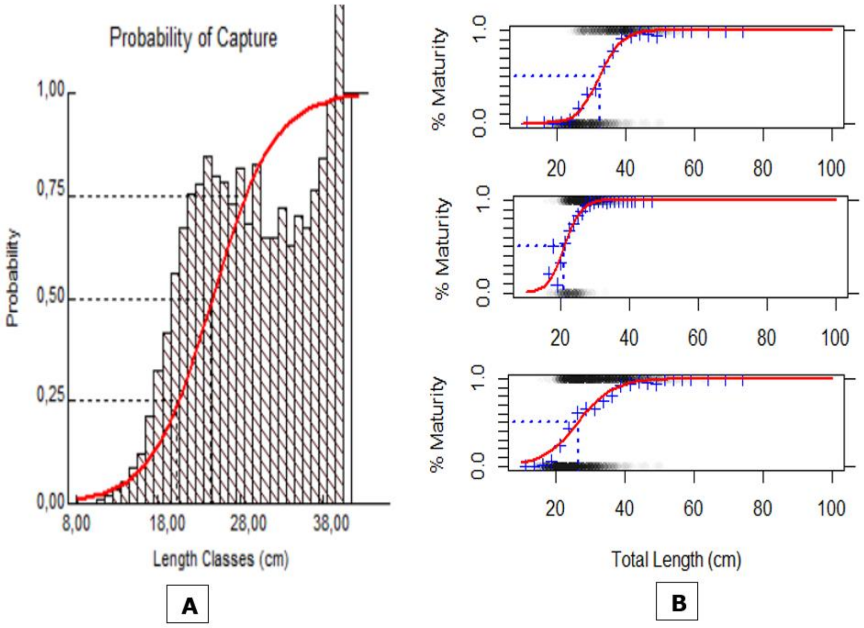

Figure 6. A. Probability of capture estimation from FiSAT Output for *Merluccius merluccius* in the Moroccan Mediterranean coast. B. Length at first maturity estimation of *Merluccius merluccius* for females (32.5 cm), males (21.8 cm) and combined sexes (24.8 cm).

Relative yield per recruit (Y'/R). Figure 7 shows the various exploitation rates determined by applying the knife-edge in Beverton & Holt (1957) study's relative yield per recruit model. The maximum relative yield per recruit was found to be E_{max}=0.555 at $\frac{LC50}{L\infty}$ =0.299 (yellow dashes). The exploitation level which maintains the spawning stock biomass at 50% of the virgin stock biomass was $E_{0.5}$=0.301 and the marginal exploitation rate was $E_{0.1}$=0.457.

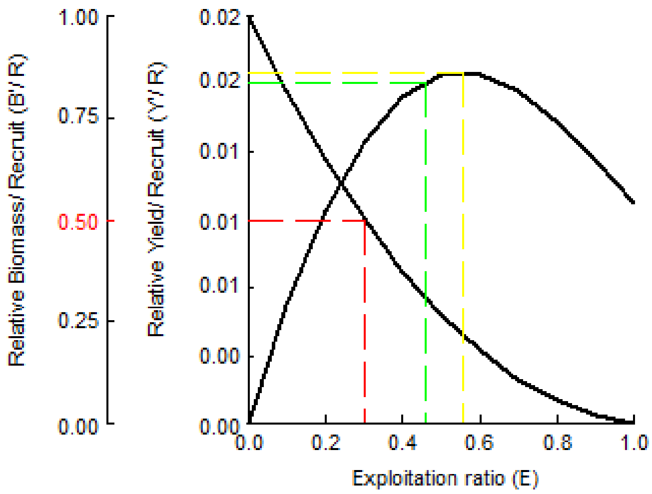

Figure 7. Relative yield (Y'/R) and relative biomass per recruit (B'/R) showing levels of yield indices for *Merluccius merluccius* in the Moroccan Mediterranean coast (Red dashes=$E_{0.5}$, green dashes=$E_{0.1}$ and yellow dashes=E_{max}).

Discussion

Growth parameters. The estimation of growth parameters ($L\infty$, K, t_0), age, mortality, and exploitation rates, are considered fundamental and constitute the first step in fishery stock assessment. The growth pattern (b) of *M. merluccius* from the current study was 3.079, which led us to conclude that the species grows isometrically, where the weight grows at the same rate for both sexes. In the Mediterranean Sea, Bouaziz et al (1998) in central region of the Algerian coast, Kahramam et al (2017) and Gül et al (2019) in Marmara Sea (Turkey) reported similar growth patterns (b=3.020, 2.9896 and 2.9718, respectively) (Table 4). On the Atlantic coast, isometric growths (b=3.1) have been reported in the study of Costa (2013), on the coastal waters of Portugal. Nevertheless, other studies in the Mediterranean areas have noted positive allometry such as Adamidou et al (2020), Uzer et al (2019) and Soykan et al (2015) in Aegean Sea, Turkey (b=3.20, 3.22 and 3.24 respectively). However, both Boudjadi & Rachedi (2021) in the extreme northeast of Algeria and Demirel & Dalkara (2012) in the Marmara Sea reported a negative allometric growth. Similarly, Sangun et al (2007) in Turkey also documented a negative allometric growth pattern for *M. merluccius* (Table 4). This divergence of results between areas could be related to sample size, year, diets, seasons, maturity stages, physical and environmental conditions or sampling methods of different studies.

Table 4

The length-weight relationships for *Merluccius merluccius* from different locations

Location	*References*	*a*	*b*	*Growth type*
Moroccan Mediterranean Sea	Present study	0.0054	3.079	=
Algerian coast	Bouaziz et al (1998)	0.0060	3.020	=
Marmara Sea, Turkey	Kahramam et al (2017)	0.0079	2.9896	=
Marmara Sea, Turkey	Gül et al (2019)	0.0082	2.9718	=
Portugal	Costa (2013)	0.0038	3.1	=
NE Mediterranean Coast	Sangun et al (2007)	0.337	2.353	-
Marmara Sea, Turkey	Demirel & Dalkara (2012)	0.010	2.886	-
Algerian coast	Boudjadi & Rachedi (2021)	0.018	2.68	-
N Atlantic coast of Morocco	Belcaid & Saghir (2011)	0.00006	3.13	+
Tunisian coasts	Khoufi et al (2014)	0.003	3.115	+
Aegean Sea, Turkey	Adamidou et al (2020)	0.0037	3.20	+
Aegean Sea, Turkey	Uzer et al (2019)	0.0034	3.22	+
Aegean Sea, Turkey	Soykan et al (2015)	0.00341	3.24	+

=: isometric, +: a positive allometric growth, -: a negative allometric growth

In this study, the age range of the fish samples was 1 to 7 years old. Our results revealed that the combined sexes attain 13.64, 20.61, 28.07, 38.2, 47.65, 56.98 and 61.55 cm of length, at the end of each year of the 7 years of life. The present results are similar to those reported on the east coast of Algeria by Betatache-Alik (2015) and in Turkey by Girgin et al (2020). However, a maximum age between 8 and 12 years has been reported by Khoufi et al (2014), Piňeiro & Sainza (2003) and by Mugahid et al (1982) in Tunisian coast, Iberian and Libyan waters respectively. In the other hand, Philips (2014), Kahramen et al (2017) and Uzer et al (2019) recorded a maximum age of 6 years in Egypt, Marmara Sea and the north Aegean Sea. In contrast, Soykan et al (2015) and Akalın (2004) concluded an age range of sample specimens between 1 and 5 years old, both in Turkey.

Table 5 compares the results of this study's growth parameters ($L\infty$, k, t_0, and Φ) to those of other research studies. In the present study, the asymptotic length L_∞ for combined sexes (L_∞=76.65 cm) is close to that observed by Belcaid & Saghir (2011), in Moroccan northeast Atlantic (72.45 cm) and by Philips (2014) in Egyptian waters (74.19 cm), though much less than those reported by Girgin et al (2020) in Turkey (84.4 cm), Uzer et al (2019) in the Aegean sea (102.6 cm), Khoukh & Maynou (2018) in the Catalan sea (110 cm), Khoufi et al (2014) on the Tunisian coast (110 cm) and El Habouz et al (2011) on the Moroccan Atlantic coast (115 cm). However, the estimated L_∞ in this study was higher than the values recorded by other authors (Gül et al 2019; Boudjadi & Rachedi 2021). Some of these results are significantly higher or lower than our findings, which may be due to the diversity of sampling strategies, periods of sampling, sizes of the largest sampled specimen (L_{max}), distribution depths of the stock, sample sizes and biological features. Therefore, we can presume that the sampling carried out in this study was representative, given the wide range of lengths. Besides, the L_∞=76.65 cm estimated in this study is realistic since the largest specimen sampled was 73.8 cm.

Table 5

Comparison with growth estimates from other studies (♂: male; ♀: female)

Area	sex	*L∞*	*K*	*t0*	*Φ*	*Authors*
Moroccan Mediterranean coast	♂♀	76.65	0.11	-1.21	2.81	This study
Moroccan northeast Atlantic	♂♀	72.45	0.280	-0.720	3.16	Belcaid & Saghir (2011)
Eastern central Atlantic	♂♀	115.4	0.14	-0.919	3.27	El Habouz et al (2011)
North -East of Algeria	♂♀	44.08	0.29	-0.517	2.7	Boudjadi & Rachedi (2021)
Tunisian coasts	♂♀	110	0.198	0.500	3.29	Khoufi et al (2014)
Egyptian Mediterranean waters	♂♀	74.193	0.119	0.281	2.81	Philips (2014)
Catalan sea	♂♀	110	0.178	0	-	Khoukh & Maynou (2018)
Strait of Gibraltar, Spain	♂♀	80.80	0.350	-1.700	3.36	Piñeiro & Saínza (2003)
North-eastern Mediterranean (Turkey)	♂♀	84.44	0.135	-0.469	2.98	Girgin et al (2020)
Central region of the Algerian coast	♀	80.64	0.139	-0.422	2.95	Bouaziz et al (1998)
	♂	48.72	0.321	-0.07	2.88	
Marmara Sea, turkey	♂♀	57.5	0.27	-0.57	-	Gül et al (2019)
Aegean Sea	♂♀	102.6	0.0992	-0.808	3.01	Uzer et al (2019)

Reported growth rates K of *M. merluccius* vary from one region to another in the Mediterranean Sea and oscillate between 0.09 to 0.35 $year^{-1}$ (Table 5). The K estimates appeared to be in line with estimates from other studies, similar to those obtained in the Egyptian Mediterranean waters (Philips 2014). However, on other Mediterranean areas, the reported values of K are higher than our estimate (Bouaziz et al 1998; Piñeiro & Saínza 2003; Belcaid & Saghir 2011; Boudjadi & Rachedi 2021).

The growth performance index from the current study (Φ=2.81) was close to estimates from other studies (Bouaziz et al 1998; Philips 2014) which implied that hake from the respective study areas are of a similar taxonomic fish family. However, the growth performance index from the current study was lower than the value estimated by Piñeiro & Saínza (2003) from Strait of Gibraltar - Spain, Khoufi et al (2014) from Tunisian coasts and El Habouz et al (2011) from eastern central Atlantic coast of Morocco (Table 6). According to Boudjadi & Rachedi (2021), the variations in growth performance index could be due to the methodological approaches adopted for the calculation, data sampling, period of sampling, sample size, as well as the size of the largest individual, food and changes in the environment.

Mortality coefficients and current exploitation rate. In order to better understand the population dynamics, our study provides the first information on mortality rates of *M. merluccius* for this area. The annual total mortality (Z) was calculated to be 0.65 year^{-1}. Natural (M) and fishing (F) mortalities were calculated to be 0.28 year^{-1} and 0.37 year^{-1} respectively. The natural mortality of *M. merluccius* in the current study is higher than what was estimated by Belhocine (2012) and Betatache-Alik (2015) on the Algerian coasts (Table 6), and relatively lower than the estimates reported by Gurbet et al (2013), Soykan et al (2015) and Uzer et al (2019) in the Aegean Sea, and Belcaid & Saghir (2011) and El Bouzidi et al (2021) on the north Atlantic coasts of Morocco. This observation could indicate that *M. merluccius* stock in the Aegean Sea and on the north Atlantic coasts of Morocco is more susceptible to the natural mortality conditions than in other areas.

The estimated fishing mortality for *M. merluccius* compared to other studies was relatively lower (Bouaziz et al 1998; Gurbet et al 2013; Betatache-Alik 2015; Soykan et al 2015; Kahraman et al 2017; Uzer et al 2019; El Bouzidi et al 2021) (Table 6). On the other hand, the instantaneous fishing mortality rate appeared to be above the maximum fishing mortality (F_{max}=0.198 year^{-1}), limiting fishing mortality (F_{limit}=0.186 year^{-1}) and favorable fishing effort (F_{opt}=0.112 year^{-1}), which suggests that *M. merluccius* is suffering higher fishing pressure in the Mediterranean coast of Morocco.

The $E_{current}$ reported in the Aegean Sea (Gurbet et al 2013; Soykan et al 2015; Kahraman et al 2017; Uzer et al 2019), in Algeria (Bouaziz et al 1998; Belhoucine 2012; Betatache-Alik 2015; Boudjadi & Rachedi 2021) and in the north Atlantic coasts of Morocco (Belcaid & Saghir 2011; El Bouzidi et al 2021) were more than 0.5, suggesting that *M. merluccius* stocks were overexploited (Table 6). From the present study, the exploitation rate ($E_{current}$=0.57 year^{-1}) was slightly higher than 0.5. Besides, the $E_{current}$ was above the estimated relative sustainable yield point ($E_{0.5}$=0.301), thus strengthening that the hake stock is in an unhealthy state and currently overexploited. This is supported by the fact that the estimated Z/K ratio for *M. merluccius* (Z/K=5.9) is greater than the proposed safe limit (Z/K=2). It can be inferred that currently, in the hake stock, the mortality dominates over the growth. It is advised to reduce the fishing effort to a rate of 0.112 year^{-1} in order to, at least, protect 50% of the biomass of *M. merluccius* along the Moroccan Mediterranean area.

Table 6

Comparison with results of total, natural and fishing mortality and exploitation rate from different area

Area	*Z*	*M*	*F*	*E*	*Authors*
Moroccan Mediterranean area	0.65	0.28	0.37	0.57	The present study
West coast of Algeria	0.86	0.23	0.63	0.73	Belhocine (2012)
Algerian center coast	0.78	0.27	0.51	0.65	Bouaziz et al (1998)
Extreme North-East of Algeria	1.53	0.61	0.92	0.60	Boudjadi & Rachedi (2021)
East coast of Algeria	2.28	0.24	2.04	0.89	Betatache-Alik (2015)
Central Aegean Sea	1.539	0.579	0.959	0.62	Soykan et al (2015)
North Aegean Sea	2.21	0.57	1.61	0.72	Uzer et al (2019)
Central Aegean Sea	2.24	0.58	1.66	0.74	Gurbet et al (2013)
Marmara Sea	2.01	0.19	1.81	0.9	Kahraman et al (2017)
Moroccan northeast Atlantic	1.80	0.5	1.31	0.73	Belcaid & Saghir (2011)
Moroccan northeast Atlantic	1.49	0.5	0.98	0.66	El Bouzidi et al (2021)

Lengths at 1st capture, at optimum capture and at first maturity. The estimated length at first capture (Lc_{50}) was clearly lower than the length at first maturity (Lm_{50}) obtained in the current study, showing that the trawl net collects immature individuals

(TL<24.8 cm), before they can afford to reach matured stages. The current Lc_{50} must be raised by reconsidering the fishing methods adopted in our study area, so that females could have the chance to spawn in a life span. Furthermore, the recorded $\frac{LC50}{L\infty}$ ratio (0.299) was less than 0.5, suggesting that juvenile individuals account for the majority of the catch, implying that overfishing is becoming more prevalent. The values of the length at first capture Lc_{50} in the current study, compared to other estimates in different areas, are slightly higher than what was recorded by Khoufi et al (2014) from the north Tunisian coast (14.20–17.04 cm).

The length at first maturity Lm_{50} in this study of *M. merluccius* was similar to what was reported by Philips & Ragheb (2014) in the Egyptian Mediterranean waters (Lm_{50}=21.8 cm for males), Belhoucine (2012) in Algeria (Lm_{50}=33.5 cm for females), and El Habouz et al (2011) in the Eastern central Atlantic of Morocco (Lm_{50}=33.8 cm for females), and lower than what was reported for combined sexes by Lahrizi (1996) from the Atlantic coast of Morocco and Carbonara et al (2019) in the Tyrrhenian Sea (Lm_{50}=33.03 cm), Sardinia (Lm_{50}=30.03 cm), Adriatic Sea (Lm_{50}=31.95 cm) and Ionian Sea (Lm_{50}=32.95 cm) (Table 7). Thus, we can conclude that *M. merluccius* living in the north eastern Mediterranean area waters are growing faster than those of the western Mediteranean basin. Genetic factors could be considered as the primary reason of differences in the length of maturation for the same species in different area, however, food and environmental variation may also have a role (Philips & Ragheb 2014).

Table 7

Reports of length at first maturity Lm_{50} of *Merluccius merluccius* in various Mediterranean fisheries

Sea	*Area*	*Sexes*	*Lm50 (cm)*	*References*
Mediterranean	Moroccan Mediterranean coast	♀	32.5	The present study
		♂	21.8	
		♂♀	24.8	
	Egyptian Mediterranean waters	♀	24	Philips & Ragheb (2014)
		♂	21.8	
	Tunisian coast	♀♂	28.79	Khoufi el al (2014)
	Bay of Oran (Algeria)	♀	33.5	Belhoucine (2012)
		♂	20.5	
	Central Aegean Sea	♀	21.49	Soykan et al (2015)
		♂	25.65	
	Tyrrhenian Sea	♀♂	33.03	Carbonara et al (2019)
	Sardinian Sea	♀♂	30.03	
	Adriatic Sea	♀♂	31.95	
	Ionian Sea	♀♂	32.95	
Atlantic	Moroccan Eastern-Central Atlantic	♀	33.8	El Habouz et al (2011)
		♂	28.6	
	Moroccan Central Atlantic	♀	41.08	Lahrizi (1996)
		♂	37.82	

♀: female ♂: male.

Conclusions. The study provides clear information on length–weight relation, growth, age, mortality and current exploitation of *M. merluccius*, revealing that the stock within Moroccan Mediterranean coasts is currently overexploited, experiencing high fishing pressure and exploitation rate, up to the maximum sustainable yield. Therefore, it is recommended: (1) to employ strict management measures; (2) to decrease the fishing pressure, in order to reduce the exploitation rates; (3) to prevent stock depletion by increasing the length at first capture (Lc_{50}) to values around 24.8 cm, in order to allow the females to spawn in their life span, before being caught; and (5) to allow young individuals to reach the marketable size.

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