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Seasonal variability of maturation status, body condition and population structure in European hake *Merluccius merluccius* (Linnaeus, 1758) from Safi fishing area on the Moroccan Atlantic coast

ABDELAZIZ MOUNIR[1,2], HASSAN ALAHYANE[1], MOHAMMED ZNARI[1] AND NOR-EDDINE CHOUIKH[3]

[1]*Laboratory "Water, Biodiversity and climate change", Department of Biology, Faculty of Sciences, Semlalia Cadi Ayyad University, Marrakech, P.O. Box 2390, 40000, Morocco*

[2]*The Natural History Museum of Marrakech, Research Centre on Biodiversity, Cadi Ayyad University, Bd Allal El Fassi Marrakech, Morocco*

[3]*Department of Environmental Engineering, Higher School of Technology, Sultan Moulay Slimane University Khenifra, 54000, Morocco*

e-mail: alahyanerh@gmail.com

ABSTRACT

Reproductive strategy in European hake, *Merluccius merluccius* (Linnaeus, 1758) from the Safi fishing area was investigated between January 2019 to December 2019. The sex ratio (♀/♂) was in favour of males (1:1.74). Of a total of 1152 specimens sampled, 589 were males (51%), 333 females (29%), and 230 immature (20%). The immature ones were represented in the small size classes, between 14 and 23.9 cm (TL). The present study showed that European hake breeds throughout the year with two spawning peaks during May-July and October. The gonadosomatic index (GSI) increases from May and has a peak in October for females and August for males, while the hepatosomatic index (HSI) reached the highest values in November for females and in May for males. The morphometric relative body condition showed a single peak in January for females and October for males. The size at first sexual maturity in male and female was 26.50 cm and 27.40 cm, respectively.

Keywords: Bentho-pelagic species, Lm_{50}, Reproductive parameters, Sex-ratio, Somatic indices

Introduction

The European hake *Merluccius merluccius* (Linnaeus, 1758) is widely distributed in the Mediterranean Sea and the north-eastern Atlantic, from Norway to the Gulf of Guinea (Froese and Pauly, 2014) and it is one of the main targeted fish in this area (Candelma *et al.,* 2021). It is a bentho-pelagic species characterised by significant bathymetric segregation during its ontology. The distribution bathymetry of this species is linked to its eco-biological behaviour (Maurin,1954; Bartolino *et al.,* 2008), reproductive cycle (Guichet, 1988) and diet (Maynou *et al.,* 2003), which determine the migration and geographical distribution of different age groups. In Morocco, it has a wide bathymetric distribution that extends from the coast to the depths of 1000 m. The species is known to inhabit the bottom waters during the day and deviates from it at night to hunt (Philips, 2014).

The Moroccan Atlantic population of European hake is considered as a single stock and is the only hake species caught by the coastal fishery (FAO, 2006). The fishing fleet which exploits this species comprises 20 long liners and 450 trawlers (El Habouz *et al.,* 2011). Global capture of hake reached 1,42,190 t in 2016 (FAO, 2020), while in Morocco annual catches have varied between 3,561-5,981 t during the last decades (FAO, 2017; MAFRDWF, 2018). It is considered one of the most heavily exploited fish (FAO, 2017). The abundance indices of *M. merluccius* shows a declining trend from 60 kg day^{-1} to 30 kg day^{-1} (2009-2019) and the presence of over 80% of juveniles in the catch (INRH, 2019) reflects the damage to the resource and the fishing pressure on the stock. For these reasons, serious measures have been taken, such as regulation of the minimum landing size (MLS) at 20 cm, reduction of the current fishing effort and prohibition of fishing during the months of June and July (El Habouz *et al.,* 2011).

Due to its commercial and ecological importance, several studies have been done on *M. merluccius* in Atlantic Ocean, related to stock assessment (Domínguez-Petit and Saborido-Rey, 2010; Deroba *et al.,* 2010; Helser and Alade, 2012; Vigier *et al.,* 2018), growth and reproductive biology (Maurin, 1954; Goni, 1983; Ramos *et al*., 1990, 1996; El Habouz, 1995; Lahrizi, 1996; Pineiro and Sainza, 2003; Dominguez-Petit *et al*., 2008b; Domínguez-Petit and Saborido-Rey, 2010; El Habouz *et al.,* 2011), spawning cycle (Murua and Saborido-Rey, 2003; Domínguez-Petit *et al*., 2008a; Domínguez-Petit *et al.,* 2010), feeding habits (Durbin *et al.,* 1983; Hill and Borges, 2000; Cabral and Murta, 2001) and parasites (Silva, 1984; Marques, 1985). Analysis of lipid reserves of European hake was reported by Gonçalves *et al.* (2004).

Biological information, especially the somatic indices such as gonadosomatic index (GSI), hepatosomatic index (HIS), and relative condition factor (K_n) and reproductive indices like length at first sexual maturity (Lm_{50}) and spawning season are crucial for stock assessment and management of its fisheries. Hence, this study was undertaken to update such information on the European hake in the Safi fishing area as it is one of the most important demersal species exploited in the Morocco Atlantic coasts.

Materials and methods

Study area and sampling

Samples of *M. merluccius* were obtained from commercial bottom trawl fishing operations in the Safi fishing area from January 2019 to December 2019. The trawlers operate in the area extending between Oualidia in the north (32°47'N, 8°58'W) and Essaouira in the south (31°29'N, 9°45'W) (Fig. 1) between 100 and 150 m depth. A total of 1152 specimens of European hake were sampled, with total length (TL) and total weight ranging from 14 to 58 cm and 15.5 to 1701 g, respectively (Table 1). For every specimen, the following parameters were recorded: total weight (TW), total length (TL), gutted weight (GW) to 0.1 g, macroscopic maturity stage of

Table 1. Number of individuals sampled (total and for both sexes) and size of the specimens

Months	Total specimens	Immatures	Females	Males	TL range (cm)	TW range (g)
Jan	96	13	38	45	14.7-38.4	33.5-391.4
Feb	93	43	28	22	17.8-43.5	35-326
Mar	100	30	21	49	14-39.5	15.5-483
Apr	94	29	32	33	14.3-36.6	18.5-344
May	75	6	28	41	15.4-58.0	39.5-1701
Jun	99	6	30	63	15.5-47.5	28-954
Jul	98	14	50	34	14-53.0	20-997
Agu	100	4	2	94	19.5-46.0	46-631
Sep	100	15	57	28	15.2-42.01	23.65-526
Oct	99	23	17	59	15-50.0	30.5-1051
Nov	100	40	20	40	14.5-34.0	19-304
Dec	98	7	10	81	15.5-40	42.75-404

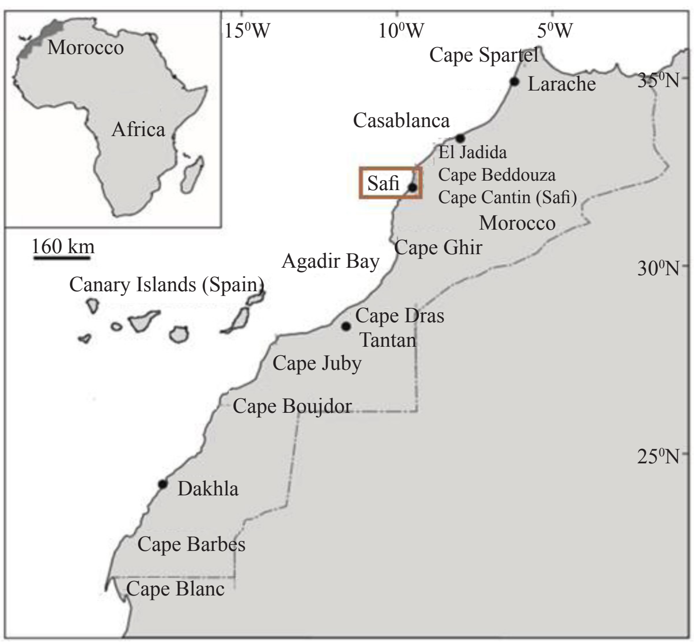

Fig. 1. Study area on the Atlantic coast of Morocco

gonads, sex and liver and gonad weights to 0.01 g. The stages of maturity were determined using the maturity scale for partial spawners described by Holden and Raitt (1974). Individuals from stage III were considered mature (Table 2). Seawater temperature was measured monthly in the Safi fishing area during the study period.

Size structure and sex-ratio

The size structure of *M. merluccius* population was represented by the distribution of sampled specimens across 2 cm size classes as percentages of immatures, females and males. The female to male ratio (sex ratio, SR) was calculated by using only mature individuals. The χ^2 (chi-square) test was used to determine any significance difference between the male and female ratio.

Size at first sexual maturity

The size (length) at first sexual maturity (Lm_{50}), defined as the length at which 50% of the population is mature (King, 1995), was estimated using the logistic equation described by Yeates (1974):

$$f(x) = \frac{1.M}{1 + a.e^{-bx}}$$

where $f(x)$ represents the percentage of mature specimens, M the maximum value of $f(x)$, x the length, a and b are parameters of the curve, and e the natural logarithm base.

Reproductive seasonality and fish condition indices

The hepato- and gonadosomatic indices and relative condition factor (K_n) were used to evaluate the monthly variation of *M. merluccius's* maturity and condition stage. The following functions defined these indices:

GSI (%) = Gonad weight/Gutted body weight *100,

HSI (%) = Liver weight/Gutted body weight *100

$Kn = W/a*TL^b$

where W is gutted weight, a and b are the regression parameters determined from the length-weight relationship and TL is the total length.

Statistical analysis

Mean values were compared for statistical significance using Chi-square and one-way ANOVA tests employing SPSS Software (Version 25.0).

Results

Population structure and sex-ratio

Out of 1152 European hake specimens sampled, the number of males, females and immature was 589 (51%), 333 (29%) and 230 (20%) respectively (Fig. 2).

The sex ratio (♀/♂) was estimated at 1:1.76 in favour of males and chi-square analysis indicated significant difference from 1:1 (χ^2, $p < 0.05$). Males were more abundant than females in all size groups from 18-20 cm, except for the higher size groups of 38-40 cm and above. The immature individuals were between 14-22 cm. The

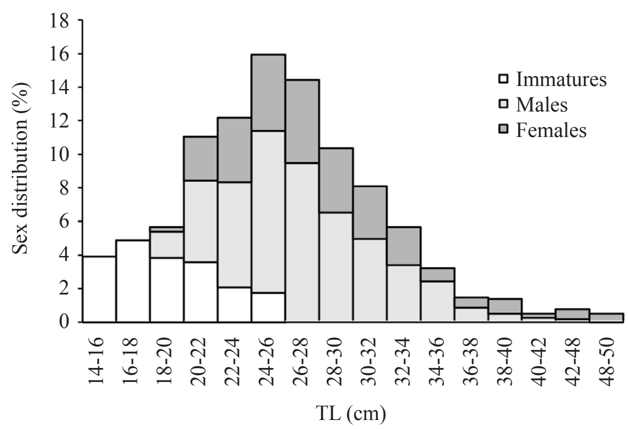

Fig. 2. Size distribution of immatures, males and females of *M. merluccius*

Table 2. Maturity scale for partial spawners (Holden and Raitt, 1974)

Stage		Description, Macroscopic characteristics
I	Immature	Ovaries and testes occupy about a third of the length of the abdominal cavity. Ovaries pinkish and translucent. Testes whitish. Eggs invisible to the naked eye.
II	Maturation and recovery	Ovaries and testes occupy about half the length of the abdominal cavity. Ovaries pinkish and translucent. Testes whitish, more or less symmetrical. Eggs invisible to the naked eye.
III	Advanced maturing	Ovaries and testes occupy about two thirds of the length of the abdominal cavity. Ovaries pinkish-yellow and grainy. Testes white to cream. No transparent or translucent eggs visible.
IV	Mature (ripening)	Ovaries and testes occupy about two thirds to the entire length of the abdominal cavity. Ovaries pink-orange with superficial blood vessels visible. Eggs mature and transparent. Testes white, creamy and soft.
V	Post-spawning	Ovaries and testes shrink to about half the length of the abdominal cavity. Walls loose. Ovaries can contain the remains of opaque, ripe eggs in disintegration. Eggs darkened or translucent. Testes flaccid and bloodshot.
VI	Regression and resting	Smaller gonads. Bloody appearance. Tubular opaque gonads. Pale orange colour.

larger specimens were represented by the size between 36-58 cm with the dominance of adult females.

Monthly variation of sexual maturity stages

The monthly distribution of maturity stages in both sexes revealed that stages I and II were predominant in the sampled species. In comparison, spawning females (Stages III and IV) were present in May, June, October and December, confirmed by the analysis of GSI (Fig. 3). Resting females (stage V) were encountered during May-July, October and December.

Size at first sexual maturity

The size at first maturity (Lm_{50}) of males was 24.85 cm and the range of maturation (L_{75}-L_{25}) was 7.31 cm. The female mean size at first maturity was 29.69 cm and the range of maturation (L_{75}-L_{25}) was 11.29 cm (Fig. 4). The smallest TL for mature females and males were 16.00 and 18.10 cm, respectively. This shows that the males reach their first sexual maturity at smaller sizes than females.

Monthly variation in the gonadosomatic index (GSI), hepatosomatic index (HSI) and effect of water surface temperature

The mean GSI of females (Fig. 5) increased from January (0.19) to October (4.18), decreasing rapidly in November (0.17) while that of males was low and displayed only a slight seasonal variation because males invest little energy in developing gonads. The water surface temperature was low in January (16.4°C) and increased to reach the highest value in October (21.7°C), following which it decreased. The mean GSI of females exhibited a direct relation to the water temperature, indicating the influence of temperature on gonadal activity.

The mean HSI (Fig. 5) varied significantly during the study period in both sexes ($p \leq 0.001$); however, the HSI did not differ significantly between females and males. The mean values of HSI were higher in November for females (3.72) and May for males (3.07). The lowest values of HSI were observed in September for both sexes with 1.58 and 1.41, respectively. These minimum values coincide with the spawning period when the liver's reserves are mobilised for use during oogenesis in the ovaries.

Monthly variation in morphometric index

The morphometric index K_n varied from 0.4 to 0.45 and from 0.65 to 0.75 for males and females respectively and did not show significant fluctuations throughout the year (Fig. 6).

Discussion

Fisheries management contributes to the implementation of sustainable exploitation programmes by limiting the "fishing mortality" of recruits, thus maintaining sufficient reproductive potential of the fish population (Domínguez-Petit *et al.,* 2008b). For this, several factors are usually applied as health indicators of the stock such as sex-ratio, spawning cycle and size at the first sexual maturity. The present work aimed to study reproductive parameters of *M. merluccius* in the Moroccan Atlantic coast.

The sex-ratio changes within size classes of the population and in the present work, the overall sex ratio was (1:1.74) in favour of males. A different pattern of sex ratio close to 1:1 has been described by El Habouz *et al.* (2011) in the eastern central Atlantic Moroccan coast and by Pineiro and Sainza (2003) in Iberian Atlantic waters.

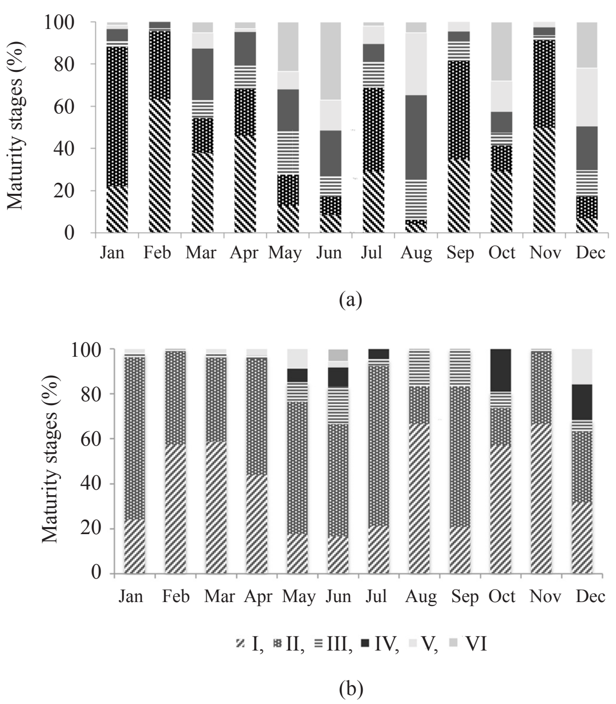

Fig. 3. Monthly percentage composition of different sexual maturity stages of (a) males and (b) females of *M. merluccius*.

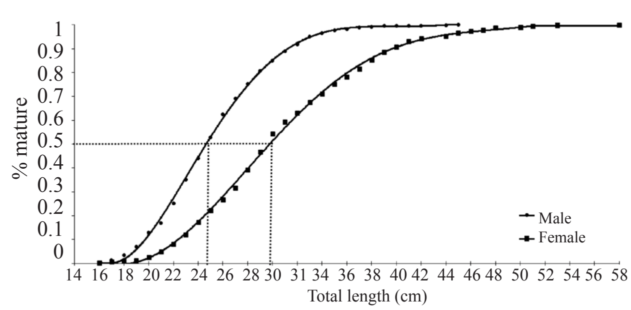

Fig. 4. Size at first sexual maturity of *M. merluccius*

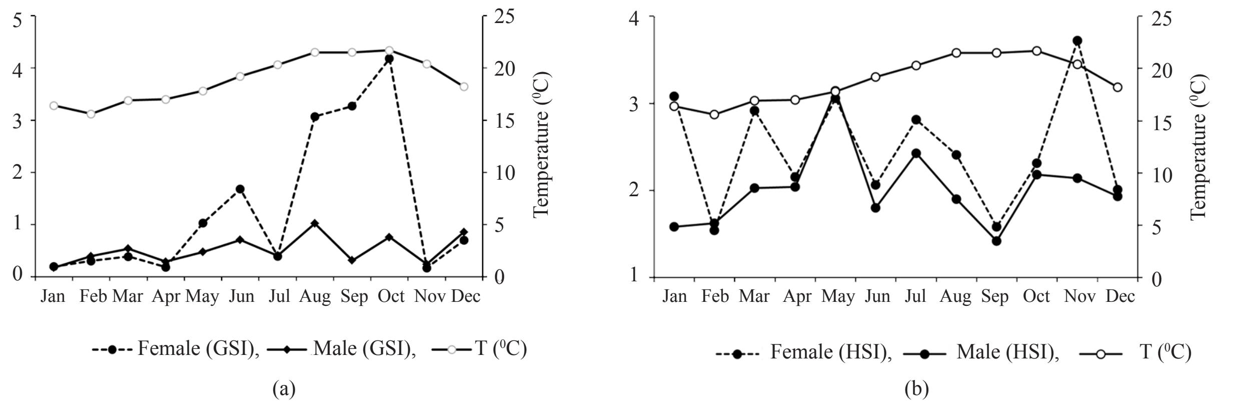

Fig. 5. Monthly variation of (a) GSI and (b) HSI of male and female *M. merluccius*

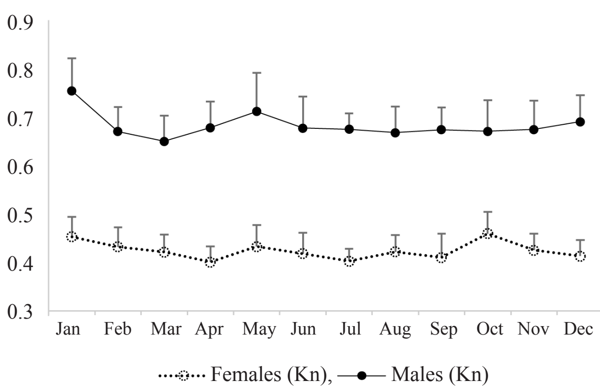

Fig. 6. Monthly variation of the body condition index (K_n) of female and male of *M. merluccius*

This could be explained by the influence of environmental parameters such as temperature on sex determination (Conover and Kynard, 1981), selective mortality by sex through differential predation and differential sexual behaviour or growth rate (Schultz, 1996). Besides, the sex-ratio may be affected by the food density and it has been documented that low food density favours female dominance, while high food density can lead to an increase in number of males (Znari and Mounir, 2021).

The size at first sexual maturity is an important factor in fisheries management for the determination of the optimum length at first capture and the minimum legal size to maintain the suitable spawning stock (Hobday *et al.,* 2000). Size at first sexual maturity of *M. merluccius* has been estimated for different areas by various authors. In the Eastern central Atlantic Moroccan coast, El Habouz *et al.* (2011) estimated Lm_{50} at 28.6 and 33.8 cm for male and female European hake. The Lm_{50} was estimated at 37.8 cm for male and 41.1 cm for female, in the north Moroccan Atlantic (Lahrizi, 1996) and at 35 cm for male and 46.5 cm for female in the central Moroccan Atlantic (El Habouz, 1995). In the present study, the Lm_{50} was estimated at 24.85 cm for male and 29.69 cm for female. In all the studies, it was found that males reach their first sexual maturity at smaller sizes than females. Compared to the results of previous works, the Lm_{50} recorded for *M. merluccius* in the Moroccan Atlantic was much smaller. This trend has been observed over the last two decades. Many studies carried out on Atlantic and Mediterranean of *M. merluccius* populations indicate a decrease in Lm_{50} (Table 3 and Fig. 7). This decrease could be explained by the overfishing of the stock of this species (FAO, 2010). The size of sexual maturity can be directly affected by latitudinal changes and by energy reserves available for gonad development (which are related trophic resources) and also by temperature, density and genetics (Santhoshkumar *et al.,* 2011; Znari and Mounir, 2021).

Somatic indices (GSI and HSI) are good proxies of the energy reserve available in the fish and give a fair indication of the reproductive period; a lower value of GSI indicates the end of the spawning period and a higher

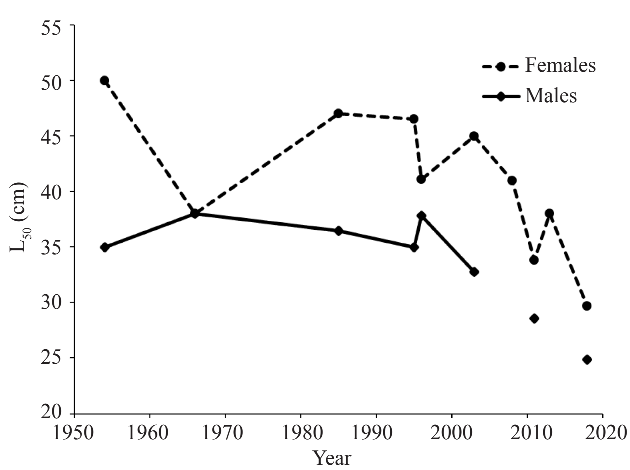

Fig. 7. Decrease in size at the first sexual maturity (cm) for *M. merluccius* in the Atlantic Ocean from 1954 to 2019

Table 3. Length at first of sexual maturity (cm) for *M. merluccius* from Atlantic Ocean

Area	Study area	L_{50} (cm)		Author	Methodology used
		Females	Males		
Atlantic Ocean	Bay of Biscay	50	35-55	Meriel-Busy (1966)	Length at which 50% of individuals are mature calculated by the evolution of the percentage of mature specimens
	Morocco Atlantic	38-42	38-42	Maurin (1954)	Length at which 50% of individuals are mature using a logistic equation
	North-west Spain	47 - 58	36.5-39.5	Perez and Pereiro (1985)	Length at which 50% of individuals are mature using a logistic equation
	Central Moroccan Atlantic	46.5	35.0	El Habouz (1995)	Length at which 50% of individuals are mature using a logistic equation
	Northern Moroccan Atlantic	41.1	37.8	Lahrizi (1996)	Length at which 50% of individuals are mature using a logistic equation
	Iberian Atlantic waters	45.0	32.8	Pineiro and Sainza (2003)	Length at which 50% of individuals are mature using a logistic equation
	North Atlantic	41.0		Domínguez-Petit *et al.* (2008b)	Logistic equation
	Atlantic central Moroccan	33.8	28.6	El Habouz *et al.* (2011)	Length at which 50% of individuals are mature using a logistic equation
	Portuguese Coast	38		Costa (2013)	Length at which 50% of individuals are mature calculated by the evolution of the percentage of mature specimens
	Central Moroccan Atlantic	29.69	24.85	This study	Length at which 50% of individuals are mature using a logistic equation

value indicates developed gonads (Lahaye, 1972). Lower GSI values at the end of the spawning season can also be explained by the fact that after spawning almost all adult females return to deep water (Bouaziz, 1992).

Recasens *et al.* (1998) reported that the European hake is reproductively active for the entire year, with some interannual variability. The present study indicated that there are two spawning peaks, the first during May-July and the second in October, when spawning activity reaches its maximum. Similarly, observations of two peaks has been observed in spring and summer in the Gulf of Tunis (Bouhlal, 1973). In the CECAF (Committee for the Eastern Central Atlantic Fisheries) area, two peaks have also been observed in winter and summer (Pineiro and Sainza, 2003). Akalın (2004) reported that reproductive period of European hake in Edremit Bay occurred throughout the year with peak reproduction from December to March. January to June was determined as the reproductive period of European hake from Mediterranean, North Sea, Scotland and West of Iceland (Muus *et al.,* 1999). Svetovidov (1986) stated that the reproductive activity of the species occurred from January to March for Morocco, from April to June for Iceland and from May to August for Scotland. Candelma *et al.* (2021) observed the reproductive season of European hake in Central Mediterranean Sea to be from April to July. The difference between areas in European hake spawning cycle could be explained by the environmental conditions and food availability. Temperature could influence patterns of maturity, either directly or through changes in growth (Cardinale and Modin, 1999; Pawson *et al.,* 2000; Chemshirova *et al.,* 2021). The onset of maturation requires that certain conditions are fulfilled at a specific time of the life cycle, either with respect to size or accumulation of energy stores, or both; thus growth is considered a prerequisite for maturation (Witthames *et al.,* 2009; Irgens *et al.,* 2020). Temperature may influence the fish maturation process indirectly through alteration of ecosystem composition, hydrographic conditions or resource availability (Mims and Olden, 2013; Thompson *et al.,* 2020; Gonzalez-Martinez *et al.,* 2021). These variations may be due to the different strategies developed by the fish in different environments to better adapt to the prevailing conditions.

The results of the present study will be useful in understanding recruitment pattern of the European hake along the Moroccan Atlantic coast and formulating fishery management plans to exclude spawning seasons and set minimum legal sizes for exploitation.

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