Maturity and batch fecundity of the European hake (*Merluccius merluccius*, Linnaeus, 1758) in the eastern central Atlantic

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SUMMARY: The reproductive biology of the European hake (*Merluccius merluccius,* Linnaeus, 1758) was studied on the eastern central Atlantic Moroccan coast from November 2001 to December 2003. The sex ratio was close to 1:1 for the specimens with a total length of less than 45 cm. European hake spawned all year round, though two spawning peaks were recorded with a certain interannual variability: the first and main peak in winter and a secondary intermittent peak in summer. Length at first maturity was estimated as 28.6 cm and 33.8 cm total length for males and females, respectively. These values are closer to Mediterranean than Atlantic hake values. The mean batch fecundity was 299872 eggs ind^{-1}. The relative batch fecundity was estimated as 228 eggs per gram of gutted weight. Batch fecundity increased proportionally with fish length and weight. The batch fecundity of European hake in the Moroccan Atlantic area is higher than that in northern Atlantic and northwestern Mediterranean areas.

Keywords: *Merluccius merluccius*, sex ratio, reproductive cycle, length at first maturity, fecundity.

RESUMEN: Madurez y fecundidad parcial de la merluza europea (*Merluccius merluccius*, Linnaeus, 1758) en el Atlántico Oriental central. – Se ha estudiado la biología reproductiva de la merluza europea (*Merluccius merluccius*, Linnaeus, 1758) en la zona central del Atlántico Oriental de la costa de Marruecos durante el período de noviembre de 2001 a diciembre de 2003. La proporción sexual fue cercana a 1:1 para los individuos de talla total menor de 45 cm. La merluza europea se reproduce durante todo el año. Se han detectado dos picos de puesta con una cierta variabilidad interanual: el primero y más importante en invierno y otro pico secundario intermitente en verano. La talla de primera madurez se estimó en 28.6 cm y 33.8 cm de longitud total para machos y hembras respectivamente. Estos valores son más cercanos a los observados para la merluza en el Mediterráneo que a los del Atlántico. La fecundidad parcial media fue de 299872 huevos ind^{-1}. La fecundidad parcial relativa se estimó en 228 huevos por gramo de hembra referido al peso eviscerado. La fecundidad parcial se incrementó proporcionalmente a la longitud y peso del pez. La fecundidad parcial de la merluza europea en el área atlántica de Marruecos, muestra valores más altos que en las áreas del Atlántico situadas más al norte y del NW Mediterráneo.

Palabras clave: *Merluccius merluccius*, proporción sexual, ciclo reproductivo, talla de primera madurez, fecundidad.

INTRODUCTION

Information on reproductive biology, especially fecundity and egg production, is fundamental in the study of the biology and population dynamics of fish species (Hunter *et al*., 1992; Murua and Saborido-Rey, 2003). It is the basis for quantifying reproductive capacity at the individual and population levels of a fish species (Murua *et al.,* 2006). Some assessment models use information on reproductive variables such as age or

length at maturity, fecundity and spawning frequency to estimate fish biomass. Annual changes in these variables could affect the stock productivity and produce variability in fish recruitment (Macchi *et al.*, 2004).

In Morocco, the European hake (*Merluccius merluccius,* Linnaeus, 1758) is found along the Mediterranean coast and in the Atlantic from the Strait of Gibraltar to 21 degrees north (INRH, 2002). This species is found over all types of bottoms from the coast down to 1000 m depth (FAO, 2006). Juveniles (total length <20 cm) abound from the coast to 500 m depth, while bigger individuals are found further offshore in bathymetric strata between 500 and 1000 m (Benchoucha *et al.*, 2006; El Habouz *et al.*, 2007). The European hake migrates for reproduction and food. Large reproductive individuals concentrate at the edge of the continental shelf to spawn (FAO, 1986).

The Moroccan Atlantic population of European hake is considered as a single stock. It is the only hake species caught by the coastal fishery. The fleet that operates on this species is composed of 450 trawlers and 20 longliners (FAO, 2006). Results from the recent assessments of the FAO Working Group on demersal resources in the CECAF area carried out in Gambia in November 2007 indicate that the European hake stock is overexploited. The Working Group therefore recommended reducing current fishing effort so that catch levels do not exceed 3500 tonnes, and banning fishing during the months of June and July to preserve juvenile individuals.

Due to its commercial importance, a series of biological studies on *Merluccius merluccius* has been carried out in Atlantic areas. Its growth and reproductive biology have been studied on the eastern Moroccan Atlantic coast by Maurin (1954), Goñi (1983), Ramos *et al*. (1990, 1991), El Habouz (1995) and Lahrizi (1996). Growth and maturity have also been studied in Iberian Atlantic waters (Piñeiro and Sainza, 2003, Domínguez-Petit *et al*., 2008b), while the reproductive strategy and spawning activity of hake have been researched in the North Atlantic (Murua and Saborido-Rey, 2003; Domínguez-Petit *et al*., 2008a) and the Bay of Biscay (Murua and Motos, 2006; Murua *et al*., 2006). The southern part of the Atlantic distribution for this species extends to 22°35'N, where it cohabits with the black hake (*Merluccius senegalensis,* Cadenat 1950*)* species from 29°21'N (FAO, 1986); therefore, there may be additional interest in studying the reproductive parameters in this part of the geographical distribution. In addition, there are still few studies that deal with all the reproductive parameters of this species. In fact, the only estimates for fecundity are from the Atlantic Iberian Peninsula (Bay of Biscay and Galicia) (Murua *et al*., 2006) and the NW Mediterranean (Catalan and northern Tyrrhenian Seas) (Recasens *et al*., 2008).

The aim of the present work is to study the reproductive potential of *Merluccius merluccius* for the first time in the Moroccan Atlantic by identifying spawning peaks, determining the size at first maturity and calculating the fecundity parameters.
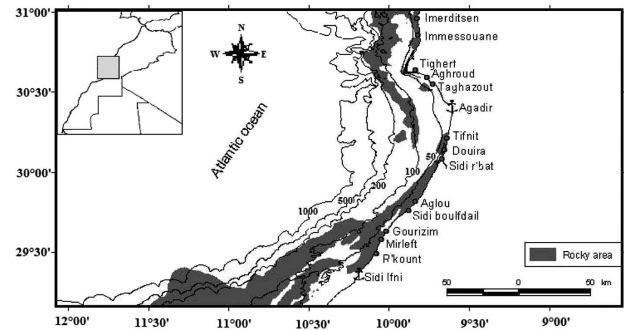

Fig. 1. – Map showing the study area between Immesouane (30°50'N, 09°49'W) in the north and Sidi Ifni (29°21'N, 10°11'W) in the south.

MATERIALS AND METHODS

European hake samples were collected monthly in the eastern central Atlantic from November 2001 to December 2003. Samples were taken in Agadir port from trawl landings. These trawlers operate in the area located between Immessouane (30°50'N, 09°49'W) in the north and Sidi Ifni (29°21'N, 10°11'W) in the south (Fig. 1), between 100 and 150 m depth (El Habouz *et al*., 2009). A total of 1332 specimens were sampled, ranging from 17 to 71 cm total length (Table 1). Individuals below 17 cm were not analysed due to the difficulty of sex identification at macroscopic level. For each specimen the following parameters were taken:

total length (TL) to the lowest half cm, total weight (TW) and gutted weight to 0.1 g, and gonad and liver weight to 0.01 g. The maturity stage was determined for *M. merluccius* using the maturity scale for partial spawners (Holden and Raitt, 1974). European hake individuals of both sexes were considered mature from stage III (Table 2).

Sex ratio

Sex ratio was defined as the proportion of males and females by length class in all the samples.

TABLE 1. – Sampling data on *M. merluccius* in the central Moroccan Atlantic.

Period	Num. ind.	Length range Total length (cm)
Nov.-Dec. 01	166	17-49.5
Jan.-Feb. 02	124	20.5-71
Mar.-Apr. 02	127	17-65.5
May-Jun. 02	98	19-43
Jul.-Aug. 02	83	21-53
Sept.-Oct. 02	81	20-56
Nov.-Dec. 02	88	19-49
Jan.-Feb. 03	88	20-42
Mar.-Apr. 03	146	20-63
May-Jun. 03	67	22-34
Jul.-Aug. 03	107	19-69
Sept.-Oct. 03	81	21-45
Nov.-Dec. 03	76	20-39.5
Total	1332	17-71

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

Stage	State	Description
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.

Gonadosomatic index (GSI) and hepatosomatic index (HSI)

The GSI was calculated as a percentage of the gonad weight in relation to the total weight of the fish. The HSI was calculated as the percentage of liver weight in relation to total weight of the fish.

Length at first maturity (L_{50})

Length at first maturity was defined as the length at which 50% of the specimens developed ripe gonads for the first time, and was estimated considering specimens in stages higher than stage I for both males and females. L_{50} was estimated for 546 females ranging from 20 to 71 cm TL and for 558 males ranging from 20 to 45 cm TL.

Length at first maturity was estimated by means of a logistic model fitted to the percentage of mature specimens per length class (Yeates, 1974) with the equation:

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

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.

Fecundity

Batch fecundity is defined as the total number of eggs released by a mature female. It was calculated according to the gravimetric method based on the relationship between ovary weight and oocyte density (Murua *et al.,* 2003). Only hydrated ovaries without recent postovulatory follicles were used to calculate batch fecundity (Hunter and Macewicz, 1985), and only oocytes with a diameter greater than 750 μm were hydrated (Murua *et al.,* 1998). The hydrated oocytes of 3 subsamples (0.1 to 0.3 g each) per ovary of a mature female were taken randomly from three parts (anterior, middle and posterior) of the right and left ovary lobes. The number of oocytes in each 100-μm diameter size class was counted using a binocular with a micrometer. A total of 30 ovaries was analysed. The average value was calculated, expanded to the total ovary weight and expressed as the number of oocytes per ovary, using the following equation:

$$F = \frac{\sum \frac{Oi}{Wi}}{n} W_{ovary} , \text{(Murua } et\ al., 2003)$$

where F represents the total number of eggs in the ovary, W_{ovary} is the ovary weight (in grams), Wi the oocyte sample weight, Oi the total number of eggs in the ovary sample, and n the number of ovary samples.

The relative batch fecundity was calculated as the number of hydrated oocytes per gram of gutted weight. Relationships between batch fecundity, total length and gutted weight of the fish were estimated by fitting power functions.

The oocyte size-frequency distribution of a standard female of 45 cm TL was studied through subsequent maturity stages (II, III and IV). The abundance of oocytes was expressed as a percentage of the 100 μm diameter classes. Three females were used for these calculations. For each maturity stage, the oocyte distribution corresponded to an individual fish.

RESULTS

Sex ratio

Out of a total of 1332 specimens ranging from 17 to 71 cm TL, 51.3% were females between 17 and 71 cm TL and 48.7% were males between 17 and 45 cm TL. The sex ratio calculated in each length class of European hake individuals is shown in Figure 2.

To compare the sex proportions in the length interval [17 to 45], a χ^2 test was applied with contingency tables and with 29 length classes (n=29, d.f.=28). The proportions of males (50.5%) and females (49.5%) show no significant differences from a ratio of 1:1 at $P = 0.05$. However, all the specimens with a TL greater than 45 cm were females (Table 3).
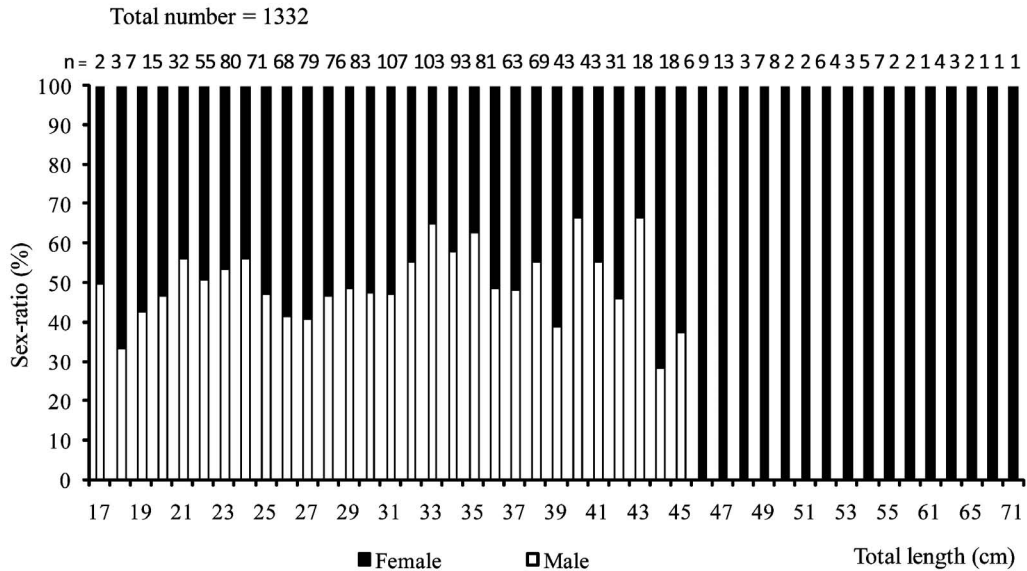
Total number = 1332

Fig. 2. – *M. merluccius* sex ratio by length class.

Table 3. – Sex ratio of *M. merluccius* by length interval, tested with an χ^2 analysis at $P = 0.05\%$

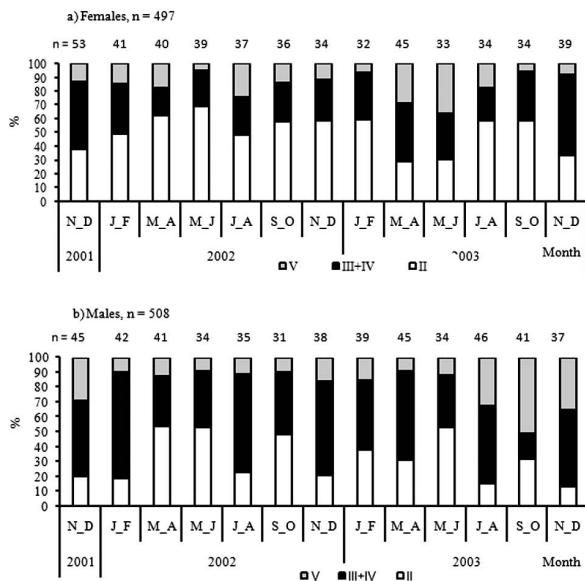| Length interval	Number of individuals	Males	Females	(d.f)	Observed χ^2	Theoretical χ^2 P=0.05
17-45 cm	1286	50.5%	49.5%	28	24	41.3
>45 cm	46	0%	100%	-		

Fig. 3. – Bimonthly percentages of *M. merluccius* in different maturity stages during the sampling period. II, maturing and recovery; III+IV, advanced maturing + spawning; V, post-spawning. (a) Females; (b) Males.
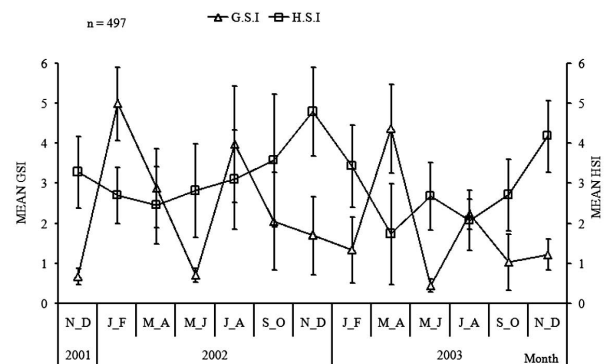

Fig. 4. – The bimonthly evolution of the mean gonadosomatic (GSI) and hepatosomatic (HSI) indexes for *M. merluccius* females during the sampling period.

Spawning cycle

The bimonthly evolution of the percentage of maturity stages showed that mature (III+IV) and post-spawning (V) females were present all year round. The same phenomenon was found for males in terms of presence of individuals in the mature (III+IV) and post-spawning (V) stages during the sampling period (Fig. 3a, b). Consequently, females and males of *M. merluccius* in the study area were reproductively active throughout the entire year.

The bimonthly evolution of the GSI and HSI of the European hake for a period of 26 months is shown in Figure 4 for females and in Figure 5 for males.

According to the evolution of the females GSI (Fig. 4), in 2002 the main spawning peak occurred in winter (January-February) and a secondary peak in summer (July-August). However, in 2003 the winter spawning peak occurred later, at the end of winter and start of spring (March-April), and the secondary GSI peak,
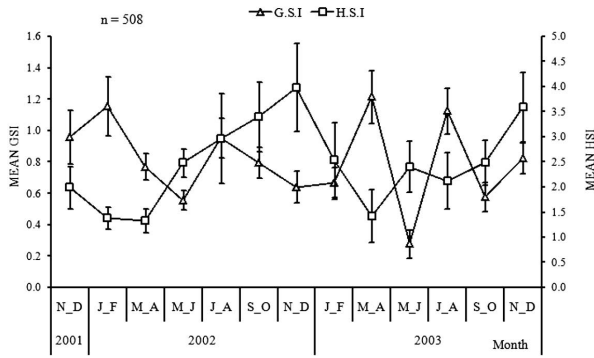
FIG. 5. – The bimonthly evolution of the mean gonadosomatic (GSI) and hepatosomatic (HSI) indexes for *M. merluccius* males during the sampling period.
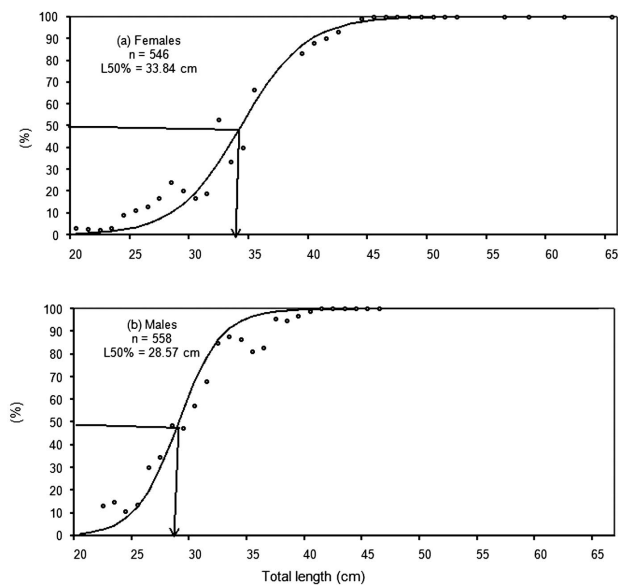

FIG. 6. – *M. merluccius* length at first maturity for a) females and b) males.
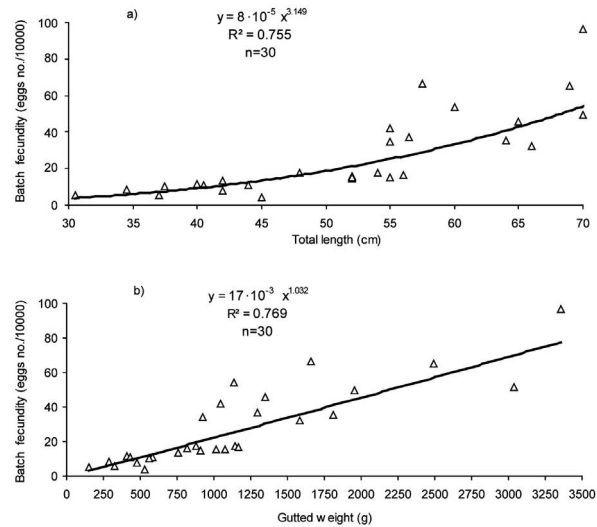

FIG. 7. – Relationships between batch fecundity and a) total length (cm), and b) female gutted weight (g).

of the HSI shows that the maximum accumulation of reserves in the liver occurred in November-December 2002 and 2003 before the main spawning period.

Length at first maturity

Length at first maturity was estimated at 33.8 cm for females and 28.6 cm for males (Fig. 6a, b). The length at which 75% of individuals are mature was 36.8 cm for females and 30.6 cm for males. While the length at which 25% of individuals are mature was 30.8 cm for females and 26.5 cm for males.

Fecundity

The batch fecundity estimates ranged from 39962 for a female of 45 cm TL to 965770 for a female of 70 cm TL. The average batch fecundity was calculated as 299872 hydrated oocytes per female.

The average relative batch fecundity was 228 eggs g^{-1} (female gutted weight) and ranged from 75 to 400 eggs g^{-1} (Table 4).

Our results indicate that the relationships between batch fecundity and fish length (TL) and gutted weight (W_g) are best described by

$$F=8\cdot10^{-5}L^{3.149} \text{ (n=30, } r^2=0.755) \text{ and}$$
$$F=17\cdot10^{-3}W_g^{1.032} \text{ (n=30, } r^2=0.769)$$

Batch fecundity correlated positively with fish length and fish gutted weight (Fig. 7a,b).

The oocyte size-frequency distribution through the subsequent mature stages of *M. merluccius* showed the

which occurred in July-August, was too low to be considered a real spawning peak. The HSI had a main peak in November-December in both years (Fig. 4). This peak preceded the spawning peaks (GSI) which took place in January-February 2002 and March-April 2003. The reserves accumulated in the liver in the HSI peaks are mobilized for use during oogenesis in the ovaries.

Figure 5 shows two spawning peaks for European hake males in each year. These two peaks took place in January-February and July-August in 2002 and in March-April and July-August in 2003. The evolution

TABLE 4. – Batch fecundity values for *M. merluccius*.

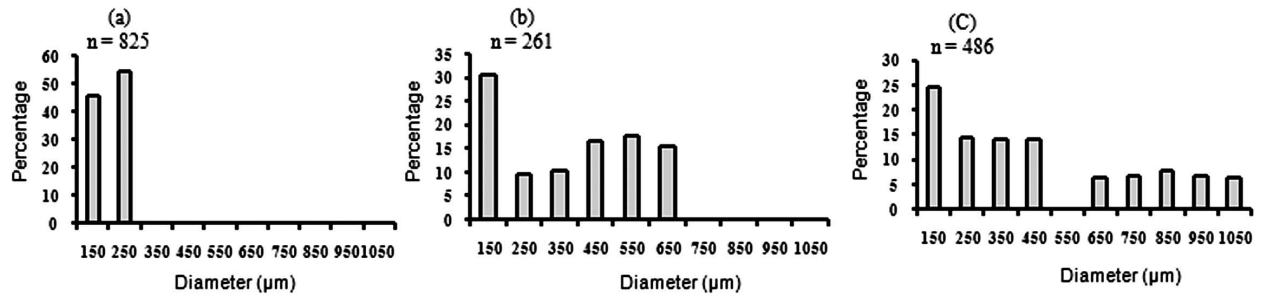|	Average	Standard deviation	Minimum	Maximum
Batch fecundity (no. eggs /fish)	299872	249692	39962	965770
Relative batch fecundity (no. eggs g^{-1}(female gutted weight))	228.33	87.22	74.86	400.08

FIG. 8. – Oocyte size-frequency distributions (percentage abundance per 100 μm diameter size classes) of a standard female European hake of 45 cm in subsequent maturity stages: a) virgin and recovery, b) In maturation and c) Mature (ripening).

continued presence of small oocytes (150 to 250 μm diameter). Hydrated oocytes with a diameter higher than 750 μm appeared in the mature and prespawning stage before ovulation. (Fig. 8a,b,c).

DISCUSSION

The evolution of the sex ratio in the length class interval [17 to 45] shows that the sex ratio was close to 1:1. Only females were found over 45 cm TL. A similar result was observed by Piñeiro and Sainza (2003) in Iberian Atlantic waters corresponding to ICES divisions IXa and VIIIc. This could be due to the differences in the different growth rates of the two sexes. Indeed, a recent study of the growth of European hake using tagging and recapture techniques (Mellon-Duval *et al.*, 2010) shows that from the second year of life, females grow faster than males.

The spawning cycle of the European hake was studied according to the bimonthly evolution of the GSI and HSI. As the GSI is an index of gonadal maturity, a higher index shows that the gonads are developing, and a lower value indicates the end of the spawning period (Lahaye, 1972). During maturation and when vitellus is accumulated, the HSI decreases rapidly (Lahaye, 1972; Billard, 1979). During the life cycle of fish, the HSI peak usually precedes the GSI peak.

The European hake is reproductively active for almost the entire year, with certain interannual variability (Recasens *et al.*, 1998); therefore, the annual evolution of the two indexes is not as clear as in species with a shorter spawning season. The winter spawning season has been observed previously in the Moroccan Atlantic (Ramos *et al.*, 1990, 1991; El Habouz, 1995); however, other authors (Maurin, 1954) have found the hake spawning season to be from December to early summer. Our results show that there was a main spawning peak in winter and a secondary one in summer in 2002; however, in 2003, the winter spawning season was delayed one month and took place in late winter and early spring, and the secondary summer spawning peak was too low to be considered a real peak. Therefore, the European hake spawning cycle in this area also shows certain interannual variability, as a winter peak was observed in the two studied years but a summer peak was only observed in the first year of the study. Two peaks have also been observed in winter and summer in the CECAF area (Cervantes and Goñi, 1986), while a maximum spawning peak was observed from January to March on the north Atlantic Spanish coast (Perez and Pereiro, 1981, 1985; Piñeiro and Sainza, 2003) and in the Bay of Biscay (Murua and Motos, 2006).

In the Mediterranean Sea, Bouhlal (1973) observed a maximum spawning peak in winter and two other

TABLE 5. – Size at first maturity (cm) for European hake from different geographic areas.

Author (year)	Study Area	L_{50} male	L_{50} female	Methodology used
Present study	eastern central Moroccan Atlantic coast	28.6	33.8	Length at which 50% of individuals are mature using a logistic equation
EL Habouz (1995)	central Moroccan Atlantic	35.0	46.5	Length at which 50% of individuals are mature using a cumulative frequency
Lahrizi (1996)	northern Moroccan Atlantic	37.8	41.1	Length at which 50% of individuals are mature using a cumulative frequency
Piñeiro and Sainza (2003)	Iberian Spanish Atlantic	32.8	45.4	Length at which 50% of individuals are mature using a Logistic equation
Domínguez-Petit *et al.* (2008b)	Iberian Atlantic	-	46.0	Logistic equation
Domínguez-Petit *et al.* (2008b)	North Atlantic	-	41.0	Logistic equation
Recasens *et al.* (1998)	Mediterranean Sea Gulf of Lions	28.8	38.0	Length at which 50% of the specimens have already matured at least once
Recasens *et al.* (2008)	Catalan Sea	-	35.8	Length at which 50% of individuals are mature using a Logistic equation
Recasens *et al.* (2008)	northern Tyrrhenian Sea	-	35.1	Length at which 50% of individuals are mature using a Logistic equation
Bouaziz *et al.* (1998)	Region of Bou-Ismail (Alger)	21.5	30.6	Length at which 50% of individuals are mature calculated by the evolution of the percentage of mature specimens

smaller peaks in spring and late summer in the Gulf of Tunis. In the Gulf of Lions a certain amount of interannual variability has been observed. In 1989 and 1990 the spawning period was in autumn, but the percentage of ripe females was always higher than 10-15% during all the seasons in 1990 (Recasens *et al*., 1998).

The length at first maturity (L_{50}) was estimated in the present study as 28.6 cm for males and 33.8 cm for females. According to the Von Bertalanffy growth equation calculated from tagging and recapture data by De Pontual *et al*. (2006), the age at first maturity for hake would correspond to one year for males and one and a half years for females. In comparison with previous studies (Table 5), the L_{50} estimated for European hake in the Moroccan Atlantic dropped significantly after a time interval of about ten years. Indeed, using data collected from commercial fishery catches in 1992, the L_{50} was estimated at 35 and 46.5 cm for males and females, respectively, in the central Moroccan Atlantic (El Habouz, 1995) and at 37.8 cm and 41.1 cm for males and females, respectively, in the north Moroccan Atlantic (Lahrizi, 1996). Overexploitation due to excessive fishing effort (FAO, 2010) could have caused the decrease in L_{50} observed for European hake. Moreover, the present first maturity sizes are lower than those recently reported in the northern Iberian Atlantic (Piñeiro and Sainza, 2003; Domínguez-Petit *et al.*, 2008b). In our results, the L_{50} for females (33.8 cm) is close to values reported for the Catalan Sea and northern Tyrrhenian Sea, estimated respectively at 35.8 cm and 35.1 cm (Recasens *et al*., 2008); these values are also slightly lower than those observed 10 years previously (Recasens *et al.,* 1998). The smallest values for these parameters are reported for the region of Bou-Ismail (21.5 cm for males and 30.6 cm for females) (Bouaziz *et al*., 1998) but this could be due to differences in methodology used for parameters estimation. First sexual maturity is therefore not late in European hake. Males reach maturity at a smaller size and at an earlier age than females. It is clear that the L_{50} has decreased compared to values observed in previous years, which could be related to the overexploitation of the stock.

Since European hake is a batch spawner with indeterminate fecundity and asynchronous ovarian organization (Murua and Saborido-Rey, 2003), batch fecundity corresponds to the number of hydrated oocytes present in the ovary during the prespawning stage. The fecundity results presented in this study represent the first estimation of the reproductive potential of European hake in the Moroccan Atlantic area. The relative batch fecundity was estimated to be 228 eggs g^{-1} (gutted weight), which is higher than that estimated in the western Mediterranean (203 eggs g^{-1}) (Recasens *et al.*, 2008) and much higher than the 165 eggs g^{-1} estimated in the Bay of Biscay (Murua *et al.*, 1998; Murua *et al.*, 2006). In comparison with other species of the genus *Merluccius*, the batch fecundity is higher than that of *Merluccius gayi* (125 eggs g^{-1}) (Cerna and Oyarzun, 1998) and very much lower than the value

estimated for *Merluccius hubbsi* (551 eggs g^{-1}) (Macchi *et al.*, 2004). However, there is both intra and interannual variability in the relative batch fecundity of *M. merluccius* (Murua *et al.*, 2006). The mean batch fecundity of European hake in the Moroccan Atlantic area, estimated as 299872 eggs per female, was also higher than that estimated in northern Atlantic areas (220636 per female) (Murua and Motos, 2006) and the northwestern Mediterranean (150000 per female) (Recasens *et al.*, 2008). The evolution of the batch fecundity by length and weight of European hake shows that the number of hydrated eggs per female increases with the length and weight.

Therefore, the results obtained in the present study clarify some aspects of the reproductive biology of *M. merluccius* on the eastern central Atlantic Moroccan coast and situate the reproductive parameters of this species at the southern end of its distribution range, closer to Mediterranean values than North Atlantic ones. A good knowledge of the reproductive strategy of *M. merluccius* will allow us to understand the recruitment mechanisms for this important commercial resource.

ACKNOWLEDGEMENTS

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