Int Aquat Res (2020) 12:171-181
https://doi.org/10.22034/IAR.2020.1896027.1027

ORIGINAL RESEARCH

Size at maturity, fecundity and spawning period of anchovy *Engraulis encrasicolus* (Linnaeus, 1758) in the central area of the Moroccan Atlantic coast

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Received: 24 March 2020 / Accepted: 02 September 2020 / Published online: 30 September 2020

Abstract This study was conducted in order to investigate reproductive parameters of anchovy *Engraulis encrasicolus* (Linnaeus, 1758) in the central area of the Moroccan Atlantic coast, from January to December 2016. The data analysis based on a total of 1633 collected fish suggest that 850 and 783 were females and males respectively with an average male sex-ratio of 46.51% ($\chi 2$= 2.74; $P > 0.05$). The Gonado-somatic index (GSI) indicated that spawning activity occurred from April to November exhibiting the highest value between June and August. The size at first sexual maturity was approximately the same for both sexes and corresponds to 10.5 cm. The fecundity estimated varied from 7323 to 21230 and was positively correlated to the fish length and weight. This study was necessary to fill the knowledge gap and provide information for the management and conservation of the investigated species in this area.

Keywords *Engraulis encrasicolus* . Sex ratio . Length at first maturity . Fecundity . Gonadosomatic index

Introduction

The Moroccan coasts are among the regions characterized by the presence of the phenomenon of upwelling, which results in a great wealth of fish concentrated in the central and southern Atlantic. Small pelagic fish, mostly sardines, anchovies, mackerel, horse mackerel and Sardinella represent 80% of total catches (Amenzoui 2010).

The European anchovy, *Engraulis encrasicolus* (Linnaeus, 1758) plays an important ecological role in upwelling regions where it occupies a fundamental intermediate trophic levels (Bakun 2006). In addition to their ecological importance, anchovies are one of the principal target species for commercial fisheries. With the other small pelagic fishes, this species are sources of income and animal protein, (Belvèze 1984). The anchovy *Engraulis encrasicolus* of the central zone of the Moroccan Atlantic coast in 2016 was in a state of full exploitation and presented 21358 tons in 558721 tons of the total catch (INRH 2016). Most of the research on the ecology of this species was performed in the northern Mediterranean Sea (Morales-Nin and Pertierra 1990; Basilone et al. 2004), the Black Sea and the Azov Sea (Mikhman and Tomanovich 1977; Bulgakova 1993), the Adriatic Sea (Dulčić 1997; Coombs et al. 2003) or the Bay of Biscay (Plounevez and Champalbert 1999). In Morocco, this specie has significant economic importance but work on its biology is lacking. Reproduction is an important physiological system that is crucial in the life cycle of fish. Fecundity is very useful in fish population studies and provides important information in the management and exploitation of the fishery (Alam MD and Das NG 1996). Knowledge of the fecundity

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parameter is essential for evaluating the commercial abundance and management of the fishery (Das 1977) and information on the fish length at first maturity is helpful for fish stock management (Fontoura et al. 2009). The present investigation aims to assess sex ratio, size at maturity, fecundity, and spawning season of anchovy in the central area of the Moroccan Atlantic coast.

Materials and methods

The study was carried out on *Engraulis encrasicolus* caught from the Central Moroccan Atlantic between the area of Safi and Agadir by the purse-seiners during one year, from January to December 2016 except in March (Fig.1). Random samples were collected monthly and were taken to the laboratory for analysis.
A total of 1633 specimens were dissected, among which 850 were females and 783 were males, and a series of measures were made on each fish. Biometric parameters of fish were recorded namely total length (measured to the centimeter below 0.5) and total weight with 0.1 g accuracy. Gonads were removed and weighed and the sex of each fish was determined by macroscopic examination followed the 5-phase maturity scale (Holden and Raitt 1974) as follows:
I- Immature: Ovary and testis about 1/3rd length of the body cavity. Ovaries are pinkish, translucent, and testis whitish. Ova are not visible to the naked eye.
II- Immature or resting: Ovary and testis about ½ length of the body cavity. Ovary pinkish, translucent; testis whitish, more or less symmetrical. Ova are not visible to the naked eye.
III- Early maturation: Ovary and testis about 2/3rds length of the body cavity. Ovary pinkish-yellow color with granular appearance, testis whitish to creamy. No transparent or translucent ova visible.
IV- Ripe: Ovary and testis from 2/3rds to the full length of the body cavity. Ovary orange-pink in color with conspicuous superficial blood vessels. Large transparent, ripe ova are visible. Testis whitish-creamy, soft.
V- Post-spawning: Ovary and testis shrank to about ½ length of the body cavity. The ovary may contain remnants of disintegrating opaque and ripe ova, darkened or translucent. Testis bloodshot (not positive about this adjective because it is always used with the eyes) and flabby.

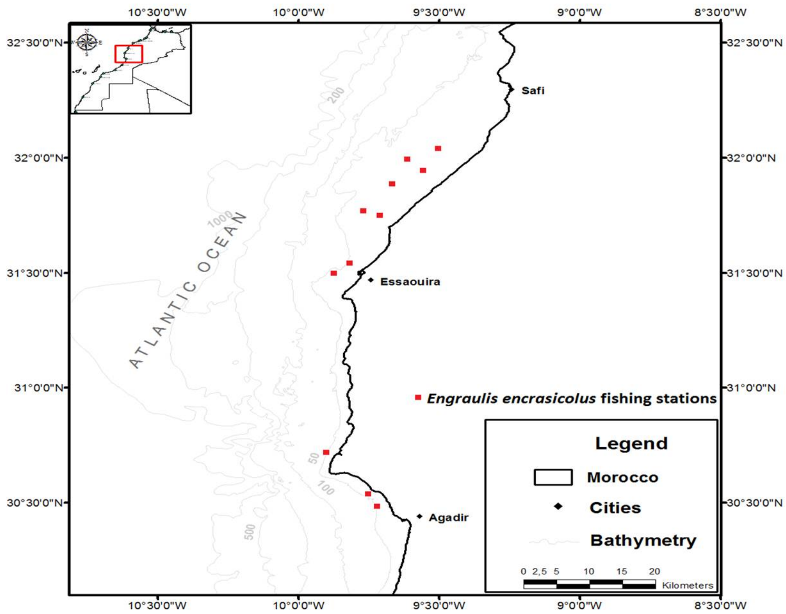

Fig. 1 Sampling area of Engraulis encrasicolus in the Atlantic Centre of Morocco

Sex ratio

In this work, we used the formula which gives sex-ratio as a percentage of males. Then, the chi-squared (χ^2) test was used to evaluate the variation of the observed values of the sex-ratio compared to the theoretical proportion of 50% (Dagnélie 2006). We supposed as hypothesis H_0: sex-ratio = 50% and tested this hypothesis by calculating the value of $\chi^2_{obs.}$

The size at first sexual maturity

This refers the total length at which 50% of individuals in a population are mature L50. Stage III is the beginning of the gonad development phase and therefore it is retained as the threshold of sexual maturity (FAO 1978). The L50 was estimated by using a theoretical maturity curve which corresponds to the regression between P parameter depending on the fish size (Pope et al. 1983):

$$P = 1/ (1+e-(a + b * L))$$

Where, P: mature proportion by size class; L: total length; a: intercept; b: slope.

The linearization of this formula by introducing the natural logarithm gives:

$$– Ln ((100 – p)/p) = a + b * L$$

The parameters a and b are obtained by the regression between Ln (P x (1-P)-1) and total length L:

$$L50 = -a/b$$

Gonad-somatic index

The spawning period was established by the maturity classification and a monthly calculation of the Gonado-somatic index (GSI). It equals both gonad weight (W) divided by the total weight of the body and expresses the gonad weight as a percentage of body weight (Bougis 1952):

$$GSI = [weight\ of\ gonad\ (g)/\ Weight\ of\ fish\ (g)]\ X\ 100$$

Fecundity

30 mature females were randomly sampled for fecundity estimation during peak spawning between June and August, ranging in total length between 11.5 and 15.5 cm. The females selected were from the actively spawning group and had oocytes in the migratory nucleus stage (Ganias et al. 2003) or hydrated oocytes (Hunter et al. 1985) but did not have recently spawned follicles.

Subsequently, three pieces of approximately 50-100 mg were removed from different parts of the ovary, weighed with a precision of 0.1 mg (Hunter et al. 1985) and the number of oocytes in the migratory nucleus stage of hydrated oocytes counted. Then, these pieces were preserved in Gilson solution: 100 ml of alcohol 60%, 880 ml of distillate water, 15 ml of nitric acid 80%, 18 ml of glacial acetic acid and 20 g of mercury chloride (Snyder, 1983). This solution allows hardening oocytes while chemically separating them from ovarian tissue.

In teleost fish, absolute fecundity is the number of oocytes that can be emitted during a spawning season by a female (Bagenal 1973). Fecundity (F) was estimated according to the following formula:

$$F = (n \times Pg) / Pe$$

Where, F: Individual fertility by act of laying; n: Number of oocytes contained in the ovarian sample; Pg: Total weight of both ovaries; Pe: Weight of the ovary sample.

The number of the oocytes was reported in the total mass of the ovary in order to estimate the batch of fecundity (F). The estimated values of fecundity are adjusted to a linear model such as: F = a +bx (x is the total length or total weight without ovary). Relative fecundity is expressed as the number of oocytes per gram of female somatic body weight.

Results

Sex-ratio

The proportions of males and females sampled monthly are shown in Table 1. On a 1633 sampled individuals, total length varied between 7 and 17 cm and the average male sex-ratio was 46.51% ($\chi 2$= 2.74; P > 0.05). The sex-ratio was always in favor of females except during January (SR=62.26%, P≤0.001) when we noted a value of sex-ratio in favor of males. In October, sex-ratio evaluated (52.50%) were not statistically significant.

The samples were gathered in groups of size of three centimeters. The evolution of sex ratio depending on size showed that size class between 6 and 9 cm shows a slight dominance of males while they are more dominant in the average sizes between 12 and 15 cm. For females, they considerably dominate large sizes between 15 and 18 cm but they are less abundant in the size classes between 9 and 12 cm (Fig. 2).

Table 1 Monthly variations of male sex-ratio for *Engraulis encrasicolus in* the Central Moroccan Atlantic Coast during 2016
P> α = 0.05: (ns) not significant, p ≤ α = 0.05 : (*) significant, p≤α = 0.001 : (***) very highly significant

Month	No. of females	No. of males	Sex-ratio	χ2 obs
January	100	165	62.264	15.94***
February	50	49	49.495	0.01 ns
March	-	-	-	-
April	84	81	49.091	0.05454 ns
May	96	92	48.936	0.0851 ns
June	189	151	44.412	4.24704*
July	42	33	44.000	1.08 ns
August	56	54	49.091	0.03636 ns
September	64	36	36.000	7.84*
October	38	42	52.500	0.2 ns
November	69	39	36.111	8.33332*
December	62	41	39.806	4.28154*
Total	850	783	46.519	2.74892 ns

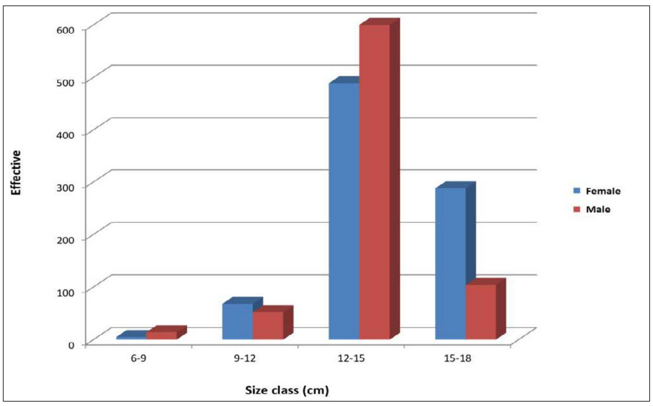

Fig. 2 The evolution of sex ratio depending on class size

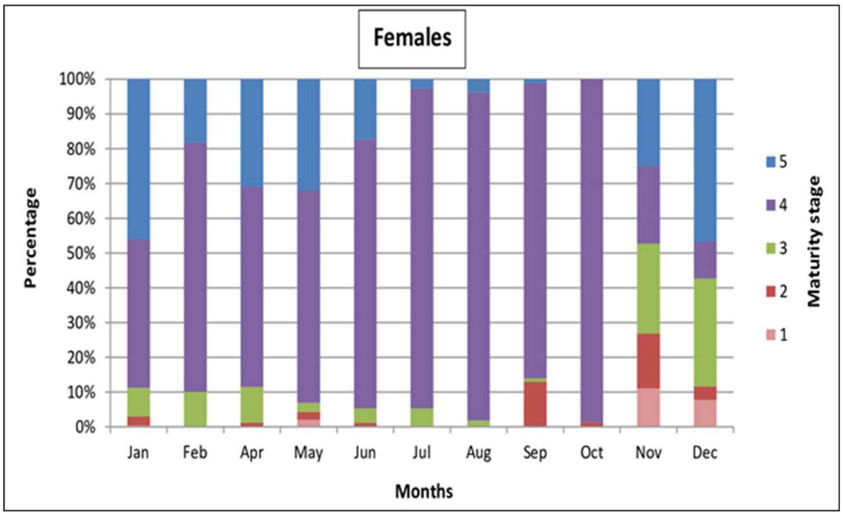

Fig. 3 Monthly percentage of maturity stages of females of *Engraulis encrasicolus* in the Central Moroccan Atlantic Coast

The figure of the monthly variations of the different stages of maturation shows an important reproductive activity of *E. encrasicolus* by the dominance of matures fish throughout the year (Figs. 3, 4). Anchovies in stage 5 and 3 are present throughout the year for both sexes except in October for female and September and October for male. For males and females at stage 4 (emission of gametes), they are abundant during all the months sampled. The immature stages (stage 1 and 2) are less abundant and have a very low percentage for both sexes.

Gonado-somatic index

Monthly fluctuations of Gonado-somatic index values of anchovy shows that it has a slightly similar pattern in both sexes. GSI was seen to peak, similar for males and females between June and August, albeit peaking was more pronounced for males (Fig. 5). For both sexes, the lowest values of GSI were recorded in winter (December to February), and then gradually increased in spring (March to May).

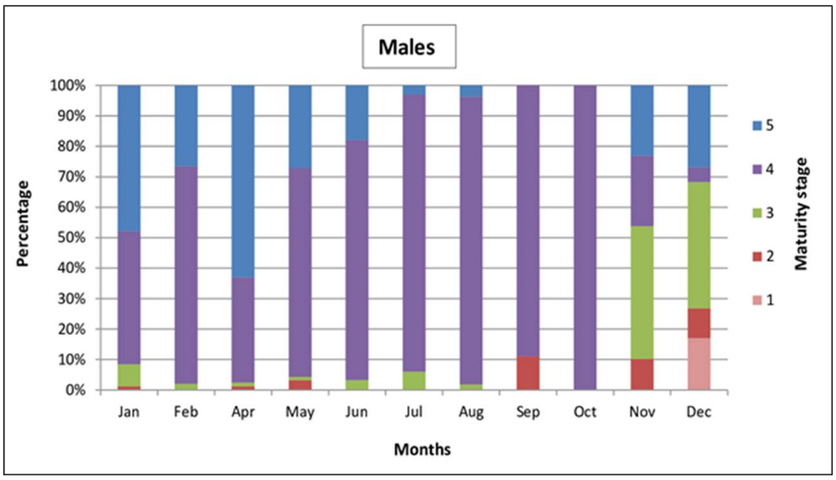

Fig. 4 Monthly percentage of maturity stages of males of *Engraulis encrasicolus* in the Central Moroccan Atlantic Coast

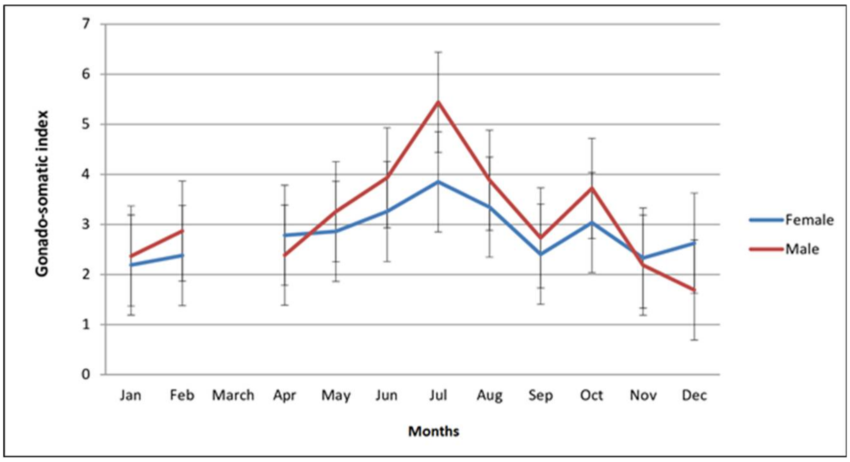

Fig. 5 Monthly evolution of gonad-somatic index (GSI) in *Engraulis encrasicolus* sampling in the Central Moroccan Atlantic Coast

Size at first sexual maturity

The size at first sexual maturity is approximately the same for both sexes (ANOVA test, $p > 0.05$) and corresponds to 10.5 cm (Fig. 6).

Fecundity

Batch fecundity was linear and increased with total length and total weight (Fig. 7, 8). The estimated values of fecundity fluctuate between 7323 and 21230 oocytes per batch females mature with a mean value of 15203 (±3656) oocytes and mean size of 13.5 (±1) cm. While relative fecundity presents values that fluctuate between 666 and 994 per gram of female somatic body weight with 857 (±105) oocytes as mean values. Batch fecundity can also vary from a female individual to another within the same size (Fig. 7, 8).
The relationship obtained between batch fecundity and biological parameters after adjustment of the pairs of values to a linear curve of the form F = ax + b, are the following:

- Relationship fecundity (F) –total length (Lt) : $F = 2985.3 \times Lt - 25696$, $R^2 = 0.72$
- Relationship fecundity (F)–total weight (P) : $F = 700.18 \times P + 2670$, $R^2 = 0.76$

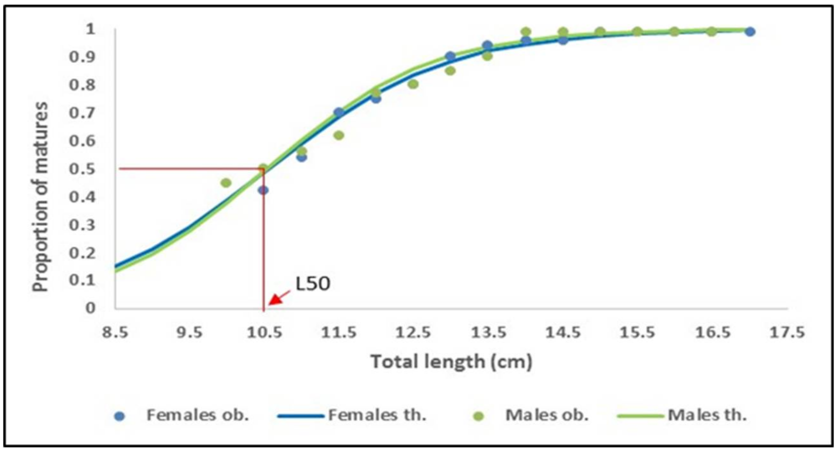

Fig. 6 The size at first sexual maturity of Engraulis encrasicolus (males and females) in the Central Moroccan Atlantic Coast

Table 2 Parameter of the size at first sexual maturity of *Engraulis encrasicolus* (males and females)

Sexes	a	b	L50 (cm)	R²	Standard deviation (Sd)
Males	-9.631	0.913	10.54	0.9	0.10
Females	-8.829	0.836	10.55	0.95	0.06

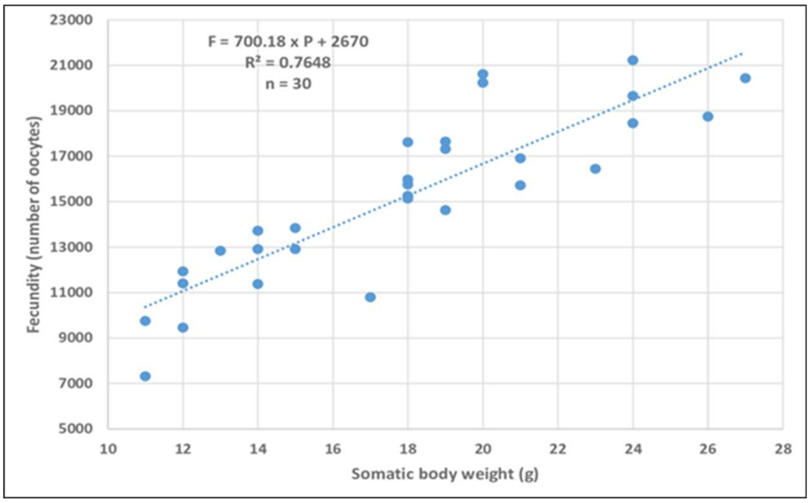

Fig. 7 Relation batch fecundity-weight of *Engraulis encrasicolus* in the Central Moroccan Atlantic Coast

Discussion

Female individuals are abundant during the warmest months (April to August), when the anchovies come closer to the Atlantic coasts where they are captured easily, these results lead us to say that the Center zone of the Moroccan coast may be considered as a zone of spawning of this specie.

The variation in sex ratio with size indicates an abundance of males in small sizes and females in larger sizes. This agrees with the results obtained by (Ouattara et al. 2008). The change in sex ratio during the fish cycle may be due to a differential migration or differential natural mortality by sex (Albaret and Gerlotto 1976). In this study, the most likely hypothesis could be the migration. Indeed, the anchovies move over great distances and at depth (200 m) and this spatial movement and time affect all size classes, but differ according to sex during the breeding season (Marchal 1993).

The sexual maturity results show that matures fish present the highest proportions throughout the year for both sexes, which shows spread reproduction. While on the east coast of Ivory Coast (Ouattara et al. 2008), the results show a single breeding period which extends from January to May. .

The monthly evolution of Gonado-somatic index revealed that reproduction of anchovy extends from April to November peaking between June and August. Protracted spawning period was recorded by others authors: (Palomera 1992; Sinovčić 2000; Gaamour et al. 2004; Mariam et al. 2009) whereas in some regions, reproductive period was shorter: (Chavance 1980; Casavola et al. 1996; Sinovčić and Zorica 2006). The environmental condition can explain the variation in spawning period. Indeed, Moroccan coasts are part of the coastal country benefiting from a permanent supply of nutrients due to the phenomenon of upwelling (Fantodji 2003). Also, our results show that reproduction is coinciding with the warming months and confirming the hypothesis of the influence of temperature on the sexual activity of anchovy (Djabali and Hamida 1989).

The size at first sexual maturity obtained in the present work (10.54 cm total length for males and 10.55 for females) was slightly higher than those observed in Mauritania for females (10.1 cm) and for males (10.4 cm) (Ba 1990). *Engraulis encrasicolus* matures at larger sizes in the Bay of Biscay (11-12 cm) (Duhamel and Masse 2004) and in the Bay of Cadiz in Spain (11.9 cm for males and 11.2 cm for females) (Millán 1999). However, the size at first sexual maturity is very small on the northern coast of

Tunisia (7.3cm) (Gaamour et al. 2004) and in the Suez Canal in Egypt (7 cm for males and 6.5 cm for females) (Mariam et al. 2009). The variation in sizes of first sexual maturity in these different regions could be explained by a strategy of adaptation of fish to different environments (Albaret 1994). For example, a resource-poor environment may delay the growth process of fish (Wootton 1990).

Anchovy is a multiple spawner and its fecundity is indeterminate (Motos 1996). In such species, potential annual fecundity is inaccessible and only batch fecundity can be estimated (Kartas and Quignard 1984; Murua et al. 2003).

The fecundity of a population can vary monthly, e.g., *Anchita mitchili* of Chesapeake Bay, annually (Luo and Musick 1991) and from an area to another (Alheit 1983). It can also vary according to species, size, age and techniques used. Batch fecundity increases, according to the size and body weight of fish. These results were reported on other areas from the Atlantic (Sanz and Uriarte 1989; Motos 1996; Ouattara et al. 2008) and from the Mediterranean (Zupa et al. 2013).

The average relative fecundity obtained in anchovy in this work is 857 oocytes / g of mature somatic body weight. This value is higher than those observed for the same species in the Adriatic Sea (640 oocytes g-1) by (Zupa et al. 2013), in the Bay of Biscay (200 oocytes g-1) by (Motos 1996) and in the Mondego estuary (800 oocytes g-1) by (Ribeiro et al. 1996). This difference could be explained by the presence of several anchovy populations in different areas of distribution or food availability (Hunter and Goldberg 1980; Sanz and Uriarte 1989; Lisovenko and Andrianov 1996; Takasuka et al. 2005). The high fecundity of large individuals makes them smaller and more lipid-rich than young ones (Van Beveren et al. 2014; Ferrer-Maza et al. 2016).

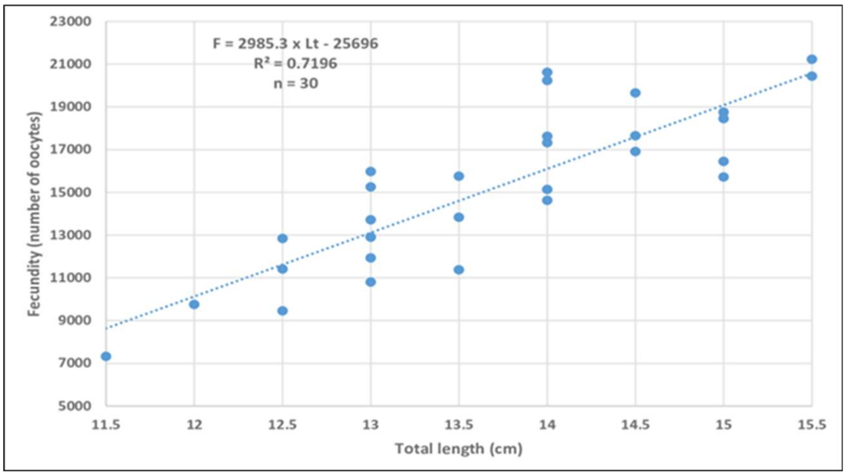

Fig. 8 Relation batch fecundity–total length of *Engraulis encrasicolus* in the Central Moroccan Atlantic Coast

Table 3 Relative fecundity of anchovy species

Species (Engraulidae)	Area	n	Relative fecundity	Authors
Engraulis encrasicolus	Essaouira area, Morocco	30	857	Present paper
	Mondego Estuary, Portugal	104	594–694	Ribeiro et al. (1996)
	Italy, Adriatic Sea	72	437	Casavola et al. (1996)
Engraulis ringens	Peru	83	651	Miñano (1968)
Engraulis mordax	Southern California Bight	119	330–448	Hunter and Golberg (1980)
	Los Angeles Bight	67	421	Hunter and Macewicz (1980)
Engraulis anchoita	Argentina (41°–48° S)	26	605	Pájaro et al. (1997)
Encrasicholina devisi	Bacan, Indonesia	26	1578	Andamari and Milton (1998)
Encrasicholina heterolobus	Jepara, Indonesia	22	180	Wright (1992)
Encrasicholina punctifer	Bima Bay, Indonesia	18	844	Andamari et al. (2002)
	Padag, Indonesia	35	985	Maack and George (1999)
Stolephorus commersoni	Bima Bay, Indonesia	21	291	Andamari et al. (2002)

For other anchovy species (Table 3), similar values were recorded in Bima Bay in Indonesia, for *Encrasicholina punctifer* (Andamari et al. 2002) to our study. High values of relative fecundity were estimated for *Encrasicholina devisi* (Andamari and Milton 1998) and very low values were identified for *Encrasicholina heterolobus* (Wright 1992).

Conclusion

Reproductive biology, providing information on the species life history, is critically important in fishery science, and useful to fisheries management. Fish reproduction was investigated in the present work by studying gonad maturity on the basis of macroscopic characteristics and gonado-somatic index. Knowledge of the spawning period and its duration is important for understanding population dynamics. Knowledge of the fecundity of anchovy can be utilized to determine the time and the number of recruitments. Furthermore, determination of the size at maturity could allow managers to set the appropriate size limit for fish catches. The same is the case for environmental factors that need to be considered, as they affect in particular the growth and reproduction of anchovy.

Acknowledgement This work was conducted at the National Fisheries Research Institute (INRH) in collaboration with the Faculty of Sciences of Rabat, Mohammed V University. We thank the staff of Biology and Ecology laboratory in the INRH of Casablanca-Morocco. The authors wish to thank Mrs Khadija Amenzoui and Mr. Ahmed Yahyaoui for their contribution to this work by expert assistance in laboratory operations, statistical analyses and valuable comments. We thank the anonymous reviewers for their careful review of the manuscript and their excellent suggestions.

Conflict of interest The authors declare that they have no conflict of interest.

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