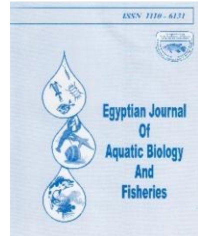
Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 25(3): 647 – 666 (2021)
www.ejabf.journals.ekb.eg



Reproductive biology of horse mackerel *Trachurus trachurus* (Linnaeus, 1758) in the North Atlantic Moroccan coast

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ARTICLE INFO
Article History:
Received: March 29, 2021
Accepted: April 18, 2021
Online: June 25, 2021

Keywords:
Trachurus trachurus,
Moroccan Atlantic coast,
reproductive biology,
sex ratio,
spawning,
fecundity.

ABSTRACT

The present study addressed the reproductive biology of the horse mackerel, *Trachurus trachurus*, in the northern area of the Moroccan Atlantic between December 2015 and November 2016, to provide more biological elements for stock management and good analysis of population dynamics. Monthly monitoring of the gonado-somatic index (GSI), the condition factor (K) and the stages of sexual maturity in the horse mackerel revealed that it is in reproductive activity during the period from January to June, with a peak spawning in February for females, and January for males. In addition, the length of the first sexual maturity was estimated at 21.75 cm (TL) for males, and 22.75 cm (TL) for females.The evolution of the sex-ratio showed a dominance of females over all size classes and during all seasons with an overall value of 0.58. The determination of fecundity allowed to assess that the total fecundity varies between 11424 and 114464 eggs with an average of 49072 ± 25045. For the relative fecundity, it varied between 159 and 770 eggs per gram of total weight, with an average of 426 ± 132, for a total length interval of 19 to 32.5 cm.

INTRODUCTION

Small pelagic fishing occupies an important place in the Moroccan fisheries sector. It covers the entire Moroccan continental shelf, Atlantic and Mediterranean and targets the main resources composed of sardines, mackerel, anchovies, sardinella, and horse mackerel. In 2017, 1.46 million tons of small pelagic landed. Catches are mainly composed of sardines (73%), followed by mackerel (17%) and horse mackerel (7%) **(INRH, 2017)**.

Horse mackerel is very common throughout the Mediterranean countries such as Morocco, Algeria and Tunisia **(Fezzani *et al.*, 2006)**. It is a pelagic and gregarious species, lives between two waters and on sandy bottoms, generally less than 200 m deep, and feeds mainly on fish such as gobies, sand lance, anchovy, sprat, sardine, herring and exclusively crustaceans **(Quéro & Vayne, 1997)**.

Mastering the reproductive biology of species, especially fecundity and egg production, is fundamental in biology and dynamics of fish populations **(Hunter *et al*., 1992; Murua & Saborido-Rey, 2003)**. It is the most reliable source for quantifying the reproductive capacity of the individual and the population of fish species **(Murua & Motos, 2006)**. For assessing the state of exploitation of stocks, several models use information relating to reproductive parameters, such as age and length at first sexual maturity, fecundity and spawning frequencies to estimate the biomass of fish. Annual changes in those variables can affect the productivity of the stock and cause variability in fish recruitment **(Macchi *et al*., 2004).**

In order to provide more reliable informations for good management of the horse mackerel, *Trachurus trachurus*, (Linnaeus, 1758), this work aimed to study its reproductive cycle in the Moroccan North Atlantic, by determining the length at the first sexual maturity, spawning peaks as well as all fecundity parameters.

MATERIALS AND METHODS

Sampling

Sampling was done on a regular basis (once a month) and randomly (one case at random), over the period between December 2015 and November 2016, in the North Moroccan Atlantic area (33'15 N and 34'00 N) (Fig. 1). The species was first identified in the commercial fishing catches landed at the Casablanca fishing port by coastal trawlers. The fishing gear used is a two-sided bottom trawl, classic type, at depths ranging from 30 to 200 m. The sample unit consisted of a standardized plastic case. A total of 842 individuals were examined, the measurements taken were total length (TL, cm), total weight (PT, g), gonad weight (g) and stages of sexual maturity.

Sex ratio

The sex ratio is an index of demographic structure and fertile biomass of a given stock **(Kartas & Quignard, 1984)**. It is defined as the proportion of male individuals in relation to the number of females. An analysis of its evolution by season and by size class was followed to show the importance of one or the other sex of the horse mackerel.

To assess the difference in the proportions of the sexes identified if it was significant or not due to sampling fluctuations, an X^2 (Chi-square) test was used.

Sexual maturity stages

The determination of the sex and the stages of sexual maturity of the horse mackerel is based on the macroscopic observation of the female and male gonads taking into account their coloration, length, the importance of the vascularization, and the thickness and the transparency of the gonad wall **(Holden & Raitt, 1974).** Those morphological criteria are therefore taken into account to follow the evolution of the male and female gonads during the reproductive cycle according to a macroscopic scale of sexual development comprising five stages **(FAO, 1978)** (Table 1& 2).

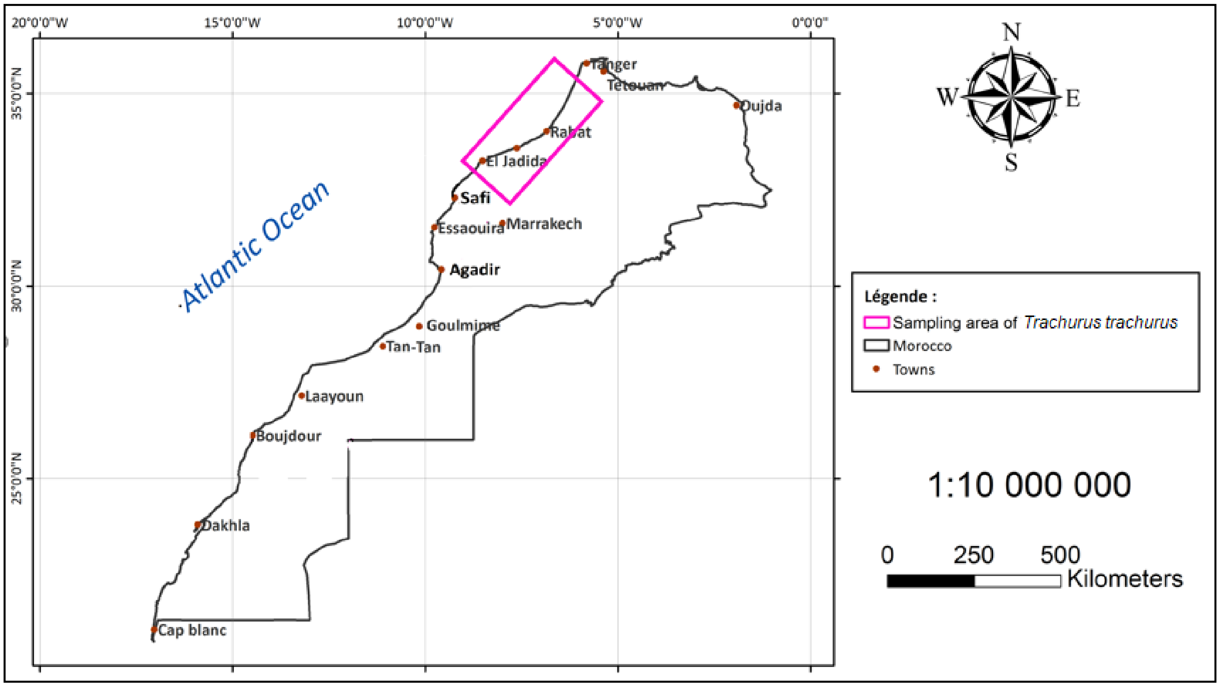


Fig. 1. Sampling area of the horse mackerel, *Trachurus trachurus.*

Table 1. Macroscopic stages of horse mackerel ovaries **(FAO, 1978)**

Maturity stages	**Ovogenesis**	**Characteristics of the ovaries**
I	Immature	Fine, translucent to pink ovary and invisible oocytes.
II	Immature developing or sexually resting adults	Ovary not very bulky, pinkish coloring, intense vascularization in fishes in sexual rest, less intense in immature developing animals and invisible oocytes.
III	Beginning of maturation	Medium-sized ovary, pale pink to light orange coloration and some oocytes are sometimes visible.
IV	Spawning	Very large ovary, occupying the entire abdominal region, very vascular, the ovary wall is very thin and transparent, large-sized hyaline oocytes are perfectly visible and are expelled at the slightest pressure on the abdomen.
V	Post-spawning	Very vascular flaccid ovary, its color is red, the ovarian wall has become very thick.

Table 2. Macroscopic stages of horse mackerel testicles **(FAO, 1978)**.

Maturity stages	Spermatogenesis	Characteristic of the testicles
I	Immature	Small, translucent and very thin testicle.
II	Immature developing or sexually resting adults	More or less symmetrical whitish testicle.
III	In the process of maturation	Wider and firm testicle, white in color and no liquid flows if an incision is made.
IV	Sperm emission	Very large and soft testicle and sperm flows by pressure on the belly of the fish; perfectly visible and are expelled at the slightest pressure on the abdomen.
V	Post-emission	Large, very flaccid, highly vascularized testicle and the pressure on the belly no longer releases sperm.

Size at first sexual maturity

The determination of the length at the first sexual maturity is defined under several components, but those most retained are:

- The length of the smallest mature individual or the largest immature individual during the reproductive season.
- The length for which 50% of individuals in a population are sexually mature during the reproductive period.

In the present work, both definitions were adopted, the researchers proceeded to a segmentation of the individuals sampled during the main reproductive season, by sex and size class, and then, the determination of the proportion of mature individuals of each size class was determined. Only specimens of sexual maturity at stage III which corresponds to the beginning of the gonad development phase **(FAO, 1978)** were retained. Length-proportion pairs of mature individuals were fitted to a symmetric sigmoid logistic curve **(Pope *et al*., 1983; Delgado &Fernandez, 1985)** according to the following equation:

$$\mathbf{P = 1 / (1 + e- (a + b \times L))} \quad (1)$$

P: Proportion of matures by size class
L: Total length
a: Originally ordered
b: Slope
The parameters **a** and **b** were obtained, after the logarithmic transformation of equation (1), by the method of least squares **(Sokal & Rohlf, 2012)**.

$$\mathbf{-\ln((1 - P) / P) = a + b \times L} \quad (2)$$

The representation of the maturity ogive was carried out by considering all the pairs of values except those which had a proportion: P = 0 and P = 1.

$$\mathbf{L50 = -a / b}$$

Gonado-somatic index

The development of the gonads during the sexual cycle was followed by weight indices, so changes in their weights were expressed relative to parameters such as body length, total body weight or somatic weight **(Kartas & Quignard, 1984)**. In the present study, the gonado-somatic index was used and defined as the weight of the gonads expressed as a percentage relative to the total weight of the fish **(Bougis, 1952)**.

$$\mathbf{GSI = Gonad\ weight \times 100 / Total\ body\ weight}$$

The close relationship between the gonado-somatic index and the weight of the fish reveals a major drawback, since the latter is strictly linked to seasonal fluctuations due essentially to the phenomena of spawning and fattening. But according to **Lahaye (1980),** the GSI remains a real coefficient for the identification of the spawning period and their duration. For a better identification and monitoring of the maturation process of the gonads, it is necessary to carry out an oocyte count.

Condition factor

Several authors use the condition index to express the general condition of the fish. It is used to find out the morphological variations, the degree of overweight or finesse following the genital development of the target species. It is also an indicator of the healthy of the population according to **Bolger and Connolly (1989).** This parameter makes it possible to follow variations in the metabolic balance of individuals through seasonal changes in overweight under the influence of external and internal factors. In this work, the condition factor (K) was calculated using the following formula:

$$\mathbf{K = (Pt \times Lt\text{-}b) \times 100}\ \text{(Fréon, 1979)}$$

Pt: Total weight
Lt: Total lenght
b: Allometric coefficient

Batch fecundity

In teleost fish, batch fecundity is the number of oocytes likely to be released during a spawning season by a female **(Bagenal, 1973).** The number of oocytes was related to the mass of the ovary in order to determine fecundity per act of spawning and per mature female. Fecundity (F) was estimated using the following formula:

$$\mathbf{F = (n \times Pg) / Pe}$$

F: Individual fecundity by spawning act
n: Number of oocytes contained in the ovary sample
Pg: Total weight of the two ovaries

Pe: Weight of the ovary sample.

Relative fecundity

Relative fecundity refers to the number of oocytes per unit of body weight, which can be; total weight, somatic weight (total weight-weight of ovaries) or eviscerated weight of fish **(Kartas & Quignard, 1984)**. In the present study, relative fecundity was expressed relative to the total weight (number of oocytes per gram of mature female) and weight of the gonads of the fish (number of oocytes per gram of ovaries). The mathematical relationships between fecundity, total length and total weight of the fish were established and expressed graphically.

Statistical analysis

The X2 and ANOVA test were applied to test the differences between sex, size and seasons using Minitab 17 software.

RESULTS

Sex ratio

During 12 months of sampling and out of a total number of 770 individuals, results revealed that the femininity rate of 63% was higher than the masculinity rate which is 37% (Fig. 2). The difference between the two sexes was significant (Table 3).

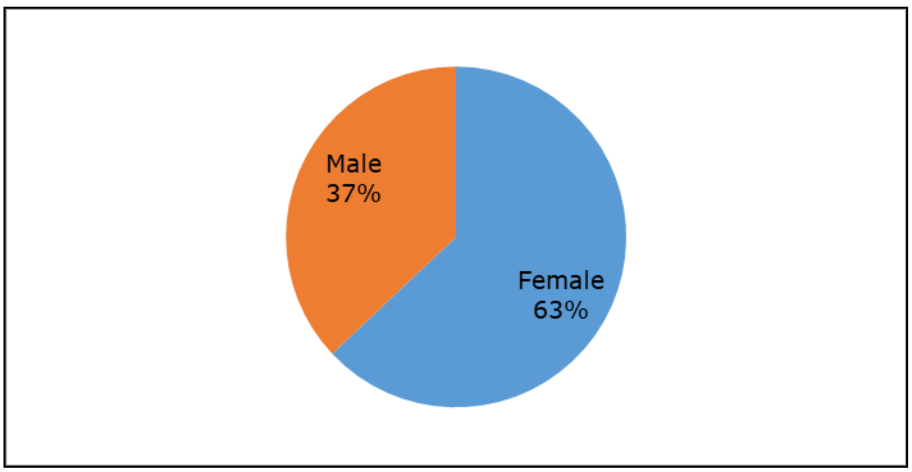


Fig. 2. Sex ratio of *Trachurus trachurus*.

Table 3. Sex proportions of *Trachurus trachurus* by year and comparison of their equality by the X^2 test at $p = 0.05$

Indeterminate	Male	Female	Male Female	X^2 (calculated)	Test
72	285	485	0.58	51.94	S

Sex ratio according to size

The sizes of the individuals varied between 14 and 35.5 cm. The sex ratio was in favor of females for all size classes with the exception of an equality which was observed for individuals of sizes 14-15 and 30-32 cm (Fig. 3). Moreover, a total dominance of females for the size classes between 33 and 35.5 cm was noted. For the other size classes, the dominance of females varied between 60 and 90%. The difference between the size groups according to the sex ratio was significant (p = 0 <0.05).

Fig. 3. Evolution of the sex ratio according to size classes in *Trachurus trachurus*.

Sex ratio according to season

A dominance of females was observed during all seasons with a maximum limit in winter of 78% and a quasi-equality between the two sexes in summer (Fig. 4). Regarding autumn and spring, a slight dominance of females was reported (58 to 60%). The variations in the sex ratio according to the seasons were not significant (p = 0.78> 0.05).

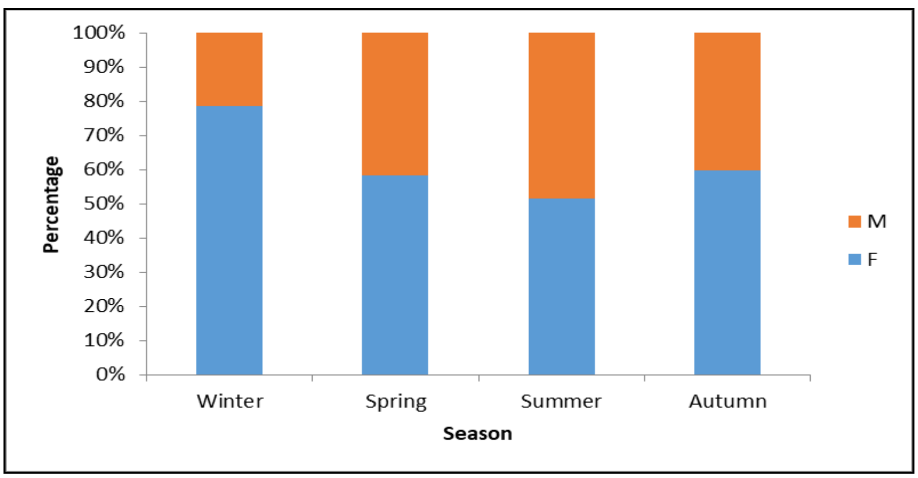


Fig. 4. Seasonal variation of sex ratio of *Trachurus trachurus*.

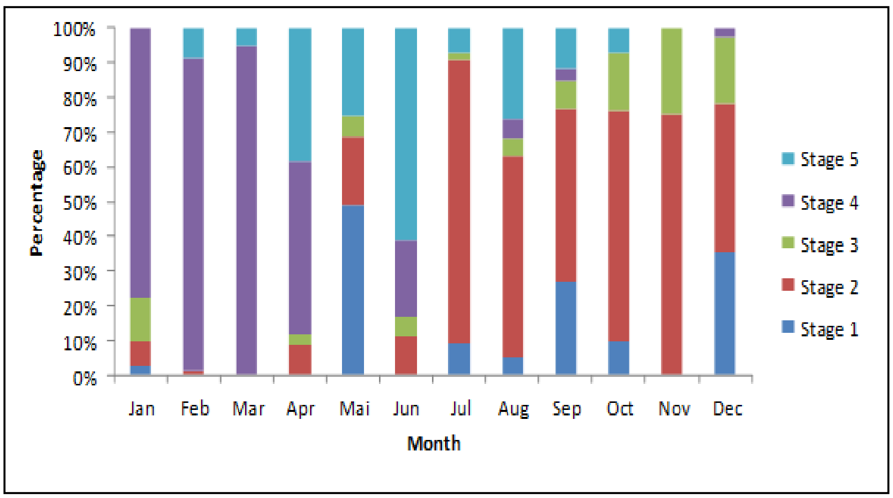
Sexual maturity stages

The monthly evolution of the percentage of maturity stages showed that the females in spawning (stage 4) were present during the entire sampling period with the exception of May, July, October and November (Fig. 5a). Concerning males, individuals in emission (stage 4) were present throughout the study period (Fig. 5b).

Sexual maturity stages according to the seasons

The seasonal evolution of the percentage of maturity stages indicated that the females in spawning (stage 4) dominated in winter (61.5%) and spring (34%). For the rest of the year, a dominance of immature females (stages 1 and 2) was observed. In the case of males, individuals at the beginning of maturation (stage 3) were present during all seasons with a maximum rate in spring (35%) and those in emissions were dominant in winter (50%) as shown in Fig. (6).

a) Females, n = 485



b) Males, n = 285

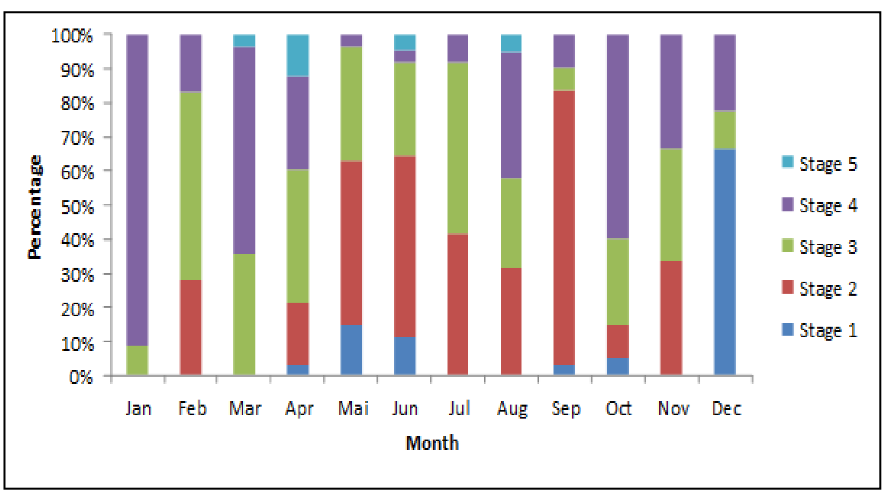
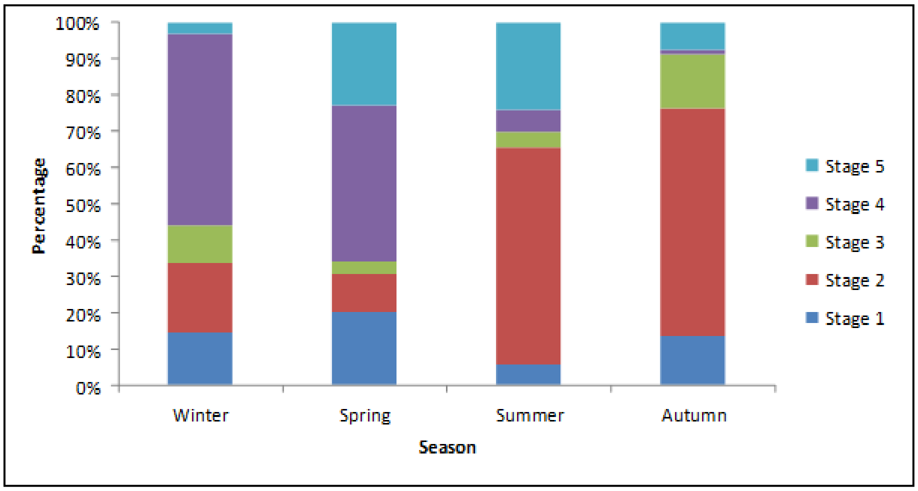


Fig. 5. Monthly evolution of the percentage of male and female *Trachurus trachurus* in different stages of maturity 1 and 2 immature; 3 at the start of maturation, 4 in spawning / emission; 5 post-spawning / emission. a) Females; b) Males

a) Females, n = 485



b) Males, n = 285

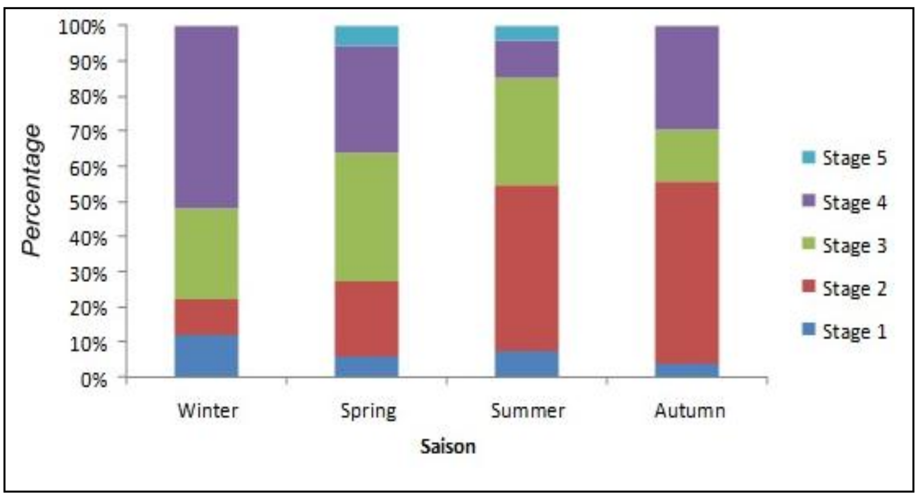


Fig. 6. Seasonal evolution of the percentage of male and female *T. trachurus* in different stages of maturity 1 and 2 immature; 3 at the start of maturation, 4 in spawning / emission; 5 post-spawning / emission. a) Females; b) Males

Gonado-somatic index (GSI)

According to the monthly evolution of the GSI of the two sexes, a main peak of reproduction was observed in January for the males (3.88) and in February for the females (4.17). The lowest GSI values were observed in November for males (0.48) and in December for females (0.33). The peak observed in June for females seems to be very small to be considered as a true spawning peak (Fig. 7).It was also found that, the GSI curves evolved almost the same way for both sexes.

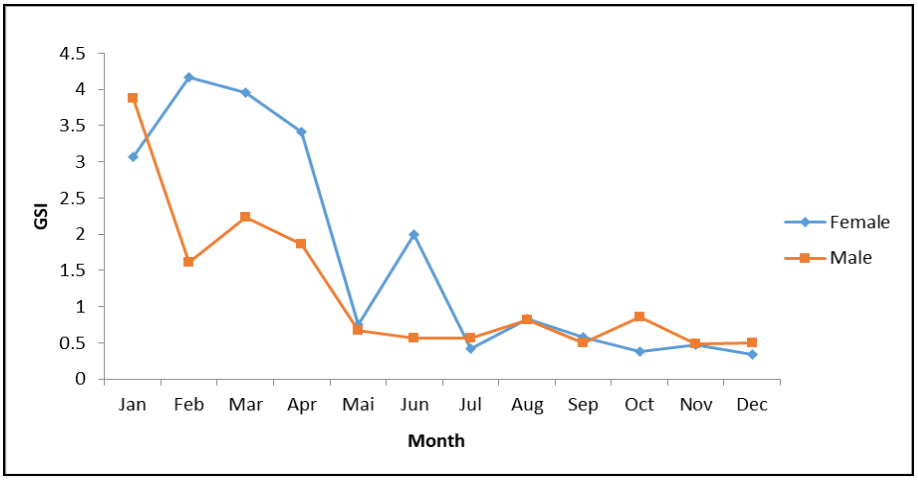


Fig. 7. Monthly evolution of the gonado-somatic index (GSI) of the two sexes of *Trachurus trachurus.*

Size at first sexual maturity

Size at first sexual maturity (L50) was estimated to be 22.75 for females and 21.75 cm for males (Fig. 8). The difference was not significant (ANOVA test, p> 0.05).

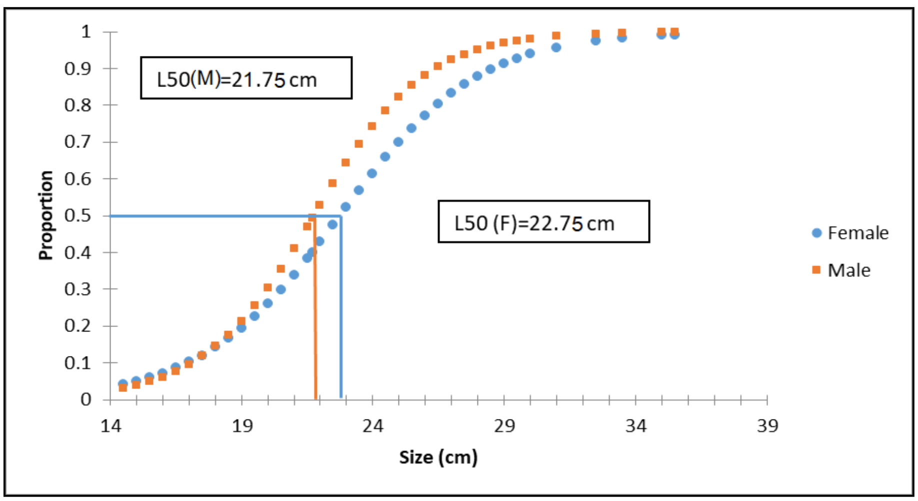
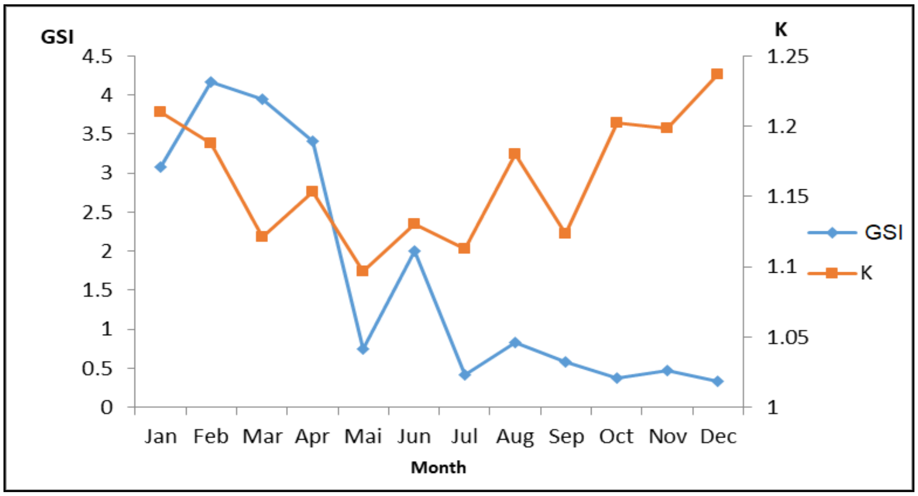


Fig. 8. Size at first sexual maturity (50%) of *T. trachurus* females and males.

Condition factor

The monthly evolution of the average condition factor (K) indicated a decrease in K (Fig. 9) from February and continued to decline until reaching a minimum value in May for females (1.09) and in March and June for males (0.98). Then, it increased to a maximum value in December for both sexes (1.24 for females and 1.11 for males). As for the GSI, the curves of the condition factor (K) evolved in the same way for both sexes. If a comparison was set between the two curves of GSI and K in both sexes, it could be noticed that they were negatively correlated. After the spawning period, GSI began to decrease to reach minimum values in November-December, while K increased and reached maximum values during the same period.

a) Females



b) Males

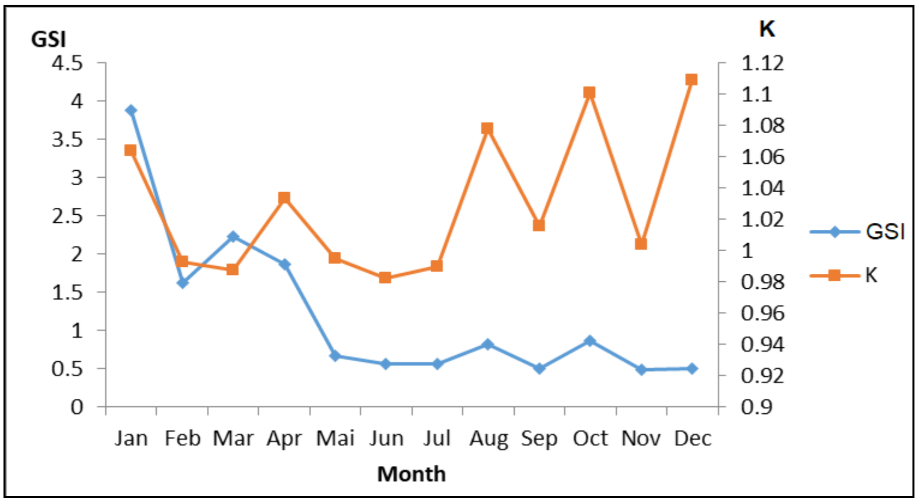
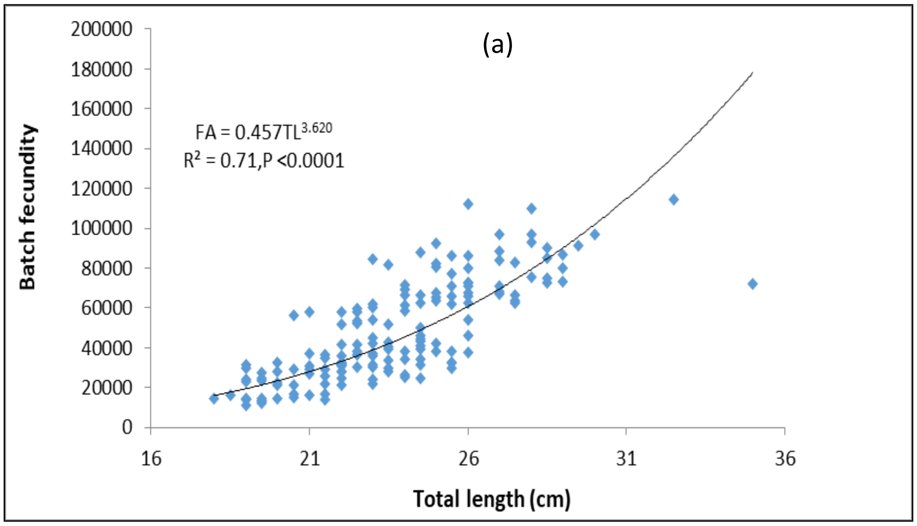


Fig. 9. Monthly evolution of the condition factor (K) of *T. trachurus*.
a) Females; b) Males

Fecundity

The estimated batch fecundity in number of hydrated oocytes in mature females of horse mackerel varied between 11424 oocytes for a female of 19 cm, and 114467 oocytes for a female of 32.5 cm in total length. The average batch fecundity was calculated at 49072 hydrated oocytes per female. Average relative fecundity was estimated at 426 hydrated oocytes per gram of female, and varied between 159 and 770 oocytes per gram of female (Table 4).



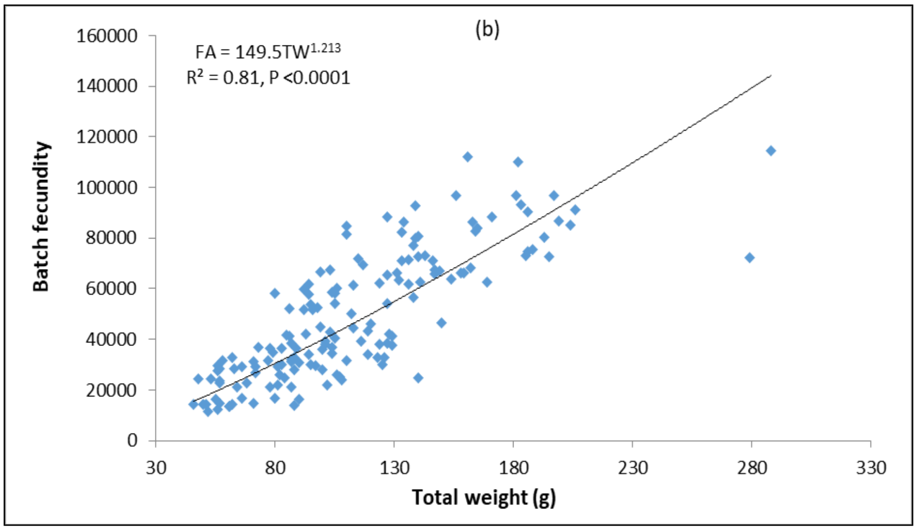


Fig. 10. Relationship between batch fecundity, total length (cm) (a) and total weight (g) (b) of mature *T. trachurus* females.

Table 4. Estimated values of batch and relative fecundity for mature females of *T. trachurus.*

	Average	Standard deviation	Minimal	Maximum
Batch fecundity (number oocytes/female)	49072	25045	11424	114464
Relative fecundity (Number of oocytes/g total weight)	426	132	159	770

The evolution of batch fecundity as a function of the total size and of the total weight of mature female horse mackerel showed that there was a positive and significant correlation between those parameters and batch fecundity (Fig. 10), expressed by the following equations:

$$\mathbf{F = 0.457 \times Lt^{3.62} (n = 156 \text{ and } R^2 = 0.71)}$$
$$\mathbf{F = 149.5 \times Pt^{1.213} (n = 156 \text{ and } R^2 = 0.81)}$$

DISCUSSION

Sex ratio

The global sex ratio of Atlantic horse mackerel showed a dominance of females in the population studied compared to males with a value of 0.58. The current result is in agreement with those observed by **Eltink (1991)** and **Karlou-Riga and Economidis (1996)** in the Saronikos golf course in Greece which found a sex ratio of 0.55. In British waters, **Kerstan (1985)** found equality between the two sexes, the same results were obtained by **Korichi (1988)** in Bou-Ismail Bay in Algeria and by **Erdoğan *et al.* (2016)** in Turkey. Apparently, the variation of the sex ratio depends on the physiological state and several factors which indicate a greater vulnerability of the males to fishing gear or a variation in the quantity and quality of the food, specific to each sex **(Kartas & Quignard, 1984).** Indeed, in migratory species, the rise of females to spawning grounds is usually later than that of males. This phenomenon leads to a variations in the sex ratio with a predominance of males among the first individuals to arrive, followed by a numerical inequality of females and males and then a predominance of females at the end of migration **(Diouf *et al*., 2010)**. The numerical superiority of the females can also be a result of their great longevities, earlier development of the ovaries which would therefore be more easily recognizable than the testicles, or even migratory movements that differ from those of males **(Khemiri & Gaamour, 2009)**. The analysis of the sex ratio by size class indicated a dominance of females in all size classes and especially large sizes, these exclusively female distributions are also observed in other pelagic fish of the Algerian coasts such as Sardine **(Mouhoub, 1986)** and Anchovy **(Hemida, 1987)**. Additionally, **Korichi (1988)** in the Mediterranean Sea of Algeria, noted that the difference in size may be due to the difference in growth by sex, that is to say that the females start to reproduce early while the males are late to reach their first sexual maturity, and therefore, continue to grow. Horse mackerel live in shoal calibrated according to size like all pelagic fish **Fréon (1984),** so it is possible that some groups are dominated by female or male. According to **Chauvet (1986),** the variation in the sex ratio is linked to ethological phenomena (wandering, demographic segregation responsible for the overdeperent and segregative distribution of the sexes).

Spawning period

Monthly monitoring of the evolution of the gonado-somatic index (GSI) and the stages of sexual maturity of both sexes revealed that the spawning period of *T. trachurus* is winter and may go further; it extends from the beginning of January to the end of June. Maximum spawning occurred in January and February for males and females, respectively. Then, a sexual rest was interpreted by the high percentage of stages I and II during the summer and autumn seasons. The spawning period of *T. trachurus* was found by several authors in different geographic areas. In the Moroccan Atlantic, it is prolonged from November to March **(INRH, 2017)** and from November to May **(INRH, 2015). Letaconnoux (1951)** reported that it spans nearly seven months in the Bay of Biscay. On the coasts of Spain, it takes place from February to May **(Miranda & Rivera, 1931)**. While, in the Sea of Marmara, reproduction of *T. trachurus* takes place from March to July **(Demir, 1961).** On the Lebanese coast, the spawning period lasts from February to May **(Mouneimne, 1978).** According to **Boely *et al*. (1973),** the reproductive period of *T. trachurus* is extensive in the Cap Blanc region in the South Atlantic of Morocco, where mature individuals are observed from August to March. In the present study, the maximum spawning occured in December and January when more than 40% of the females are in the spawning state (Table 5).The condition factor is an index that reflects seasonal accumulation and energy depletion, and can provide reliable information on total annual production **(Winters & Wheeler, 1994)**. For horse mackerel, there was a negative correlation between K and GSI. It was observed that, a minimum of overweight corresponded to the months of the cold season (January to April). It is the spawning period when the species exhausts a lot of energy during reproduction, then weight gradually increases as the waters warm up during sexual rest.

Table 5. Reproduction periods of horse mackerel by country.

Area-Author / Months	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Spain/ Miranda and Rivera, 1931		+	+	+	+							
Turkey / **Demir, 1961**			+	+	+	+	+					
Libanon / **Mouneimne, 1978**		+	+	+	+							
Morocco (South) / **Boely *et al*, 1973**	+	+	+					+	+	+	+	+
Aydin and Karadurmus, 2012	+	+	+								+	+
Present study	+	+	+	+	+	+						

Size of first sexual maturity

Males of *T. trachurus* have a size of first sexual maturity smaller than those of females. Maturation generally occurs at the end of the first year of life for short-lived species **(Beverton, 1963)**. The value obtained agrees with the results obtained by **Borges and Gordoa (1991)** on the Portuguese coasts and **Karlou-Riga and Economidis (1996)** in the Aegean Sea. In the Bay of Biscay the recorded values varied between 19 cm for coastal fish, and 23 cm for offshore fish **(Letaconnoux 1951)**. **Kerstan (1985)** indicated that females reach maturity from 26.25 cm in British waters (Table 6). Environmental and genetic factors can influence size at first sexual maturity **(Wootton, 1998; Sampson & Al-Jufaily, 1999)**, but also other factors such as fishing pressure, in the long term can have an impact on L50 **(Jennings *et al*., 2001)**. This factor can have serious repercussions on size at first sexual maturity, forcing the population to mature at a smaller size in order to ensure the survival of the species **(Olsen *et al*., 2004)**.

Table 6. Size at first sexual maturity (L50) of *T. trachurus* found in different areas. TL Total length / FL Fork length

Author	Year	Region	Maturity size (cm)	Length
Barraca	1964	Portugal	19	FL
Karlou-Riga and Economidis	1996	Aegean Sea	22	TL
Borges and Gordoa	1991	Portugal	22.5	TL
Sedletskaya	1971	North Africa	16-23	TL
Abaunza *et al*.	1995	Spain	20.9 M-21.9 F	TL
Abaunza *et al.*	2003	Greece	22	TL
Present study	2018	Morocco	21.76	TL

Fecundity

The total fecundity varies depending on the size and weight of the fish, there is a positive correlation between the size (R2 = 0.71) and the weight (R2 = 0.81). The results obtained (Table 6) showed , the average relative fecundity obtained was estimated at 426 oocytes per gram of fish. The present values were high compared to those obtained by **Eltink (1991)** and **Priede (1994)** (208 and 209 oocytes per gram of total weight respectively) in the East Atlantic, and also to that of **Borges *et al*. (1993)** in South Atlantic. In the Saronikos Gulf of Greece, **Karlou-Riga and Economidis (1997)** found 205 oocytes per gram of weight. By studying the relative fecundity, a noted increase in this fecundity was detected with the size, followed by a slight decrease in the large specimens. This phenomenon, common in fish in general, is due to the fact that young females produce a very large number of oocytes per gram of ovary. **Hagerman (1952)** noted in this sense that an old female produces more eggs in absolute value than a young one, but produces less in relative value. **Woodmead (1974)** made it possible to follow the impact of aging on the structure of the ovary. This hypothesis was confirmed by **Girardin (1981)** who claimed that the eggs begin to regress due to the aging of the fish which can no longer produce large quantities of large diameter eggs.

Table 7. Total fecundity of *T. trachurus* in different regions.

Region	Total fecundity (Thousand)	Size (cm)	Authors
West Africa	50 - 70	22 - 98	Komarov, 1964
England North Canal	76 - 209	21 - 29	Polonsky and Tormosova, 1969
England West Canal	168 - 785	25 - 37	Macer, 1972
Algeria	9 - 90	14 - 20	Osman and Ouahrani, 1990
Morocco	11-114	14 - 35	**Present study**

CONCLUSION

The study of the reproductive biology of the horse mackerel, *Trachurus trachurus*, in the Moroccan North Atlantic has shown that the sex ratio is in favor of females during the whole study period. This parameter varies significantly depending on the size of the individuals. The spawning period is long and extends from January to June with a peak of laying in winter. In fact, the size at first sexual maturity (L50) of the females was greater than that of the males. For average relative fecundity, the value found is greater than the values estimated by other authors in the East Atlantic.

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