Available online at www.sciencedirect.com

ScienceDirect

C. R. Biologies 329 (2006) 892–901

Comptes Rendus Biologies

http://france.elsevier.com/direct/CRASS3/

Animal biology and pathology / Biologie et pathologie animales

Analysis of the cycle of reproduction of *Sardina pilchardus* (Walbaum, 1792) off the Moroccan Atlantic coast

Khadija Amenzoui [a,*], Fatima Ferhan-Tachinante [b], Ahmed Yahyaoui [b], Souad Kifani [a], Abdel Hakim Mesfioui

[a] *Institut national de recherche halieutique, 2, rue de Tiznit, Casablanca, Morocco*
[b] *Faculté des sciences, université Mohammed-V, 4, av. Ibn-Battouta, BP 1014 RP, Rabat, Morocco*

Received 23 February 2006; accepted after revision 4 August 2006

Available online 18 September 2006

Presented by Pierre Buser

Abstract

This work focuses on aspects of reproductive biology of *Sardina pilchardus* from the Atlantic coast of Morocco. The mean values of batch fecundity estimated for the species is 23 150 (±1301) oocytes for a mean size of 19.5 (±0.49) cm, the mean relative fecundity being 346 (±7.34) oocytes per gram of female without ovary. Batch fecundity increases with total length and body weight without ovary. Sizes at first sexual maturity (L_{50}) are reached for males and females at 15.8 (±0.29) cm and 15.8 (±0.35) cm, respectively. The spawning period for the population extends between October and July and the spawning peak occurs from October to February. However, the small sardines (14.5–17 cm) in their first reproduction spawn between November and June, whereas larger fish (17.5–25 cm) spawn between October and July. The factor of condition (K) increased in summer during the sexual resting phase. It is weak in winter during the period of reproduction. Regarding, the sex ratio, there was no significant difference in the number of males and females. ***To cite this article: K. Amenzoui et al., C. R. Biologies 329 (2006).***

Résumé

Analyse du cycle de reproduction de *Sardina pilchardus* (Walbaum, 1792) de la côte atlantique marocaine. Différents aspects du cycle sexuel de *Sardina pilchardus* sont abordés. La fécondité partielle, sa valeur moyenne est de 23 150 (±1301) ovocytes par acte de ponte et par femelle mature dont la longueur totale moyenne est de 19,5 (±0,49) cm. La fécondité relative est de 346 (±7,34) ovocytes par gramme de femelle mature (sans ovaires). La fécondité partielle augmente avec la longueur totale et le poids total (sans ovaire) des individus. La taille à la première maturité est atteinte respectivement chez les mâles et les femelles à 15,8 (±0,29) cm et à 15,8 (±0,35) cm. La saison de reproduction se situe entre octobre et juillet, avec une période de ponte maximale entre octobre et février. En effet, les grandes sardines (17,5–25 cm) ont une saison de ponte plus étendue, allant d'octobre à juillet, alors que les jeunes sardines (14,5–17 cm) présentent une période de reproduction réduite, de novembre à juin. Le facteur de condition K est élevé en été, période qui précède le démarrage de la reproduction. Ceci implique une accumulation des réserves chez la sardine avant la période de reproduction. Le *sex ratio* ne montre pas de différence significative. Il varie avec la taille et les femelles sont nettement plus nombreuses dans les grandes tailles. ***Pour citer cet article : K. Amenzoui et al., C. R. Biologies 329 (2006).***

* Corresponding author.
E-mail address: amenzoui_khadija@yahoo.fr (K. Amenzoui).

1631-0691/$ – see front matter
doi:10.1016/j.crvi.2006.08.002

Keywords: Atlantic coast of Morocco; *Sardina pilchardus*; Sex ratio; Fecundity; Spawning period

Mots-clés : Côte atlantique marocaine ; *Sardina pilchardus* ; Sex ratio ; Fécondité ; Période de ponte

Version française abrégée

Les petits pélagiques constituent un potentiel halieutique important le long des côtes atlantiques marocaines. Ils sont constitués de sardines, maquereaux, chinchards, anchois et sardinelles. La pêche sardinière est l'une des principales composantes des pêcheries marocaines. Elle constitue 70% de l'ensemble des débarquements. Son activité économique et sociale représente un enjeu considérable, en raison de son implication dans les activités connexes, tant en amont qu'en aval.

L'objectif du présent travail est d'étudier le cycle sexuel de la sardine, de suivre le processus de maturation et de déterminer la saison de reproduction. Il a également pour objectif d'estimer la fécondité partielle, la taille à la première maturité sexuelle et d'étudier le *sex ratio*.

Parmi les aspects du cycle sexuel étudiés :

- le *sex ratio* est le rapport entre le nombre de femelles et le nombre de mâles. La variation du *sex ratio* en fonction des années et durant la période de ponte maximale a été analysée. Aussi, sa répartition en fonction de la taille a été étudiée ;
- la fécondité a été estimée en nombre d'ovocytes hydratés émis par acte de ponte et par femelle mature. La fécondité relative est exprimée en nombre d'ovocytes hydratés par gramme de femelle (sans ovaire). Les valeurs observées de la fécondité sont ajustées à un modèle linéaire ($F = a + bx$, où F est la fécondité partielle, x est la longueur totale ou le poids total sans ovaire des femelles) ;
- la taille à la première maturité sexuelle est définie comme étant la longueur totale (L_{50}) à laquelle 50% des individus sont matures. Le pourcentage des poissons mûrs (stades III, IV et V) de chaque classe de taille est calculé. Le modèle logistique de type sigmoïde est choisi pour la représentation graphique : $p = 100/[1 + \mathrm{e}^{-(a+b\times L)}]$, p étant le pourcentage d'individus mûrs par classe de taille.

La période de ponte de la sardine a été déterminée en utilisant deux approches :

- une approche qualitative, basée sur le suivi mensuel du pourcentage des stades de développement macroscopique des gonades. Nous avons utilisé une échelle de maturité sexuelle à cinq stades chez les deux sexes : stade I, immature ; stade II, immature ou au repos ; stade III, pré-ponte ; stade IV, ponte et stade V, post-ponte ;
- une approche quantitative, qui consiste à suivre l'évolution mensuelle du rapport gonado-somatique : RGS $= (G/W) \times 100$, avec G le poids des gonades et W le poids total du poisson.

Le facteur de condition K reflète les conditions écologiques et physiologiques (maturation et ponte) :

$K = (W/L^3) \times 10^3$, avec W le poids total et L la longueur totale du poisson.

Le *sex ratio* global ne montre pas de différence significative. Il est en faveur des femelles, qui se regroupent pour se reproduire durant la saison de ponte intense. La répartition du *sex ratio* en fonction de la taille montre une prédominance des femelles aux petites et aux grandes tailles. Cette dépendance du *sex ratio* à la taille du poisson a été mentionnée chez la sardine marocaine, chez d'autres populations de sardine méditerranéennes et chez d'autres petits pélagiques, comme la sardinelle du Venezuela et l'anchois de la baie de Cadiz.

La valeur moyenne de la fécondité partielle est de 23 150 (±1301) ovocytes par acte de ponte et par femelle mature, dont la longueur totale moyenne est de 19,5 (±0,49) cm. La fécondité relative moyenne est de 346 (±7,34) ovocytes par gramme de femelle mature (sans ovaires). La fécondité partielle augmente avec la longueur totale et le poids total (sans ovaire) des femelles. Un meilleur ajustement a été obtenu avec le modèle linéaire fécondité partielle–longueur totale qu'avec le modèle fécondité partielle–poids total des femelles (sans ovaires).

La taille à la première maturité sexuelle est atteinte respectivement chez les mâles et les femelles à 15,8 (±0,29) cm et à 15,8 (±0,35) cm. Cependant, ce résultat général varie d'une année sur l'autre. Ces fluctuations annuelles de la L_{50} sont attribuées à la croissance différentielle des cohortes annuelles successives qui ont vécu des conditions environnementales différentes.

L'étude combinée des RGS et des stades de maturité sexuelle a montré qu'au niveau de la zone de Laâyoune, la sardine peut se reproduire au long de l'année avec une période de reproduction maximale entre octobre et février. Ce résultat est confirmé par des études d'ichtyoplancton : des œufs de sardine sont collectés durant toute l'année le long de la côte atlantique marocaine ; leur densité est maximale en hiver et devient faible en été. Toutefois, il existe des variations interannuelles du cycle sexuel de la sardine, qui sont dues aux conditions environnementales du milieu, en particulier la température. L'étendue de la saison de reproduction et de ponte maximale dépend de la taille du poisson. En effet, les jeunes reproducteurs (14,5–17 cm) ont une période de reproduction réduite et peuvent se reproduire entre novembre et juin, avec une période de ponte maximale entre novembre et janvier, tandis que les grandes sardines (17,5–25 cm) ont une période de ponte plus étendue, d'octobre à juillet, avec une période d'activité sexuelle maximale d'octobre à février. Ces différences liées à la taille résultent probablement du fait que les jeunes ont encore un taux de croissance élevé et, de ce fait, investissent moins d'énergie dans la reproduction que les poissons âgés.

Le maximum du facteur de condition K correspond au mois (en été) qui précède le démarrage de la reproduction. Cela implique une accumulation de réserves chez la sardine avant la période de ponte, puis un transfert de l'énergie vers la production des gamètes. D'où la relation inverse entre K et RGS. Les variations du facteur de condition observées en atlantique sont en relation avec les indices d'*upwelling*.

Chez les poissons, le processus de sénilité peut engendrer une diminution de la fécondité ou une diminution de nombre de pontes. Or, notre étude a montré une évolution croissante de la fécondité en fonction de la longueur totale, du poids total (sans ovaire) des femelles. Donc, l'effet de la sénilité n'apparaît pas chez la sardine, qui est une espèce exploitée à longévité courte.

Au Maroc, la reproduction de la sardine a lieu toute l'année, mais, du fait de l'existence du phénomène d'*upwelling*, qui fait apparaître des variations saisonnières bien marquées, certaines périodes sont beaucoup plus favorables que d'autres. La ponte de la sardine marocaine est donc maximale en hiver, saison d'*upwelling* minimal et de production zooplanctonique minimale. Elle devient faible en été, saison d'*upwelling* maximal et de production zooplanctonique maximale.

1. Introduction

Pelagic fish species such as *Sardina pilchardus*, *European pilchardlla* spp, *Engraulis encrasicolus*, *Scombrus* spp, *Trachurus* spp constitute important fishery resources throughout the Atlantic coast of Morocco, the first of which remaining the most abundantly caught, reaching 70% of total landings. In these waters, there are three spawning areas for the sardine [1,2]: (1) between Larache and Casablanca, (2) between Tan-Tan and Cap Juby, and (3) between Dakhla and Cap Barbas. Moreover, sardines are considered to belong to three stocks for assessment and management purposes (off northern, central and southern, respectively). Moroccan catches of sardine have been in the order of 600 000 tons, the largest contribution being from the southern stock [3].

The sardine, like most clupeids, is a batch spawner, whose oocytes do not mature simultaneously. Females spawn partially on several occasions within a single season [4].

Previous studies carried out along the Moroccan Atlantic coast on the biology of sardine reproduction concerned either the observations of abundance of eggs and larvae [1,2,5], or temporal distribution of macroscopic stages of gonad development of this species [6]. These studies show that sardine reproduces mainly in winter and secondarily in summer. The hypothesis of a main spawning season in winter and another secondary one in summer was stated.

This present paper consists of an original study of some reproductive characteristics of the Moroccan Atlantic sardine, including maturation process, batch fecundity, size at first maturity and timing of spawning during a three-year period (from January 1999 to December 2001). Interannual fluctuations in these features are discussed. The fecundity was estimated only in January 1998.

2. Material and methods

The studied specimens were collected from commercial landings carried out between January 1999 and December 2001 at the port of Lâayoune, in southern Morocco (Fig. 1). A total of 4644 sardine was sampled, among which 2383 were females and 2261 males. The sampling procedure follows [6]. The sampling rate per week was related to fish availability. Each time, ten specimens were sampled per class of size, measured to the nearest half centimetre. For each specimen, measurements included total length (L_t) to the nearest half centimetre, total weight (W) and the gonads' weight (G) to the nearest decigram; sex and stage of sexual maturity were determined. The scale of sexual maturity followed [6]. It includes five stages of sexual maturity for both sexes, as follows: stage I, immature; stage II, immature or in resting phase; stage III, pre-spawning; stage IV, spawning; stage V, post-spawning.

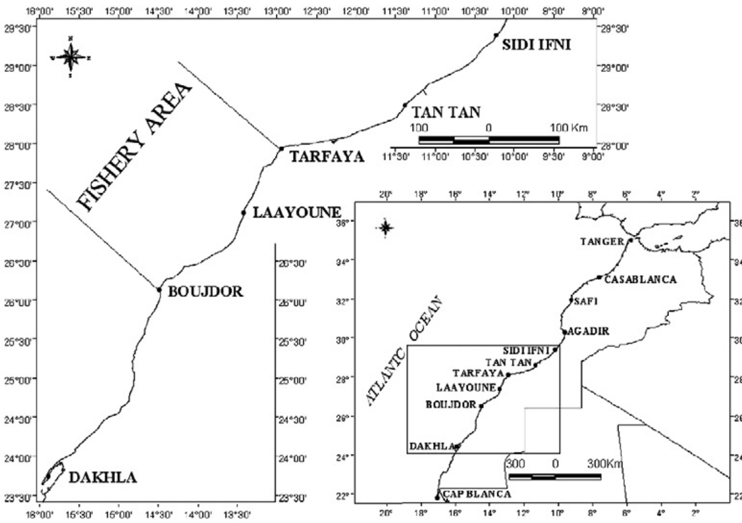

Fig. 1. Zone of samples selection of *Sardina pilchardus*.

Sex ratio of males and females is monthly calculated according to the following equation:

Sex ratio $= (F/M)$, M: number of males, F: number of females. The sex ratio was analysed by 1-cm length class basis. The sex ratio at peak spawning was calculated. Deviation from 1:1 null hypothesis was statistically tested by χ^2-test.

The laying period is determined by two methods: a qualitative method based on monthly changes of the percentage of macroscopic development of gonad stages and a quantitative method based on monthly changes of parameters related to sexual maturity, such as mean gonadosomatic index (GSI) and factor of condition (K).

The gonadosomatic index is defined by [7] as follows: GSI $= (G/W) \times 100$; G: gonad weight, W: total weight. Factor of condition (K) follows [8]: $K = (W/L_t^3) \times 10^3$; W: total weight, L_t: total length. In addition, mean GSI and K were estimated by considering separately two size ranges, which were established in accordance with the length at first maturity and the previous study on age and growth of Moroccan Atlantic sardine [6]. The first size range (14.5–17 cm) includes one-year-old fish in their first maturation, and the second one (17.5–25 cm) fish aged two or more years.

Size at first sexual maturity (L_{50}) was estimated in both sexes and for the species from the percentages of mature individuals (stages III, IV and V) occurring over the reproductive period (previously determined from monthly mean GSI) [9].

The logistic model follows [10]:

$$p = 100/\left(1 + e^{-(a+b\times L)}\right) \tag{1}$$

p being the percentage of the ripe individuals by class of size. The parameters a and b are obtained by a logarithmic transformation curve of the expression (1). We obtain a linear equation of a line (2) having the following form:

$$-\ln\left[(100 - p)/p\right] = a + b \times L \tag{2}$$

Estimates were compared statistically using analysis of variance (ANOVA) [11]. Length at full maturity (L_{95}) was also estimated in both sexes.

Some samples of females sardine are collected during the surveys made by the *AtlantNiro* boat in January 1998, off Laâyoune. One hundred and twenty-three females were used for ovarian histology and 56 others for the estimation of partial fecundity. Mature females at stage IV, ranging in total length between 15.5 and 23 cm and ovaries (without recent post-ovulation follicles) containing hydrated oocytes, were selected for the estimation of the partial fecundity following the gravimetric methods of [4].

Three regions of ovary were cut in the anterior, median and posterior lobe of ovary, respectively [12]. Then, their parts were weighed and preserved in 10% formalin [4]. The oocytes were counted under the binocular. The hydrated oocytes are identified with regard to sizes and transparent aspect. The number of the oocytes was reported to 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 without ovary.

Table 1
Annual sex ratios of *Sardina pilchardus*, over the period January 1999–December 2001

Year	N	Females	Males	Females/Males	χ^2	P
1999	1508	787	721	1.09	2.88	NS
2000	1916	951	965	0.98	0.10	NS
2001	1220	645	575	1.12	4.02	S
1999–2001	4644	2383	2261	1.05	3.20	NS
			$\chi^2_{1;0.05}=3.84$			

S: significant.
NS: non-significant.

Table 2
Sex ratio at peak spawning of *Sardina pilchardus*, over the period January 1999–December 2001

Year	N	Females	Males	Females/Males	χ^2	P
1999	280	146	134	1.09	0.51	NS
2000	429	236	193	1.22	4.31	S
2001	270	137	133	1.03	0.06	NS
			$\chi^2_{1;0.05}=3.84$			

3. Results

3.1. Sex ratio

Annual sex ratios were not significantly different from the expected 1:1 ratio, except in 2001 (Table 1). During the period of peak spawning, females outnumber males, but the sex ratio is significantly different only in 2000 (Table 2). Sex ratio by size class (all years) shows a dominance of females in sizes ranging between 9 and 14 cm, except for the class of size 12 cm, where males outnumbered females (Fig. 2). In mean size ranging between 15 and 19 cm, males outnumbered females, except for size 18 cm, where females outnumbered males. In the largest sizes, from 19 cm, the females were the most abundant.

3.2. Batch fecundity

The estimated values of fecundity fluctuate between 14 578 and 33 851 oocytes per batch and per female mature with 23 150 oocytes (±1301) as mean value and 19.5 cm (±0.49) as mean size. These estimated values vary according to class of size. Fecundity shows increases with total length and total weight without ovary (Figs. 3 and 4). The relative fecundity presents values that fluctuate between 297 and 418 oocytes per gram of female without ovary (mean: 346 ± 7.34 oocytes per gram of female without ovary). The relationships fecundity versus total length and total weight without ovaries are:

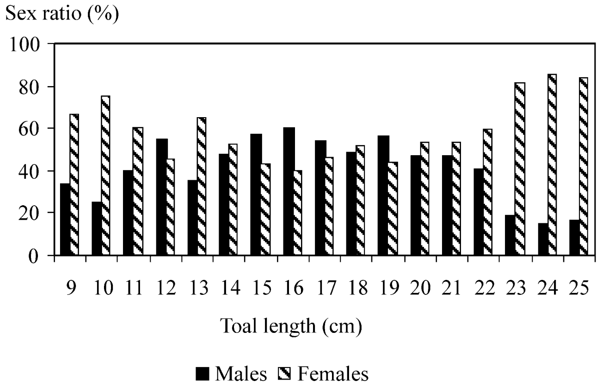

Fig. 2. Variation of the sex ratio *of Sardina pilchardus* with the size, over the period January 1999–December 2001.

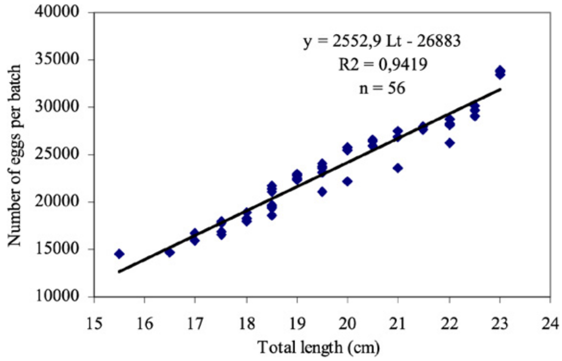

Fig. 3. Relation batch fecundity–total length of *Sardina pilchardus*, January 1998.

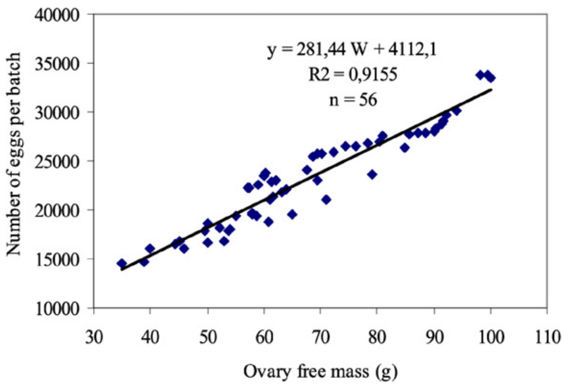

Fig. 4. Relation batch fecundity–ovary free weight of *Sardina pilchardus*, January 1998.

- relationship fecundity–total length:

$$F = -26\,883 + 255.29L_{\mathrm{t}}, \quad r^2 = 0.94$$

- relationship fecundity–total weight without ovary:

$$F = 4112.1 + 281.44W, \quad r^2 = 0.91$$

3.3. Size at first maturity

During our study period (from January 1999 to December 2001), length at first maturity (L_{50}) was estimated as 15.8 (±0.29) cm for males, and 15.8 (±0.35) cm for females (Fig. 5). Length at full maturity (L_{95}) was 22.5 cm for males, and 21 cm for females (Table 3). No significant differences were found in the L_{50} between sexes (ANOVA) [11] (Table 4). However, they fluctuate according to years in the both sexes (Table 3).

3.4. Macroscopic stage of maturity

The monthly composition of sardine (male and female) maturity stage from January 1999 to December 2001 (Fig. 6) shows that the spawning season did not start simultaneously for all fish. Pre-spawning (stage III) and post-spawning (stage V) individuals are less represented in samples with variable percentages depending on the year. The percentage of spawning fish becomes important from January to March 1999 and from October to December 1999, from January to June 2000 and from October to December 2000, from January to February 2001, in May 2001 and from October to December 2001 (Fig. 6). By August, most sardines have finished spawning and enter the sexual resting period (stages I and II), except some rare individuals that still could spawn.

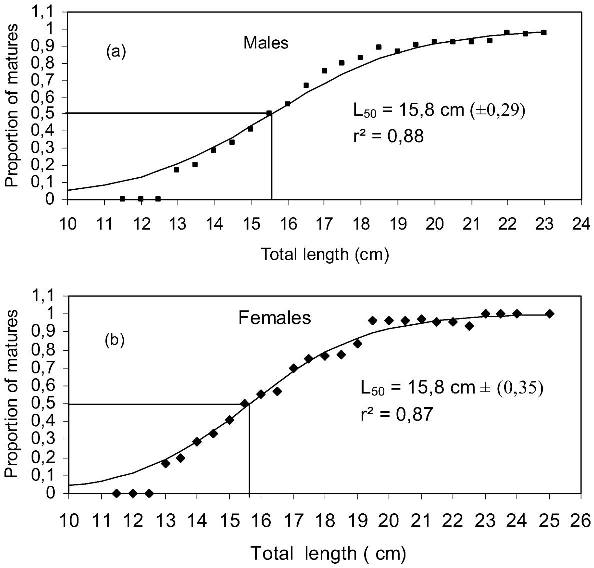

Fig. 5. Maturity ogive and length at first maturity (L_{50}) in (a) males and (b) females of *Sardina pilchardus*, over the period January 1999–December 2001.

Table 3
Annual estimates of total length (cm) at first (L_{50}) and at full (L_{95}) maturity, as a function of sex of *Sardina pilchardus*, over the period January 1999–December 2001

Years	Males			
	L_{50}	L_{95}	r^2	n
1999	15.7	21.5	0.97	483
2000	16	20.3	0.95	864
2001	15.5	19.9	0.91	304
1999–2001	15.8	21.3	0.88	1651
Years	**Females**			
	L_{50}	L_{95}	r^2	n
1999	15.9	21	0.96	648
2000	16.4	21.6	0.95	947
2001	16	21.2	0.92	405
1999–2001	15.8	21.2	0.87	2000

Table 4
ANOVA of total length at first (L_{50}) maturity by sex and year. F: statistical test; P: probability values

	By sex		By year	
L_{50}	F	P	F	P
	3.02	NS ($p > 0.05$)	1.56	NS ($p > 0.05$)

NS: non-significant.

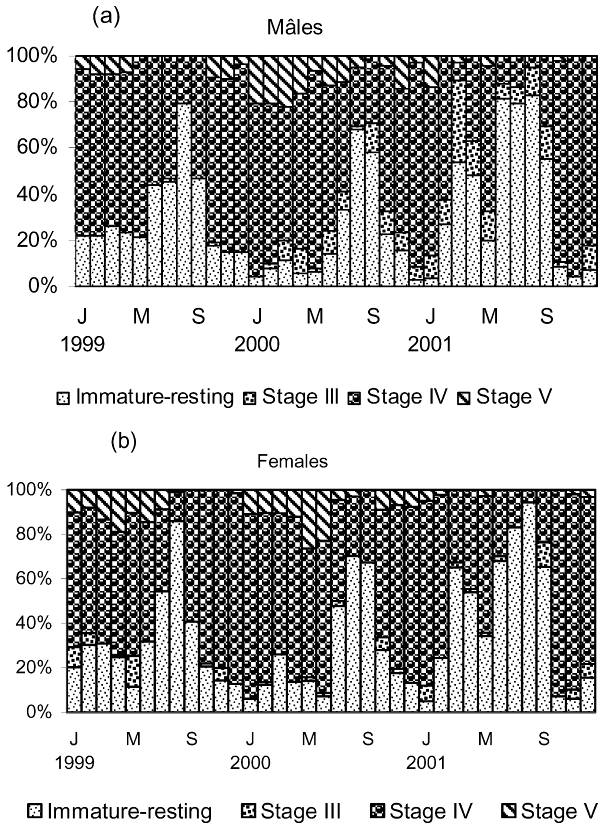

Fig. 6. Monthly percentages of macroscopic stages of maturity in (a) males and (b) females of *Sardina pilchardus*, over the period January 1999–December 2001.

3.5. Gonadosomatic index (GSI) and factor of condition (K)

The evolution of mean GSI of males and females shows similar patterns. The mean values of gonadosomatic index gradually increased from September to December/January and then dropped, reaching the lowest values in summer (Fig. 7). One GSI peak was observed in May 1999, and November 2001, whereas in 2000, the spawning season was more extended with GSI peaks in January and December 2000 (Fig. 7).

The analysis of the seasonal patterns of the percentage of mature sardines (stage IV) (Fig. 6) and mean gonadosomatic index (Fig. 7) indicate the existence of a protracted spawning season that extends from October to July, with a maximal sexual activity between October and February. The sexual resting period takes place between July and August.

The factor of condition K shows similar patterns in both sexes (Fig. 8). From 1999 to 2001, temporal trends of K showed a rather apparent seasonal cycle (Fig. 8), sardines reached a higher condition from June to August and a lower condition from January to April. There was one annual peak in July 1999 and 2000 and two annual peaks in May and August 2001.

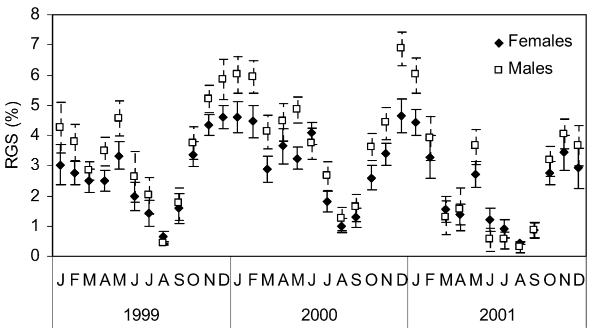

Fig. 7. Annual cycle of the gonadosomatic index (mean ± SD) in males and females of *Sardina pilchardus*, over the period January 1999–December 2001.

3.6. Reproductive cycle and factor of condition (K) by size range

Data of both sexes are regrouped because there is no big difference between males and females. GSI and the factor of condition K are calculated by size class.

The duration of the spawning season is probably related to fish size (Table 5). Sardines first spawned at a length of 14.5–17 cm, with a reproductive period from November/January to March/June and GSI peak in November or January (Table 5). Larger fish (17.5–25 cm) reproduce during all the year, except in August 2001, with a GSI peak in May, December or November. Both percentages of spawning sardines (stage IV) (Fig. 6) and GSI peaks indicated that, in the smaller fish, the spawning peak occurs between November and January, and, in the larger ones, between October and February.

In smaller sardines (14.5–17 cm), the maximal annual values of condition appeared in June or July,

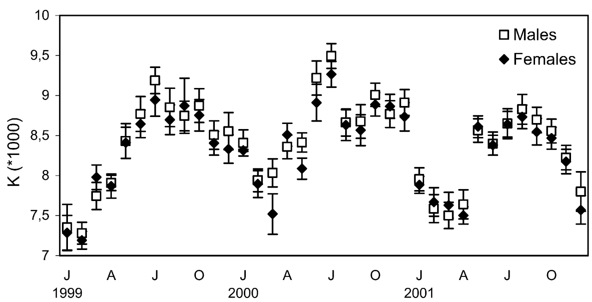

Fig. 8. Annual cycle of factor of condition (K) (mean ± SD) in males and females of *Sardina pilchardus*, over the period January 1999–December 2001.

Table 5
Monthly mean (± SD) gonadosomatic index (GSI), by size range of *Sardina pilchardus* (both sexes), over the period January 1999–December 2001

Month	1999		2000		2001	
	14.5–17 cm	17.5–25 cm	14.5–17 cm	17.5–25 cm	14.5–17 cm	17.5–25 cm
January	4.01 (2.40)	1.78 (1.08)	5.28 (2.19)	4.98 (2.13)	4.58 (2.72)	5.30 (2.10)
February	3.32 (2.01)	3.12 (2.10)	4.61 (2.76)	5.81 (2.17)	3.48 (2.11)	3.94 (2.26)
March	2.24 (1.38)	3.27 (1.94)	3.57 (2.11)	3.57 (2.14)	1.73 (0.68)	3.46 (2.11)
April	2.66 (1.82)	3.70 (1.62)	2.78 (2.12)	4.32 (2.48)	0.47 (0.42)	2.42 (1.98)
May	2.14 (1.83)	4.58 (1.93)	2.77 (2.15)	4.28 (1.83)	1.08 (0.80)	3.96 (2.00)
June	1.70 (1.46)	3.26 (2.08)	3.82 (2.12)	3.91 (1.94)	0.36 (0.21)	2.19 (1.68)
July	0.85 (0.34)	2.65 (1.98)	0.35 (0.15)	2.73 (2.06)	0.34 (0.19)	1.12 (1.01)
August	0.70 (0.56)	1.40 (1.04)	0.04 (0.01)	2.59 (1.78)	0.34 (0.15)	0.32 (0.19)
September	1.20 (1.08)	2.64 (1.46)	0.83 (0.11)	3.16 (1.72)	0.72 (0.43)	1.06 (0.92)
October	2.12 (1.82)	4.19 (1.62)	2.05 (1.72)	4.38 (1.73)	2.39 (1.61)	3.06 (1.54)
November	3.65 (1.34)	5.06 (1.71)	1.67 (1.53)	4.91 (1.63)	2.90 (1.56)	3.93 (1.91)
December	3.76 (1.83)	6.04 (2.14)	3.58 (2.47)	6.45 (2.12)	2.21 (1.93)	3.69 (1.74)

Table 6
Monthly mean (± SD) factor of condition (K), by range of *Sardina pilchardus* (both sexes), over the period January 1999–December 2001

Month	1999		2000		2001	
	14.5–17 cm	17.5–25 cm	14.5–17 cm	17.5–25 cm	14.5–17 cm	17.5–25 cm
January	7.34 (0.83)	7.10 (0.66)	8.39 (0.77)	8.35 (0.63)	7.68 (0.39)	7.96 (0.46)
February	7.26 (0.50)	6.87 (1.59)	7.81 (0.83)	8.04 (0.62)	7.63 (0.68)	8.11 (0.72)
March	7.86 (0.69)	8.01 (0.55)	7.73 (0.86)	7.89 (0.95)	7.69 (0.55)	8.00 (0.57)
April	7.92 (0.56)	7.89 (0.45)	8.54 (0.80)	8.41 (0.55)	7.80 (0.44)	7.78 (0.57)
May	8.37 (0.64)	8.69 (0.68)	8.19 (0.64)	8.29 (0.52)	8.34 (0.46)	8.97 (0.58)
June	8.35 (0.61)	8.75 (0.70)	8.22 (0.60)	9.04 (0.88)	8.62 (0.48)	8.61 (0.44)
July	8.90 (0.70)	9.24 (0.67)	9.52 (1.77)	9.62 (0.59)	8.60 (0.77)	9.15 (0.66)
August	8.60 (0.94)	9.21 (0.84)	8.11 (0.68)	9.45 (0.66)	8.40 (0.94)	9.23 (0.53)
September	8.34 (0.52)	9.23 (0.67)	8.14 (0.60)	9.30 (1.02)	8.34 (0.51)	9.13 (0.47)
October	8.10 (0.84)	9.06 (0.69)	8.57 (0.74)	9.18 (0.65)	8.35 (0.53)	8.83 (0.53)
November	8.12 (0.76)	8.55 (0.69)	8.43 (0.86)	9.02 (0.63)	8.13 (0.96)	8.47 (0.51)
December	8.19 (0.62)	8.57 (0.91)	8.13 (0.84)	8.96 (0.63)	7.56 (0.65)	8.01 (0.58)

Table 7
ANOVA of factor of condition K by size range. F: statistical test; p: probability values

	By size range	
Factor of condition K	F	p
	9.68	($p < 0.01$)

whereas the minimal values appeared in winter and early spring (Table 6). In larger fish (17.5–25 cm), maximal values are observed from July to October, whereas minimal values are observed in winter and early spring (Table 6). The difference is significantly found between the factor of condition K in both size ranges (ANOVA) (Table 7).

4. Discussion

Sardina pilchardus off Lâayoune is a gonochoric species without sexual dimorphism and presents a sex ratio without significant difference. Similar data are reported by [13] for specimens from the Canary Islands. By contrast, females outnumbered males off the Moroccan northern Atlantic area [6] and in the Alboran Sea [14,15]. Females predominate during the peak spawning season. A similar result was noted by [16] in *Sardinella aurita* of Senegal. [17] states the existence of reproductive aggregations, which is due to the dominance of females during the period of intensive spawning.

The high proportion of females in the small lengths would be explained by the fact that the ovary is precociously identified. The females outnumbered males in large size classes. Growth of females and males are probably different. This size dependence of the sex ratio was reported in the Moroccan sardine by [6] and other sardine populations by [15,18]. This biologic characteristic was also reported in other small pelagics, like in *Sardinella aurita* of Senegal [16], in *Engraulis encrasicolis* of Mauritania [19] and in *Sardinella aurita* of Venezuela [20].

The fecundity of a population increases according to the size and body weight of fish [21] but, it can vary monthly, e.g., *Anchita mitchili* of Chesapeake Bay [22] and of *S. pilchardus* from Portugal [23]. This fecundity can also vary annually and from an area to another, such as in *Engraulis mordax* and *Engraulis ringens* [24].

The estimated values of relative fecundity of *Sardina pilchardus* from Portugal [23,25] are higher than that estimated in the present study (Table 8). Similar values were recorded in *European pilchardlla brasilensis* from Brazil [26]. High values of relative fecundity estimated for *Sprattus sprattus* [27] and for *European pilchardlla aurita* [28].

The values of the length at first maturity (L_{50}) estimated in Moroccan Atlantic Sardine are higher than those observed in other areas [13,15,29].

At first glance, the inter-annual variability in length at maturity (Table 2) could be attributed to the differential growth of successive annual cohorts when facing different environmental conditions [30].

In the Moroccan Atlantic, the sardine shows a spawning period spread out all year, with an intense sexual activity between October and February. This result is confirmed by the studies of ichtyoplankton [1,2,5]: *Sardina pilchardus* eggs are collected during all the year along the Moroccan Atlantic coasts, their density is maximum in winter and lower in summer. However, interannual variations in the extent and timing of peak spawning are recorded. These variations seem to be related to changes in physical and biotic conditions [31].

The work carried out authors in the Atlantic Ocean [13,23,32] and the Mediterranean Sea [15,33] over the periods of reproduction of *Sardina pilchardus* indicates

Table 8
Relative fecundity of certain species of the family of clupeids

Species (Clupeidae)	Area	*n*	Relative fecundity	Authors
Sardines				
Sardina pilchardus	Portugal	127	427	[25]
Sardina pilchardus	Portugal		422	[23]
Sardina pilchardus	Lâayoune area	56	346	Present paper
Sardinella				
Sardinella aurita	Senegal		400	[28]
Sardinella brasilensis	Brazil	23	356	[26]
Sprat				
Sprattus sprattus	Southern North	41	413	[27]

early or late spawning and the existence of a single season of principal spawning that can be spread out over a short or long period of the year according to areas.

The GSI trends by size indicate that the spawning extent and the timing of peak spawning are size dependent (Table 3). Larger fish (17.5–25 cm) reproduce during all the year and are responsible for both the onset and end of the reproductive cycle for the whole population. Their maximum sexual activity occurs between October and February. Conversely, smaller fish (14.5–17 cm) attain first-time maturity later and have a shorter spawning season, their peak spawning occurring between November and January. The interannual differences in the size composition of the stock would result in different combinations of these two size-based reproductive strategies in a given year [17]. Similar size-dependent differences in the maturation process have been observed in other clupeids [15,23].

The mean changes of the factor of condition (K) (periods of fattening and slimming) are contrasted with mean GSI values. This is a common characteristic of *Sardina pilchardus* from the Mediterranean Sea [15,33, 34] and from the Atlantic Ocean [23,29]. The factor of condition K shows that the males develop a strategy similar to that of females in the use of energy contributions during gonadic maturation and spawning.

The maximum mean values of K coincide with the end of the spawning season for the first two years and with the sexual resting phase for the year 2001. These results are in agreement with [15,23,29,33].

In summer, when the trophic conditions are the best, the specimens feed abundantly, while accumulated reserves are in agreement with previous observations [35]. In autumn, phase of gonad maturation, the decrease of mean K could be explained by reserves used for sexual products and moreover the gonads growth depressed the digestive tract of fish [7], and stopped food consumption.

In winter, the zooplankton is less abundant, the fish fed a bit less [36] and the emission of eggs reduces the body mass. This slimming ceases with the resumption of food and the condition improves in spring with a more or less important time shift according to the year. The changes of the factor of condition K observed in the Atlantic are related to upwelling indices [29]. The changes of the upwelling periods influences the spawning periods of clupeid species, such as *Sardinella aurita* [37].

5. Conclusion

In fish, the process of senility can lead to a reduction in fecundity or a reduction in the number of spawnings. However, our study showed an increasing evolution of fecundity according to the total length, of the total weight without ovary. Thus, the effect of senility does not appear in the European pilchard, which is an exploited species with short longevity [8,38].

The sardine of the Moroccan Atlantic coast has a maximal spawning rate in winter, season of minimum upwelling and minimum zooplankton production. And it has a low spawning rate in summer, season of maximum upwelling and maximum zooplankton production. In fact, small pelagics adopt a spawning strategy that aims at minimising the losses by advection, in order to reproduce outside the season of maximum upwelling [39].

References

[1] J. Furnestin, M.L. Furnestin, La reproduction de la sardine et de l'anchois des côtes atlantiques du Maroc (saisons et aires de ponte), Rev. Trav. Inst. Pêches Marit. 23 (1) (1959) 79–104.

[2] O. Ettahiri, Étude de la phase planctonique de la sardine, *Sardina pilchardus* (Walb.), et de l'anchois, *Engraulis encrasicolus* (L.) des côtes atlantiques marocaines, thèse, université de Bretagne occidentale, 1996 (262 p.).

[3] S. Kifani, Climate dependent fluctuations of the Moroccan sardine and their impact on fisheries, in: M.H. Durand, P. Cury, R. Mendelssohn, C. Roy, A. Bakum, D. Pauly (Eds.), Global

Versus Local Changes in Upwelling Systems, ORSTOM, Paris, 1998, pp. 235–248.

[4] J.R. Hunter, B.J. Macewicz, Measurement of the spawning frequency in multiple spawning fishes, in: R. Lasker (Ed.), An Egg-Production Method For Estimating Spawning Biomass of Pelagic Fish: Application to the Northern Anchovy, *Engraulis mordax*, NOAA Tech. Rep. NMFS 36 (1985) 79–94.

[5] O. Ettahiri, A. Berraho, G. Vidy, M. Ramdani, T. Dochi, Observation on the spawning of *Sardine* and *Sardinella* off the south Maroccan Atlantic coast (21–26°N), Fish. Res. 60 (2003) 207–222.

[6] H. Belvèze, Biologie et dynamique des populations de sardine (*Sardina pilchardus*) peuplant les côtes atlantiques et proposition pour un aménagement des pêcheries, thèse d'État, université de Brest occidentale, 1984 (531 p.).

[7] J. Lahaye, Les cycles sexuels chez les poissons marins, Oceanis 6 (7) (1980) 637–654.

[8] F. Kartas, J.P. Quignard, La fécondité des poissons téléostéens, Coll. Biol. Milieux Marins, Masson, Paris, 1984 (121 p.).

[9] A. Fontana, Étude de la maturité sexuelle des sardinelles *Sardinella eba* (Val.) et de *Sardinella aurita* C. et V. de la région de Pointe-Noire, Cah. ORSTOM, Ser. Oceanogr. 7 (2) (1969) 101–109.

[10] L.J. Lozano, M.A. Caldentey, J.A. Gonzalez, J. Carrillo, J.I. Santana, Talla de primera madurez sexual de seis esparidos de interes pesquero en Canarias, Inf. Tec. Inst. Esp. Oceanogr. 84 (1990) (30 p.).

[11] J.H. Zar, Biostatistical Analysis, second ed., Prentice-Hall, Englewood Cliffs, NJ, USA, 1984.

[12] G.J. Macchi, M.E. Acha, C.A. Lasta, Desove y fecudidad de la corvina rubia Micropogonias furnieri Desmarest, 1832 del estuario del Rio de la Plata, Argentina, Bol. Inst. Esp. Oceanogr. 12 (2) (1996) 99–113.

[13] J.M. Mendez-Vilamil Mata, J.M. Lorenzo, P. Nespereira Gonzalez, R. Soto Aguilera, Periodo reproductor y madurez sexual de la sardina *Sardina pilchardus* (Walbaum, 1792) en aguas de Gran Canaria (islas Canarias), Bol. Inst. Esp. Oceanogr. 13 (1–2) (1997) 47–55.

[14] A. Garcia, C. Franco, A. Sold, A. Lago, de Lanzos, Sardina (*Sardina pilchardus*, Walb.) daily egg production of the Galicia, Cantabrian and Bay of Biscay waters, ICES C M 1991/H: 37 (15 p., Mimeo).

[15] R. Abad, A. Giraldez, Reproduccion, factor de condicion y talla de primer madurez de la sardina, *Sardina pilchardus* (Walb.), del litoral de Malaga, mar de Alboran (1989 a 1992), Bol. Inst. Esp. Oceanogr. 9 (1) (1993) 145–155.

[16] T. Boely, Étude du cycle sexuel de la sardinelle ronde (*Sardinella aurita* Val. 1847) au Sénégal, Cah. ORSTOM, Ser. Oceanogr. 17 (1) (1982) 3–13.

[17] M. Millán, Reproductive characteristics and condition status of anchovy *Engraulis encrasicolus* L. from the Bay of Cadiz (SW Spain), Fish. Res. 41 (1999) 73–86.

[18] J. Bouchereau, Contribution à l'étude de la biologie et la dynamique de la population exploitée de *Sardina pilchardus* (Walbaum, 1792) dans la baie d'Oran (Algérie), thèse de 3^e^ cycle, université d'Aix–Marseille-2, 1981 (239 p.).

[19] S. Ba Ibrahima, Biologie et dynamique des populations d'anchois (*Engraulis encrasicolus*) des côtes mauritaniennes, thèse de 3^e^ cycle, université de Bretagne occidentale, 1988 (139 p.).

[20] P. Fréon, M. El Khattabi, J. Mendoza, Unexpected reproductive strategy of *Sardinella aurita* of the coast of Venezuela, Mar. Biol. 128 (1997) 363–372.

[21] J.L. Alcazar, J.F. Carrasco, J.A. Llera, M. Mendez, J.A. Ortea, A. Vizcaaino, Aportacion al estudio del besugo en el Principado de Asturias, in: Recursos pesqueros de Asturias, vol. 4, Serv. Publ. Principado de Asturias, Oviedo, 1987 (88 p.).

[22] J. Luo, J.A. Musick, Reproductive biology of the bay anchovy in Chesapeake bay, Trans. Am. Fish. Soc. 120 (6) (1991) 701–710.

[23] J. Zwolinski, Y. Stratooudakis, E. Soares, Intra-annual variation in the batch fecundity of sardine off Portugal, J. Fish Biol. 58 (2001) 1633–1645.

[24] J. Alheit, B. Alegre, V. Alarcon, B. Macewicz, Batch fecundity and spawning frequency of various anchovy (Genus : Engraulis) population from upwelling areas and their estimates, in: Fish. Rep. FAO, United Nations, Rome, 1983, pp. 977–985.

[25] N. Perez, I. Figueredo, C.H. Lon, Batch fecundity of *Sardina pilchardus* (Walb.) of the Atlantic Iberian Coast, Bol. Inst. Esp. Oceanogr. 8 (1) (1992) 155–162.

[26] V.J. Isaac-Nahum, R. Cardoso, G. Servo, C.L.B. Rossi-Wongtshowski, Aspects of the spawning biology of the Brazilian *Sardinella brasilensis* (Steindachner, 1879) (Clupeidae), J. Fish Biol. 32 (1988) 383–396.

[27] J. Alheit, Variation of batch fecundity of sprat, *Sprattus sprattus*, during the spawning season, ICES C M 1987/H: 44, 1987 (6 p.).

[28] C. Conand, Contribution à l'étude du cycle sexuel et de la fécondité de la *Sardinella* ronde, *Sardinella aurita* : pêche sardinière dakaroise en 1975 et premier semestre 1976, Cah. ORSTOM, Ser. Oceanogr. XV (4) (1977) 301–312.

[29] N. Perez, C. Porteiro, F. Alvarez, Contribucion al conocimiento de la biologia de la sardina de Galicia, Bol. Inst. Esp. Oceanogr. 2 (3) (1985) 27–37.

[30] P. Sparre, E. Ursin, S.C. Venema, Introduction to tropical fish stock assessment: Part 1, Manual FAO Fish Tech. FAO, Rome 306 (1) 1989 (377 p.).

[31] R.J. Wootton, Environmental factors in fish reproduction, in: C.J.J. Richter, H.J.T. Goos (Eds.), Reproductive Physiology of Fish, Pudoc, Wageningen, The Netherlands, 1982, pp. 210–219.

[32] M. Le Duff, Cinétique de l'ovogenèse et stratégies de ponte chez les poissons téléostéens en milieu tempéré, thèse, université de Bretagne occidentale, 1997 (170 p.).

[33] J.-A. Tomasini, J.-L. Bouchereau, A. Ben Sahala Talet, Reproduction et condition chez la sardine (*Sardina pilchardus* Walbaum, 1792) des côtes oranaises (Algérie), Cybium 13 (1) (1989) 37–50.

[34] F. Kartas, Les clupéidés de Tunisie. Caractéristiques biométriques et biologiques, étude comparée des populations de l'Atlantique est et de la Méditerranée, thèse d'État, faculté des sciences de Tunis, 1981 (608 p.).

[35] Y. Tsuruta, Reproductive potential of the Japanese sardine and anchovy: two types of fluctuation patterns of population seize, Bull. Fish Oceanogr. Soc. Jpn. 51 (1987) 51–54.

[36] A. Thriot, Les remontées d'eaux (*upwelling*) et leur influence sur la production pélagique des côtes atlantiques du Maroc, Bull. Inst. Sci. Pech. Marit. 22 (1976) 5–12.

[37] C. Roy, P. Cury, A. Fontana, H. Belvèze, Stratégies spatio-temporelles de la reproduction des clupéidés des zones d'*upwelling* d'Afrique de l'Ouest, Aquat. Living Resour. 2 (1989) 21–29.

[38] G.V. Nikolsky, The Ecology of Fishes, Academic Press, London, 1963.

[39] R.H. Parrish, C.N. Nelson, A. Bakun, Transport mechanisms and reproductive success of fiches in the California Current, Biol. Oceanogr. 1 (2) (1981) 175–203.