Biological parameters of *Sardinella aurita* (Valenciennes, 1847) exploited in the Dakhla zone (South Atlantic Morocco)

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Abstract—The monthly sampling of the round sardinella, *Sardinella aurita*, were obtained from small-scale fisheries in the Dakhla area between January and December 2016. The annual sex ratio was 1.33 and in favor of females. It varied according to the size and seasons. The size at first sexual maturity was 26.73 and 27.89 cm respectively for males and females, and the difference between the sexes was not significant. The breeding period was spread over the entire period of study, it was between January and July and November-December. The breeding peak was occurred in the spring (April-May) during the period of high upwelling. The size frequency data were used to estimate von Bertalanffy growth parameters ($L\infty$ = 39.39 cm, k = 0.50 yr-1 and t0 = 0.59 yr). The maximum age and growth performance index ϕ 'calculated were respectively 5 years and 2.90.

Index Terms— Moroccan Atlantic coast, Dakhla zone, *Sardinella aurita*, sex ratio, size of first sexual maturity, reproduction period, growth parameters.

1. INTRODUCTION:

Morocco has a real fishing potential concentrated mainly in the central and southern Atlantic. Small pelagic fish, mainly sardine, mackerel, horse mackerel, anchovy and sardinella species, represent quantitatively the main resources exploited and account for almost 75% of catches. Sardine is the dominant species and accounted for about 69% of the total catch of small pelagic fish in 2016. Catches of round sardinella were around 10,000 tonnes in 2016 [1]. These species are often associated with upwelling systems and have an important socio-economic and ecological role. The study area is characterized by permanent upwelling with intense spring activity and high primary productivity [2]. The round sardinella is a tropical pelagic marine fish with subtropical and coastal planktonophagus moving in schools and carrying out seasonal migrations related to water temperature and plankton richness. Its geographical distribution is very wide, being found in the Black Sea, throughout the Mediterranean, in the eastern Atlantic, from Gibraltar to South Africa (Saldanha Bay), in the western Atlantic, from Brazil to the Gulf, from Mexico as well as in Indo-Pacific (Indonesia, China Sea) [3]. In the North-West Africa region, sardinella have a cross-border distribution and therefore require specific management and regional cooperation to take into account the resource in its cross-border context. They are exploited by riparian countries as well as by fleets from foreign countries. The regional assessment indicated a state of overexploitation for the sardinella stock. Previous work carried out along the Atlantic coast of Morocco on the biology of sardinella is limited to that carried out by [4], [5], [6], [7]. This observation explains the interest in a better knowledge of the biology of this species. This work completes and deepens previous studies. Our study on sardinella biology was conducted to provide biological information used in assessment models, management and stock comparison for this species. This is to ensure the profitability and sustainability of its operation. The objective of this work was to study the reproductive biology of the round sardinella through knowledge of sex ratio, size at first sexual maturity (Lmat) and breeding period. It was also intended to determine the von Bertalanffy growth parameters by sardinella size frequency analysis and to calculate the relationships between the size at first sexual maturity and the asymptotic size: (Lmat / $L\infty$) and between the maximum size (Lmax) and asymptotic size: (Lmax / $L\infty$).

2. MATERIAL AND METHODS

The sardinella studied come from the biological sampling of small-scale commercial landings in the Dakhla area (southern Moroccan Atlantic) during the period from January to December 2016 (Fig. 1). The sampling frequency was monthly and depending on the availability of sardinella. Indeed, sardinella migrate, they are not always available in fishing zones. In addition, the weather conditions are not always favorable for fishing. Data collected included total body length (L) to mm, total body weight (P) and gonad weight (Pg) with an accuracy of 0.01 g. Sex was determined macroscopically.

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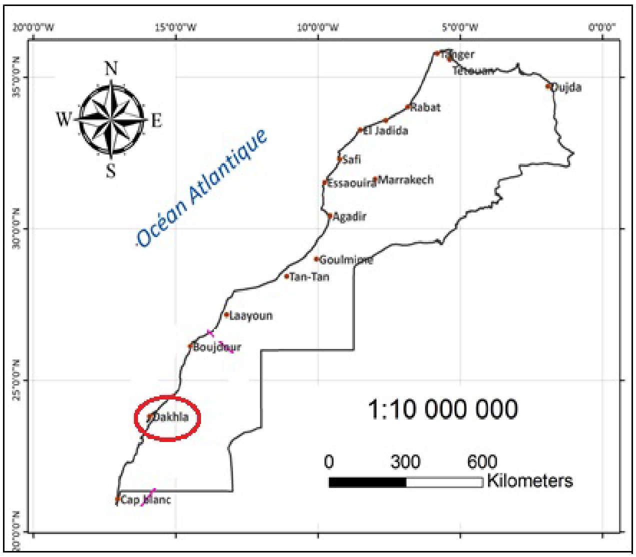

Fig. 1. Study area

The annual sex ratio was the ratio of the number of females to the number of males. The deviation from the 1: 1 null hypothesis was tested statistically by the χ^2 test at the 5% threshold. Sex ratio was also expressed as a percentage of males and females and was analyzed by season and size class.

Length at first maturity (Lmat) was calculated from the percentage of mature individuals (stages 3, 4 and 5) observed during the breeding season. The total length at which 50% of the specimens were mature was estimated by a method based on a symmetric sigmoid logistic regression model [8] whose mathematical expression was as follows: P = 1 / (1 + e- (a + b × L)). Where P: proportion of mature by size class, L: total length, a: intercept and b: slope of logistic regression. Lmat = -a / b. The estimated sizes were compared statistically using an analysis of variance (ANOVA) [9].

The reproductive period was determined by following the monthly evolution of the gonado-somatic index (GSI) coupled with that of the percentages of the stages of sexual maturity. Stages of sexual maturity were assigned according to the five-stage maturity scale (stage 1: immature, stage 2: immature or at rest, stage 3: early maturation, stage 4: egg-laying and stage 5: egg-laying position) for partial breeders defined by [10]. The gonado-somatic index (GSI) was calculated on a monthly basis according to the equation:

GSI = (Pg × 100) / P.

Monthly data of sardinella length frequencies were used to estimate von Bertalanffy growth parameters [11]: growth rate (k) and asymptotic length (L∞). These data were processed by the FISAT II software and the ELEFAN 1 program [12]. The von Bertalanffy growth model (VBGF) used is: Lt = L∞ (1-e-k (t -t0)), where Lt is the total length at age t. The theoretical age at birth (t0) was estimated using the equation of [13]:

log10 (-to) = -0.3922 - 0.275 * log10L∞ - 1.038 * log10K. The longevity of individuals (tmax) was estimated according to the expression: tmax = 3 / k + t0 [14]. The Phi prime Ø test was used to evaluate the reliability of the growth parameters: Ø '= log k + 2 log L∞ [15]. The relationship between the size at first sexual maturity and the asymptotic length (Lmat / L∞) was calculated. As well as, the ratio between the maximum size (Lmax) observed in the samples and the asymptotic size (Lmax / L∞).

3. Results

3.1. Sex-ratio

829 sardinella were analyzed: 309 males, 411 females and 109 individuals whose sex was indeterminate (their size varied between 12.5 and 24.5 cm). The sex ratio of all sizes combined was 1.33 for females and the difference between the sexes was significant (test $\chi^2$0.05 = 3.84). A significant variability in sex ratio between size classes has been shown in Fig. 2. In small size classes between 12 and 24 cm and in large sizes between 33 and 35.5 cm, more than 60% of individuals were females. Males dominated in the intermediate size classes, between 24 and 33 cm except in size class 30-31.5 where a balance between males and females was observed. The difference in sex ratio between size classes was significant (ANOVA test, p <0.05). Similarly, the variability of the sex ratio according to the seasons was significant (ANOVA test, p <0.05). Females dominated during summer and winter. In contrast, males were numerous in spring and autumn (Fig. 3).

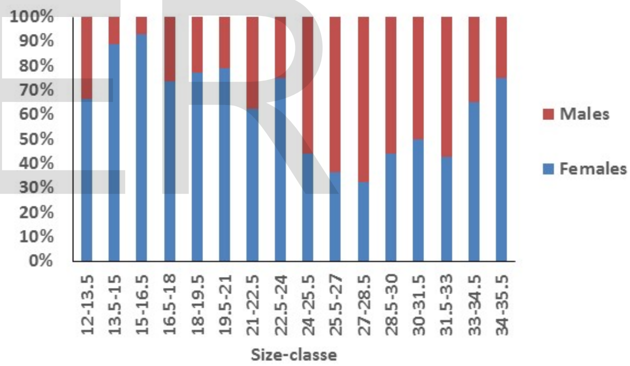

Fig. 2. Sex ratio variation with size classes

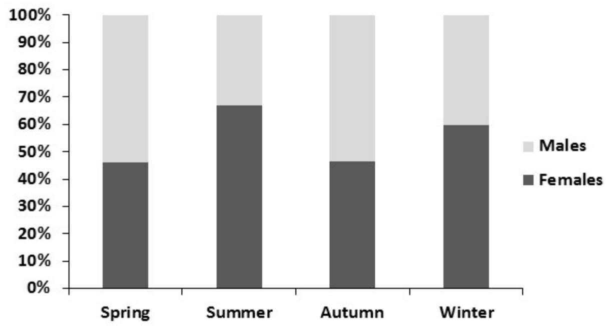

Fig. 3. Evolution of the sex ratio according to the seasons

3.2. Size at first sexual maturity (Lmat)

The sizes at first sexual maturity estimated for males and females were respectively 26.73 and 27.89 cm (Fig. 4). Females reached sexual maturity at a slightly greater size than males and the difference between the sexes was not significant (ANOVA test, $p > 0.05$).

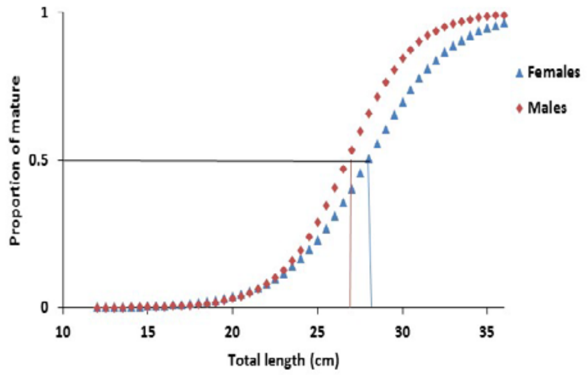

Fig. 4. Sexual maturity of males and females of *Sardinella aurita*

3.3. Stages of sexual maturity

Early sardinella (stage 3) had a high percentage in March (39.5%) and was observed throughout the year excepted samples of June and August. Spawning individuals (stage 4) recorded a significant percentage in February (65.5%) then their percentage decreased to zero in August. In June, 94% of females were post-laying (stage 5) and were met in all months except August. Immature or sexually resting sardinella (1 + 2 stages) dominated in January (91.5%), August (100%) and November (72%) in December (60.8%) (Fig. 5).

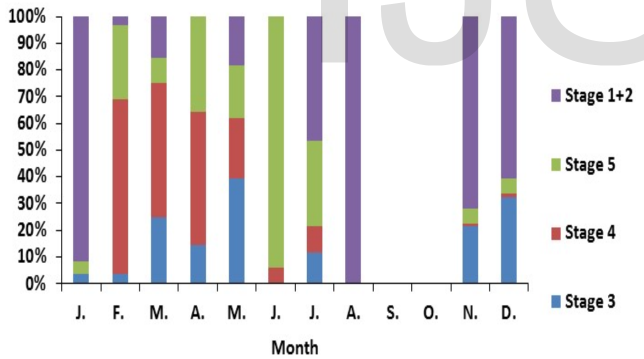

Fig. 5. Monthly changes in sexual maturity stages of *Sardinella aurita*

3.4. Gonado-somatic index (GSI)

The highest mean GSI value (3.92%) was recorded in April and the low values were observed in January (0.16%), August (0.06%), November (0.23%) and December (0.39%). The strong deviations from the mean of the GSI reflected the large difference between individuals in the maturation population and the spawning time (Fig. 6).

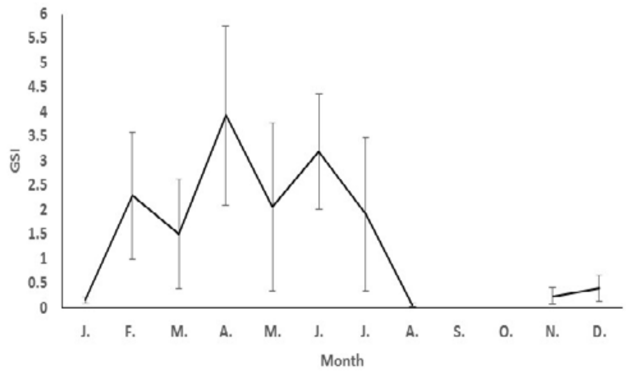

Fig. 6. Monthly fluctuations of *Sardinella aurita* IGS

3.5. Growth

The von Bertalanffy growth parameters estimated for round sardinella were: asymptotic size ($L\infty$ = 39.39 cm), instantaneous growth rate (k = 0.51 yr-1) and theoretical age at birth (t0 = - 0.59 years). The von Bertalanffy equation obtained was as follows:
(Lt = 39.39 (1-e-0.51 (t - (- 0.59)))). The maximum size (Lmax) was 35.5 cm, less than the asymptotic size. The maximum age (tmax) calculated was 5.3 years old. The ratio between the maximum length (Lmax) and the asymptotic length ($L\infty$) was 0.90. The value of the growth performance index ϕ 'was 2.90. The ratios between the sizes of first sexual maturity (Lmat) of males and females and the asymptotic length ($L\infty$) were respectively 0.68 = Lmat / $L\infty$ and 0.70 = Lmat / $L\infty$.

4. Discussion

The round sardinella is a gonochoric species and without sexual dimorphism. The annual sex ratio has been in favor of females. A similar result was reported by [16], [17] respectively in Tunisian and Senegalese waters. On the other hand, a balanced overall sex ratio has been observed in Venezuelan waters [18], the north-east of the Mediterranean [19] and the southern Moroccan Atlantic [7]. The proportion of the sexes varied according to the size classes. The same thing has been reported in this species by [19], [7]. This biological characteristic has been observed in other clupeiformes such as the flat sardinella, *Sardinella maderensis* [20]; Peruvian anchovy, *Engraulis mordax* [21]; anchovies, *Engraulis encrasicolus* from Cadiz Bay [22] and sardine, *Sardina pilchardus* [23]. This dependence of the sex ratio of fish size was related to sexual differences in growth, mortality or reproduction [24]. Also, seasonal variations in the proportion of males and females were observed. Female dominance outside the intense breeding period may be explained by the fact that adult females in intense sexual activity are in areas and / or depths that are not covered by commercial purse seiners [22].
Females of round sardinella reached sexual maturity at a higher height than males. Sexual variations in size at first sexual maturity could be explained by the fact that reproductive energy costs are generally higher for female fish, fecundity and size of eggs increases with female size

[25]. Lmat values close to our observations have been reported for Atlantic round sardinella by [17] (males: 25 cm and females 23.6 cm total length) and [7] (males: 26.78 cm and females 26.17 cm of total length). However, in the Mediterranean the round sardinella reached its sexual maturity at smaller sizes: (males: 14.1 cm and females 15.2 cm total length) [16] and (males: 15.5 cm and females 16.83 cm total length) [19]. The acquisition of sexual maturity could be dependent on environmental factors, genetic and long-term fishing pressure [26], [28].

The monthly monitoring of the average GSI and the stages of sexual maturity showed that the breeding season of round sardinella in the southern Moroccan Atlantic zone spread over the entire period of our study between January and July, and November-December. The breeding peak was occurred in spring (April-May) during the period of high upwelling. This result is consistent with previous work done on the *Sardinella aurita* stock from the Moroccan Atlantic [5], [7]. Also, a period of maximum sexual activity during the period of strengthening of upwelling was found in sardinella from Senegal and Venezuela respectively by [17], [18]. According to [18], the reproductive strategy of this species gives priority to optimizing the availability of spring food. This is a unique nesting strategy for small pelagic. In northwestern Africa, extensive sexual activity over a fairly long period of the year has also been reported [29], [7]. A shorter breeding season was reported in the Alboran Sea [30], [16]) and a very short period of two months in the Aegean Sea [19]. These latitudinal differences in seasonal patterns of reproduction have been related to different temperature regimes [22], [23]. Also, changes in the demographic composition and fishing mortality may influence the seasonality and extent of the breeding season [22], [31], [32]. Other factors such as the presence of several sardinella populations in its range would have an impact on the reproduction of this species [33].

TABLE 1. Von Bertalanffy growth parameters (L∞, k and t0) as well as the maximum size (Lmax), the maximum age (Tmax) and the growth performance index ϕ' observed in different regions of the Mediterranean and the Atlantic. 1, 2 and 3: Methods used (1: Scales, 2: Otoliths and 3: Total length frequencies).

Zones	L∞ (cm)	k (an^{-1})	t0 (an)	Lmax (cm)	Tmax (an)	ϕ'	Authors
Mediterranean							
Aegean Sea1	24.86	0.51	-0.88	24.8	5	2.49	[34]
Tunisia2	31.32	0.24	-2.58	27.35	7	2.27	[16]
Algeria3	34.96	0.24	-0.71	25.5	4	2.46	[35]
Egypt1	25.83	0.29	-0.88	22.52	4	2.29	[36]
Algeria2	M 27.3	0.18	-1.9	24.4	6	2.12	[37]
	F 32.26	0.13	-1.99	25.5	7	2.13	
Atlantic							
Mauritania1	41.63	0.26	-0.87	39.1	8	2.66	[38]
Morocco2	M 33.66	0.97	-0.02	35	5	3.04	[6]
	F 33.72	0.83	-0.34	35.5	5	2.97	
Morocco3	39.39	0.51	-0.59	35.5	5.3	2.90	Present study

The longest life span of round sardinella was 8 years, reported in Mauritania and the lowest was 4 years, observed in Algeria and Egypt (TABLE 1). The longevity of clupeids rarely exceeds 5-10 years [39]. The values of the asymptotic length (L∞) and the maximum length (Lmax) of the sardinella exploited in the southern zone of the Moroccan Atlantic are close to those of the sardinella of Mauritania. On the other hand, smaller values have been observed in the Mediterranean Sea. The highest growth rate (k) was reported for sardinella in Morocco in 2015 and the lowest is estimated in Algeria (TABLE 1). Sardinella from the southern Moroccan Atlantic had the highest growth performance index (ϕ') and was followed by sardinella from Mauritania. Indeed, growth performance in fish depends strongly, among other things, on the quality and quantity of food consumed [40]. In the northwestern African zone, sardinella was characterized by rapid growth. In the first year of life they reached 19 cm and 33.2 cm at the maximum age of 5 years [6]. In the Aegean Sea, the growth rate was average and sardinella reached a size of 15.31 cm at 1 year and 23.61 cm at its maximum age of 5 years [34]. While in the north coast of Sinai, growth was slow and sardinella reached 11.7 cm at 1 year and 20.3 cm at its maximum age of 4 years [36]. The growth differences observed in the Mediterranean and Atlantic populations of Round Sardinella could be explained by the environmental differences between the Mediterranean Sea and the Atlantic Ocean: the temperature of the water, the degree of salinity and the pronounced oligotrophy of the sardinella in the Mediterranean [41]. Upwelling areas such as northwestern Africa are characterized by cold waters and high primary production [2]. Other factors could include cannibalism and predation as well as interspecific competition between many species with the same biotope as sardinella (sardines, mackerel, anchovies, etc.) and which results in a reduction of food resources and therefore a decrease in growth. These differences could result from the genotype-phenotype relationship given the isolation of the breeders. High-growth individuals probably had a particular genotypic structure [33]. Other processes could intervene and cause differences in growth between areas such as: density-dependence and mortality by size [42]. This variability in growth between different regions probably resulted from the heterogeneity of the methods used (otoliths, scales and size frequency data) or age readings that were not uniform (TABLE 1). Thus the comparison of the results became difficult.

The maximum length (Lmax), the asymptotic size ($L\infty$) and the size at first sexual maturity (Lmat) are important parameters of the life cycle [43]. The ratio (Lmax / $L\infty$) varied between 0.56 and 1.34 with an average value of 0.90 for 103 Greek marine fish stocks [43]. A value similar to the average calculated by [43] was found in the round sardinella of the Dakhla zone (0.90). The ratio (Lmat / $L\infty$) for 165 stocks recorded in Fish-Base 98 varies from 0.18 to 0.97 with an average value of 0.56 [43]. These values are somewhat higher than those of the Hellenic stocks (between 0.33 and 0.47 with an average value of 0.49) and may indicate that the relative length at maturity of the Hellenic fish is lower [43]. The values of the ratio (Lmat / $L\infty$) calculated for the males (0.68) and females (0.71) of round sardinella in the southern Moroccan Atlantic zone were within the range indicated for 165 stocks recorded in Fish-Base 98 but they were superior to those of the Hellenic fishes [43].

5. Conclusion

Knowledge of biological parameters is essential for a good analysis of population dynamics, for stock assessment and management. Life cycle parameters tend to reflect the environment occupied by a stock due to their sensitivity to extrinsic variables [44], but do not provide any information about the genetic makeup of a stock [25]. The life cycle parameters of many marine fish stocks vary in response to changes in environmental conditions. These fluctuations can affect fish physiology and the abundance and density of their food source [45]. Similarly, increased fishing can influence temporal and spatial trends in life cycle parameters. In fact, high fishing pressure can lead to a decrease in biomass, predator abundance, a decrease in maximum size (fewer older individuals), a decrease in growth and a maturing rate in the stocks of fishes [46]. The sardinella, *Sardinella aurita* has a remarkable plasticity and adaptability to the fluctuations of the environment from which it takes advantage [29].

6. References

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