International Journal of Fisheries and Aquatic Studies 2016; 4(1): 165-171

ISSN: 2347-5129
(ICV-Poland) Impact Value: 5.62
(GIF) Impact Factor: 0.352
IJFAS 2016; 4(1): 165-171

www.fisheriesjournal.com
Received: 13-11-2015
Accepted: 14-12-2015

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Demographic parameters and exploitation rate of *Sardinella maderensis* (Pisces: Lowe 1838) in the nearshore waters of Benin (West Africa) and their implication for management and conservation

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Abstract
Most fisheries in Africa are overexploited or are at the peak of exploitation. A key contributor to this overfishing is poor data on fisheries, inefficient management strategies and unenforced policies. This paper deals with growth, mortality parameters and the exploitation rate of *Sardinella maderensis* collected between August 2012 and July 2013 from the nearshore waters off Benin to contribute to sustainable management of this fishery. Growth parameters and performance index φ' estimated based on the von Bertalanffy model using routine ELEFAN$_I$ FiSAT gave the asymptotic length $L\infty$, the growth coefficient K, the theoretical age at length zero and the performance index φ' 33.6 cm, 0.65 per year, 0.24 per year, and 2. 86 per year respectively. *S. maderensis* grew isometrically with an abundance of medium size specimens. This species recruits twice a year indicating probably two spawning periods. The estimated average value of instantaneous rate of total mortality was 3.92 per year, natural mortality was 1.30 per year, giving fishing mortality of 2.62 and the rate of exploitation (E = 0.67) showing an overexploitation of the stock of this species. Several immediate management actions, such as size-limit regulation by gradually increasing fishing gears mesh size and time-limit regulation by restricting fishing during the spawning seasons and in nursery areas, are considered necessary for sustainable exploitation and conservation of this species.

Keywords: *Sardinella maderensis*, growth parameters, mortality, recruitment patterns, conservation

1. Introduction

Marine artisanal fisheries are practiced in the inshore waters below five miles [1]. 75% of the catches are mainly composed of pelagic species of which 60% are some small pelagic inshore species. Among these species are some Clupeids (*Sardinella maderensis*, *Ilisha africana*, *Sardinella aurita*), Engraulid (*Engraulis encrasicolus*). Indeed the species of the genus *Sardinella* represent an important part in landings of the Beninese marine artisanal fisheries (16.23% comprising 96% of *Sardinella maderensis* for 4% of *Sardinella aurita*) [1]. The production of these species increased from September to November with a marked pick in November [1]. Compared to the round Sardinella, adults of flat Sardinella are distinctly more sedentary [2]. *Sardinella maderensis* is widely distributed in two of the four fishing strata of Benin's coast [1]. Observations made on the Ivory Coast coastline allow to conclude that for *Sardinella maderensis* the period of genesis activity appears throughout the year with a strong reduction from May to July (transition warm season, cold season) [3]. *Sardinella maderensis* is recognizable by the following characters. The body is lengthened to a variable height. The dorsal fin possesses 18 to 21 rays, the anal fin, 17 to 23 rays and the ventral fin 8 rays. Scales are cycloids and the lateral line counts 44 to 47 scales. The bottom part of the first gill rakers possesses 70 to 166 branchiospines. Maximal observed size was 300 mm, standard length [4]. Morphometric parameters are essential for fishery management decisions [5]. The fundamental parameters are the length-weight relationship, growth according to age, mortalities, the exploitation rate and the factor of condition [6]. Data on age and growth are especially important to describe the status of a population of fish and to predict the potential output of fishing. These two parameters facilitate the evaluation of production, size of stock, recruitment and mortalities [7]. Mortality of fish is caused by several factors that include age [8], predation [9], environmental stress [10], interferences and illnesses [11] and fishing activity [8].

The considerable contributions on studies of fish growth have been made [12, 13, 6, 14] but these studies have been conducted on moderate country stocks. The statistical models of stock assessment are conceived for the evaluation of natural mortality [15, 16]. Most of these models use sampled fish size frequency distribution. While considering the method of distribution of size frequency of Peterson for tropical fishes, there were some considerable contributions [17, 14, 18]. In spite of these efforts, data related to length-weight, growth, and mortality and exploitation rate of many tropical fish species miss again. The rate of exploitation is an indication that appraises the level of utilization of a fishery. The value of this rate lies in the fact that the Maximum Sustainable Yield (MSY) is optimized when the coefficient of fishing mortality is equal to natural mortality [19, 20]. Affirms that the knowledge of the biological parameters of the exploited fish species is an essential tool in the assessment of fish stock and for a good understanding of the dynamics of exploited fishery resources. The most recent assessment of stocks of Beninese demersal coastal fishes has been carried out in 1990 [21, 22]. These findings constituted the basis of the first management plan for maritime fisheries in Benin [23]. Recent studies revealed that the stocks of *P. typus* and *P. senegalensis* in Benin were overexploited [24]. This study which addresses some aspects of the growth, mortality and exploitation rate of *S. maderensis* of the nearshore waters off Benin aims to provide a better basis for management decisions to be taken for this fishery.

2. Methodology

2.1. Study area, fish sampling and data collection

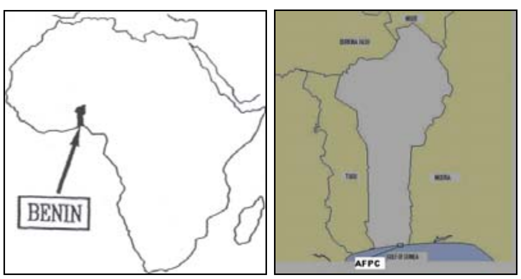

Fig 1: Location of the sampling site

1,548 specimens of *S. maderensis* were collected on a monthly basis from August 2012 to July 2013, from commercial landed capture at the marine artisanal fishing Port of Cotonou (AFPC) (Fig. 1) where more than 75% of total annual production is landing. About 130 specimens were selected randomly to measure the total length (TL), the standard length (SL) and the fork length (FL) to nearest 0.1cm and the ungutted body weight (W) to nearest 0.1g.

2.2 Population structure and sex ratio

Size frequency was analyzed at a 2 cm interval length class using a histogram to determine the type of distribution, which characterizes the fish population. The fluctuations of the sex ratio according to fish size provide a useful tool to examine the biological characteristics of the fish species, such as sexual inversion, longevity in relation to sex, vulnerability to fishing gear and the spatial, seasonal and even daily distribution of species. With the numerical abundance by sex, the following ratio was computed [25]:

Sex-ratio S-R = 100 x number of males/number of females

2.3 Length–weight relationship

The length-weight relationship was determined by the following allometric equation $we = aSL^{b}$ [6], where we is the gutted weight (We, g), SL is the standard length (SL, cm) and "a" and "b" are intercept and slope of the regression curve of the length and weight of the fish, respectively. The correlation (r^2), which is the degree of association between length and weight, was computed from the linear analysis.

Paired sample t-test within SPSS software version 16.0 was used to compare "b" to 3, and a Pearson correlation was used to test the significance of all regressions.

2.4 Growth and mortality parameters

The asymptotic length ($L\infty$) is the theoretical maximum length that the species would reach if it lived indefinitely, and the growth coefficient (K) is a measure of the rate at which the maximum size is attained [26]. Monthly length frequency distribution data were used to estimate $L\infty$ (cm) and growth coefficient K ($yr-1$), which can be calculated following the equation [27]: $Lt = L\infty[- \exp(-K(t- t_0))]$.

The ELEFAN routines incorporated in the FiSAT software [28] were used to determine $L\infty$ and K following the Powell–Wetherall method [29]. This method was used to provide an initial estimate of $L\infty$. This initial estimate of $L\infty$ was later used as a seed value to determine the value of K [30]. Minor adjustments to $L\infty$ and K were made to maximize the "goodness of fit" criterion built into ELEFAN [31]. The theoretical age at length zero (t_0) was estimated using Pauly's empirical equation [32]: $Log_{10}(-t_0) = -0.392 - 0.275\ Log_{10}(L\infty) - 1.038\ Log_{10}(K)$. The inverse von Bertalanffy growth equation [33] was used to find the lengths of the fish at various ages. The estimates of $L\infty$ and K were used to compute the φ' (in terms of length) of the species [34, 35]: $\varphi' = Log_{10}(K) + 2Log_{10}(L\infty)$. The fitting of the best growth curve was based on ELEFAN I [36], which allows the fitted curve through the maximum number of peaks of the length–frequency distribution. The annual instantaneous rate of total mortality, Z, was estimated by constructing linearized length-converted catch curves [33]. Instantaneous natural mortality rates, M, were computed using the empirical equation [33] and a mean annual surface temperature (T) of 27.9 ◦C as described below:

$Log_{10}(M) = -0.0066 - 0.279\ Log_{10}(L\infty) + 0.6543\ Log_{10}(K) + 0.463\ Log_{10}(T)$. The instantaneous fishing mortality rate, F, was calculated as Z–M, and the exploitation ratio (E) was $E = F/Z$ [25].

2.5 Probability of capture and length at first capture (LC or $L_{50\%}$)

The probability of capture provides a clear indication of the estimated real size of fish in the fishing area that are being caught by specific gear. Probability of capture is also an important tool which enables fishery managers to determine what should be the minimum size of the target species of a fishery. The probability of capture was estimated by backward extrapolation of the descending limb of the length converted catch curve. A selectivity curve was generated using linear regression fitted to the ascending data points from the plot of probability of capture against length, which was used to estimate the final value of L_{25}, L_{50} and L_{75} (i.e., lengths at which 25%, 50% and 75% of the fish will be vulnerable to the gear, respectively). Estimates of length-at-first capture (L_{50}) were derived from the probabilities of capture generated from the catch curve analysis output by FiSAT.

2.6. Longevity (t_{max})
The value of the mean coefficient of growth K has been used to generate longevity as shown by the formula: $\mathbf{t_{max} = 3 / K}$ [25].

2.7. Exploitation rate
The exploitation rate (E) was derived by FiSAT from the linearized length-converted catch curve of each species.

3. Results
3.1. Population structure and sex ratio
A total of 1,548 specimens were sampled comprising 735 males and 813 females (Table 1). The population size structure of *S. maderensis* (Fig. 2) shows a bimodal distribution with respective modal classes at 18.0-20.0 cm and 24.0-26.0 cm. Pooled sample shows that females were slightly numerous than males (S-R = 90%) (Table 1).

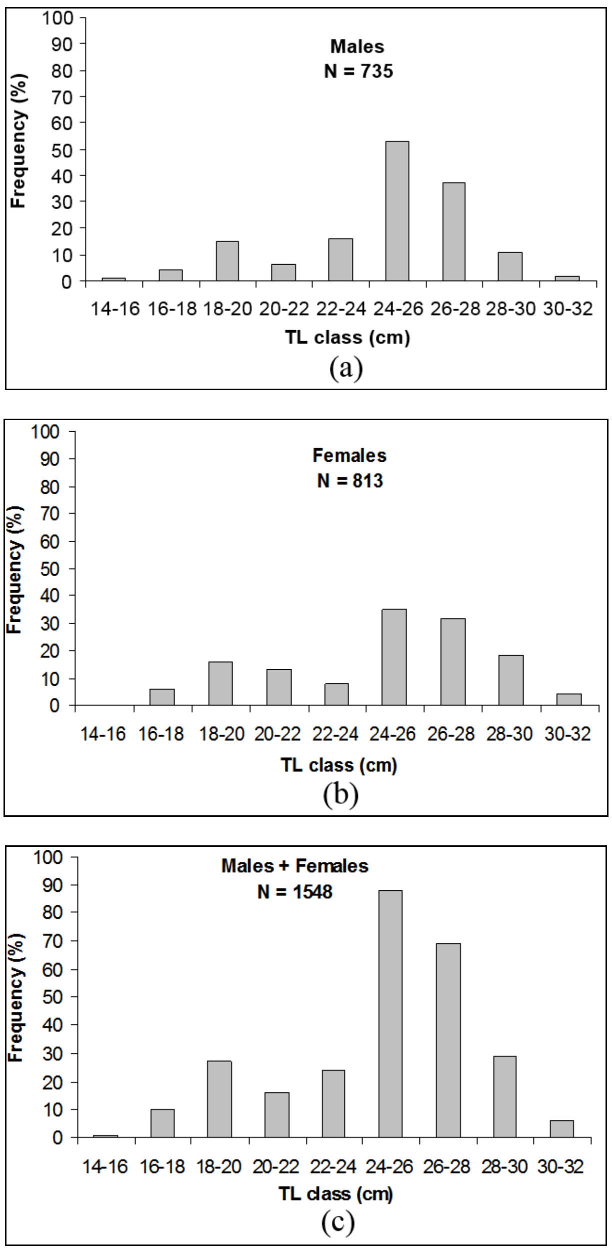

Fig 2: Size structure of males (a), females (b) and both males and females (c) of *S. maderensis* off Benin's nearshore waters

Table 1: Mean Fork length (FL), mean gutted weight (We), number of specimens (N) and sex ratio (S-R) of *S. maderensis* off Benin's nearshore waters

	N (S-R)	Mean FL (cm) (range)	Mean W (g) (range)
Males	735	16.8 (12.1-21.5)	107.95 (34.3-181.6)
Females	813	17.4 (12.4-22.4)	127.5 (39.0-216.0)
Males + Females	1,548 (90.40%)	17.25 (12.1-22.4)	125.5 (34.6-216.0)

3.2. Length-length and Length-weight relationships
Total length- fork length relationship as well as Total length-standard length relationships (Fig. 3) show a strong correlation between total length and fork length (r^2 = 0.96) and between total length and standard length (r^2 = 0.95).

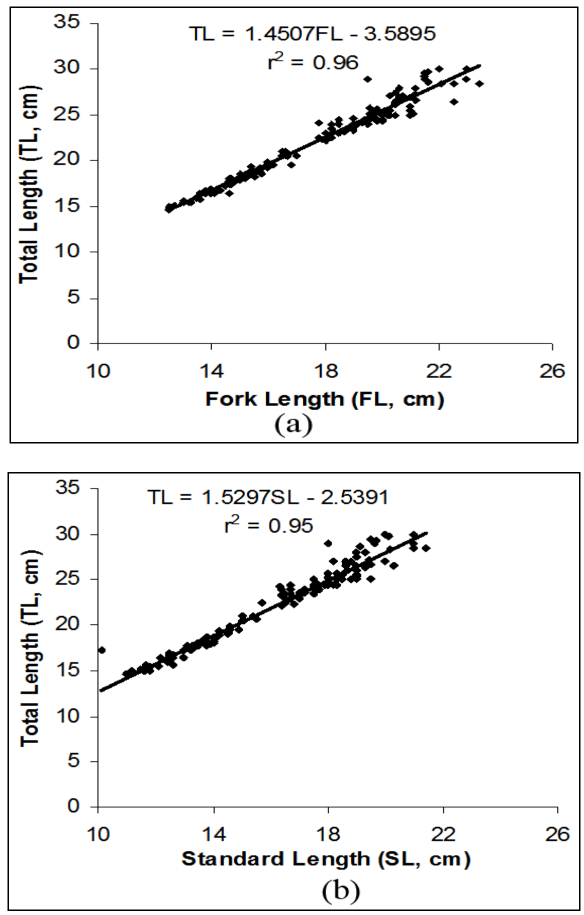

Fig 3: Total length-Fork length (a) and Total length-Standard length (b) relationships of *S. maderensis* off Benin nearshore waters

The results of the length–weight analysis of *S. maderensis* by gender are reported in Table 2. There is no significant difference between males and females in the length–weight regressions ($p > 0.05$). The respective length–weight relationships for males, females and pooled samples are presented in Fig. 4. The ungutted body weight (W) was strongly correlated with fork length (FL) (r^2 = 0.93) for pooled samples. The slope "b = 2.86", was not significantly different from "3" (t-test, $p > 0.05$). This result implies that *S. maderensis* grew isometrically in Benin's nearshore waters.

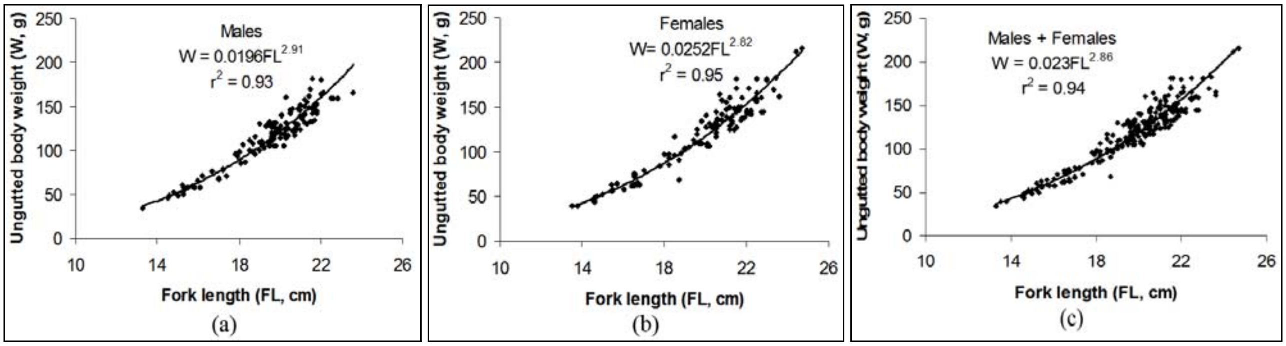

Fig 4. Length-weight relationships for males (a), females (b) and both males and females (c) of *S. maderensis* off Benin's nearshore waters

Table 2: Length–weight relationship parameters of males, females and both males and females of *S. maderensis* off Benin's nearshore waters

Gender	DF	Slope	95% CI	r^2	Intercept	95% CI
Males	734	2.91	2.87 –2.96	0.93	0.0196	0.0188 – 0.0199
Females	812	2.82	2.78 – 2.85	0.95	0.0252	0.0249 – 0.0255
Males + Females	1546	2.86	2.84 – 2.88	0.94	0.0230	0.0227 – 0.0234

$P < 0.001$ for all regression slopes.

3.3. Growth and mortality parameters (M, F and Z)

(Fig. 5) shows the linearized length-converted catch curve which enabled estimation of the average annual instantaneous total mortality rate, Z, as 3.92 yr^{-1}. The estimated instantaneous fishing mortality rate F = 2.62 yr^{-1}, is beyond the double of the estimate of the rate of natural mortality (M) of 1.30 yr^{-1} and could reflect an overexploitation of the fish stock.

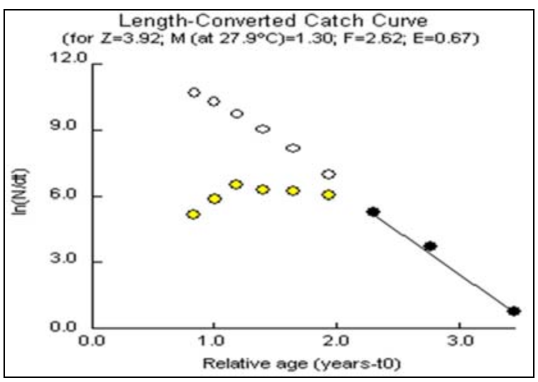

Fig 5. FISAT output of linearized length-converted catch curve for *S. maderensis* off Benin's nearshore waters.

3.4. Recruitment patterns

The recruitment patterns were decomposed using NORMSEP and fitted with up to two Gaussian generated by groups of starting estimation (in months) $g_1 = 6.64$ and $g_2 = 15.34$ output Fig. 6 and Table 3.

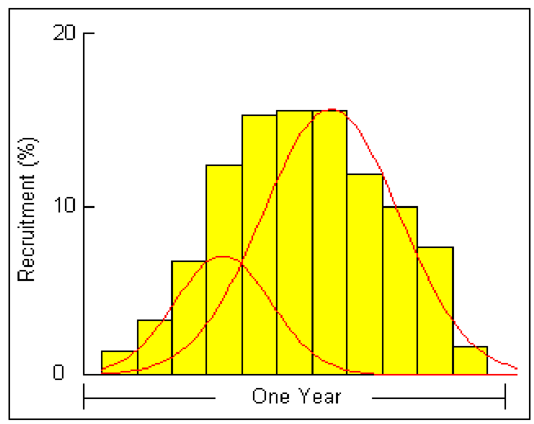

Fig 6. FISAT output of recruitment patterns of *S. Maderensis*

Table 3 Percent recruitment per month

Relative time	Aug 12	Sep 12	Oct 12	Nov 12	Dec 12	Jan 13	Feb 13	Mar 13	Apr 13	May 13	Jun 13	Jul 13
Percent Recruitment	1.4	3.0	6.6	12.4	15.2	15.4	12.4	11.7	9.7	7.6	6.4	1.6

3.5. Estimation of growth parameters (L_∞, K, t_0) from length frequency data

The length frequency distribution with the superimposed growth curve output for the eighteen successive months from the FiSAT analyses is shown for *S. maderensis* in Fig. 7.

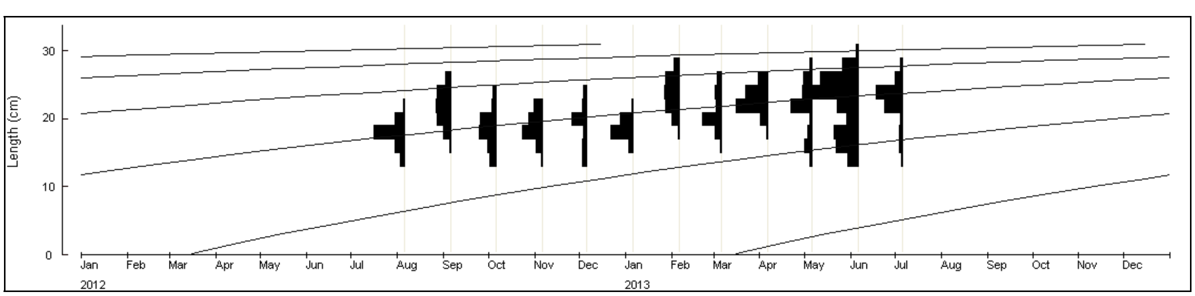

Fig 7: Length frequency distribution output from FiSAT with superimposed growth curves for *S. maderensis* off Benin's nearshore waters.

Estimated growth parameters of *S. maderensis* off Benin's nearshore were respectively TL∞ (cm) = 33.6, K (yr^{-1}) = 0.65, t_0 = 0.24 (yr) andφ' = 2.86. The equation of von Bertalanffy function of this species becomes TL = 33.6{1 – exp [-0.65(t-0.240)]}. The lengths of the fish at various ages are presented in Table 4. This fish species attain at least 50% of the asymptotic length in the second year class, indicating rapid growth in length at the early age class.

Table 4: Calculated age-length data for *S. maderensis* on their von Bertalanffy growth equation

Year class (yr)	TL (SL) (cm)	%TL∞
1	13.01 (9.97)	38.98
2	22.90 (16.72)	68.14
3	28.01 (20.20)	83.36
4	30.68 (22.06)	91.31

3.6. Probability of capture and length at first capture (Lc or $L_{50\%}$)

(Fig. 8) shows the probability of capture of 25%, 50% and 75% of fish individuals and gives the length at first capture as 21.6 cm, 23.8 cm and 24.8 cm respectively.

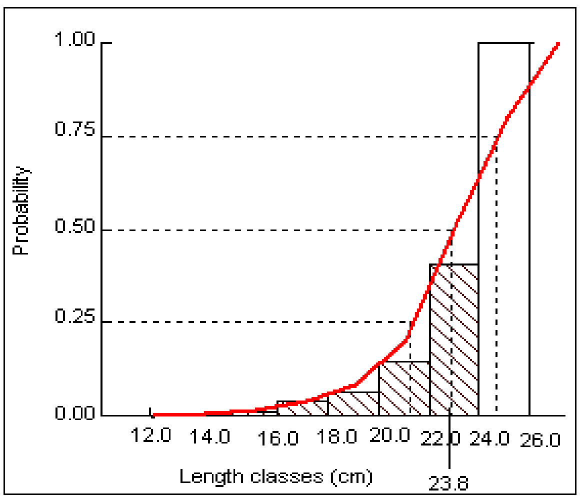

Fig 8. FISAT output of probability of capture and length at first capture

3.7. Longevity (t_{max})

The longevity of this species was t_{max} = 4.61 yrs and the natural instantaneous mortality M is 1.30 yr^{-1}. Based on the results in Cameroon [37] where the natural mortality M of this species was 0,75 $yr^{-1}$and longevity was 6.25 yrs, it is possible to conclude that weaker the natural mortality rate is and greater is the longevity.

3.8. Exploitation rate (E)

The exploitation rate (E) derived by FiSAT from the linearized length-converted catch curve of *S. maderensis* species off Benin's nearshore waters was E = 0.67.

4. Discussion

4.1. Population structure, sex ratio, recruitment patterns and probability and length at first capture.

The population structure of *S. maderensis* was bimodal, indicating probably the existence of two cohorts within the population. This hypothesis is well confirmed by the two groups shown by the recruitment patterns indicating probably two spawning periods for this species per year. The estimated theoretical maximum length of (TL∞ = 33.6 cm) suggests that the stock of *S. maderensis* being exploited in the nearshore waters off Benin consists of relatively smaller-sized individuals. Larger specimens reaching TL = 43 cm have been reported in Nigeria [38]. The length-at-first sexual maturation (L_{50}) of *S. maderensis* reported in Nigeria was 19.10 cm for males and 17.43 cm for females. Comparing these values with the length of the first capture in the present study, it appears that *S. maderensis* off Benin nearshore waters reaches the size of first sexual maturation before its first capture. Females were slightly numerous than males as reported in Senegal [2] and in Cameroon [39]. Variations of the sex ratio according to size have a considerable impact on the fertility of stocks according to whether the adult individual majority captured is female or male. However, the sex ratio is influenced by many factors. The difficulties of determining the sex of immature and hermaphrodite individuals could greatly affect the proportion of males and females obtained [40, 41].

4.2. Length-length and Length-weight relationships

In this study, the length-weight (according to sampling time) and length-length (overall) relationships of *S. maderensis* was estimated off Benin's nearshore waters. The length-length relationships were significantly linear. Significant linear relationships among TL, FL and SL in some fish species were also found [42]. These significantly linear relationships among the length parameters showed that certain fish species exhibited characteristic morphological features [43]. The value of "b" in the length–weight relationship should be exactly "3" if the growth is isometric [6]. This cube law relationship is hardly expected, as most of the species change their shape [44]. These changes are due to sex, maturity, season and even the time of day due to stomach content [45]. *S. maderensis* in the present investigation shows an isometric growth, which implies that the fish length increases in equal proportion with fish body weight for constant specific gravity. However, this isometric growth pattern reported in Mauritania [46, 47] does not agree with the results reported in Senegal [48] and in West Africa [49], as reported in Table 5. The "b" values found by these authors were higher than those in the present investigation, perhaps due to the dominance of juveniles in the artisanal gears. The coefficient of correlation between fork length and ungutted body weight (Fig. 3) was found to be highly significant (Pearson correlation, p = 0.005 at 5% level of significance).

Table 5 Length–weight relationships derived by other authors.

Authors	Countries	W-L relationship
Current study	Benin	$W = 0.0230FL^{2,86}$
[46]	Mauritania	$W = 0,0180FL^{2,83}$
[47]	Mauritania	$W = 0,0098FL^{3,18}$
[48]	Senegal	$W = 0,0093FL^{3,17}$
[49]	West Africa	$W= 0,0130FL^{3,14}$

4.3. Growth, mortality parameters (M, F and Z) and longevity

According to literature (Table 6), the value of asymptotic length in the present survey is close to what was reported in Cameroon [50] and higher than what was reported in the Nigerian waters [38], and in Congo [51]. The difference in these results could be explained by the diversity of methods used for the assessment of growth parameters, the sensitivity of the Von Bertalanffy model using keys such as age-length, as well as the quality of the sampling. *S. maderensis* grows rapidly beyond 50% of asymptotic length in the second year class. Indeed, the individual growth is conditioned by features of the reproduction of the species, that spread all year round or with one or two peaks per year; thus, the area and the period of spawning (temperature, food availability) would be determinant factors of the individual growth. The value of the growth performance index of *S. maderensis* in the current investigation (φ'= 2.86) is close to what was reported in Senegal [52] (φ' = 2.88) (Table 5) and higher than what was reported by other authors in Cameroon [38, 53]. The growth performance index could be assigned to important food availability and other favorable environmental conditions. Total instantaneous mortality of *S. maderensis* in this investigation (Z = 3.92 yr^{-1}) was higher than the range of 0.7 to 2.12 reported in Pointe-Noire (Congo) [54] and in Cameroon [53] (Z = 0.84 yr^{-1}). Differences between these evaluations could be assigned to several factors that affect the determination of mortality through the population structure. Among these could be cited the variations of lengths of the fish individuals in the same cohort [53]. The value of M = 1.36 yr^{-1} in this survey is extremely lower than what was reported in Sierra Leone M = 4.22 yr^{-1} [55] for *S. maderensis*. Differences in instantaneous natural mortality (M) are probably due to the fact that *S. maderensis* in Benin's nearshore waters is not easily available for predators or doesn't die easily from natural factors such as illness and life in an environment of great productivity. The longevity of this species was t_{max} = 4.61 yrs and the natural instantaneous mortality M is 1.30 yr^{-1}. Based on these results and on what was reported in Cameroon [53] (natural mortality M = 0, 75 $yr^{-1}$and longevity = 6.25 yrs), it could be concluded that the weaker the natural mortality rate the greater the longevity.

Table 6 Estimated growth parameters of *S. maderensis* off Benin's nearshore waters compared to those off other regions.

Authors	Countries	TL∞ (cm)	K (yr^{-1})	φ'	t (yr)
Current study	Benin	33.60	0.65	2.86	0.240
[37]	Cameroon	27.24	0.48	1.76	-0.060
[38]	Nigeria	37.50	0.34	2.68	-0.250
[50]	Cameroon	32.50	0.59	2.79	N/A
[52]	Senegal	35.00	0.60	2.88	N/A
[56]	Congo	24.93	0.98	2.79	0.024

N/A: Non Available

5. Conclusion

The stock of *S. maderensis* in the nearshore off Benin is over-exploited. Several immediate management actions, such as size-limit regulation by gradually increasing fishing gears mesh size and time-limit regulation by restricting fishing during the spawning seasons and in nursery areas, are considered necessary for sustainable exploitation and conservation of this species.

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