

1 **Population Dynamics and Stock Status of the Round Sardinella (*Sardinella aurita*,**
2 **Valenciennes, 1847) in the Coastal Waters of Côte d'Ivoire (West Africa).**

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3
4 **ABSTRACT**

5 This work was carried out to fill for a short time the lack of available data on the dynamic of
6 *Sardinella aurita* within Côte d'Ivoire's coastal waters. A total of 2000 samples of *S. aurita*
7 were collected from April 2022 to March 2023, measured for total lengths and examined using
8 FISAT II. The asymptotic length (L_{∞}) and growth rate (K) were 31.50 cm and 0.78 year⁻¹
9 respectively implying that this species is a fast-growing and a short live species. The lengths at
10 first maturity and first capture were estimated at 18.49 cm and 23.42 cm respectively. ~~Natural~~
11 ~~The natural~~ mortality rate ($M=1.49$ year⁻¹) was higher than ~~the~~ fishing mortality rate
12 ($F=0.61$ year⁻¹). The recruitment trend was continuous throughout the year with two major peaks
13 showing the presence of strong recruitment into the stock. However, the exploitation rate
14 ($E=0.29$) was lower than the 0.5. Furthermore, using the Quadrant rule, the investigated stock
15 was categorized as underexploited. However, the current exploitation rate is higher than $E_{0.5}$
16 inviting us to be more careful and to take appropriate measures.

17 **Keywords:** Growth, Mortality, pelagic fisheries, *Sardinella aurita*, Côte d'Ivoire.

18
19 **1.INTRODUCTION**

20 Pelagic fish can be categorized as coastal and oceanic fish based on the depth of the water they
21 inhabit. *Sardinella aurita* known as the round sardine is a coastal pelagic species with ~~the a~~
22 preference for saline waters. It is a cold-water species preferring temperatures between 18-25°C
23 [1]. Indeed, the concentration of the species near the surface is highly variable and relies on the
24 variability of the coastal upwelling intensity [2]. The round sardinella is found along the West
25 African Coast from the Mediterranean to Cape Frio (18°S). In the Eastern Central Atlantic, the
26 species is found abundantly in the Gulf of Guinea [3] where its feeds on zooplankton
27 particularly copepods and mysid larvae, but sometimes phytoplankton especially by juveniles
28 [4]. Fish stocks in many parts of the ~~word-world~~ are declining. Unfortunately, the stock of
29 *Sardinella aurita* in ~~the~~ coastal waters of Côte d'Ivoire, is not exempt ~~of from~~ this sad reality.
30 ~~In addition, catches of the species decreased from 50000 tons in 1979 to around 13964,761 tons~~
31 ~~in 2018 [5].~~ Despite this reduction in total catches, *Sardinella aurita* remains very important

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32 because it is ranked among the main ones for purse seines fisheries [6], beach seines and gillnets
33 fisheries [7]. Its importance is also justified by both an economic point of view and a purely
34 food security point of view. Consequently, *S. aurita* fisheries like other commercial fisheries
35 have for sometimes been subject to intense fishing pressures to meet increasing demands. In
36 addition, within the coastal waters of Côte d'Ivoire, the publish limited information available
37 on the population parameters of the species which is crucial to the issue of food security slows
38 down for a while any measure of sustainable management of this resource. Thus, the present
39 study aims to estimate the population parameters of the species with a view to its sustainable
40 management.

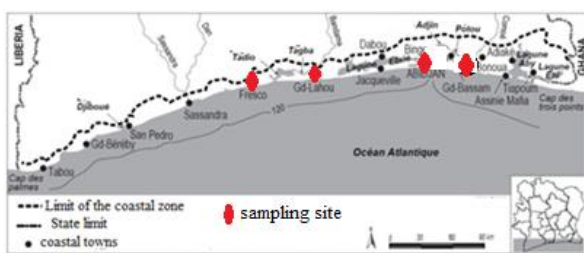
41 2. MATERIAL AND METHODS

42 2.1. Study area

43 Sampling zones were chosen based on the fishing activity intensity (Abidjan, Grand-Bassam,
44 Fresco and Grand-Lahou) [figure-Figure 1](#).

45 2.2. Data collection

46 Data were collected from fishermen chosen randomly and using various fishing gear notably
47 gillnets, purse seines and beach seines. Each specimen in the catches was identified to the
48 species level using [8] identification key. Then each individual was measured for its total length
49 (Lt) to the nearest 0.1 cm by using a fish ruler and weighed to the nearest 0.01g using an
50 electronic scale model FEL-500S. In all, a total of 2000 samples of *Sardinella aurita* were
51 assessed from march April 2022 to March 2023 (i.e 12 months).



52

53 **Fig.1:** Map showing the fish landing locations ([Insert the source](#)).

54 2.3. Data analysis

55 FiSAT II software [9-] was used for data analysis. In addition, for the sake of harmonious
56 processing, the size frequency data were grouped into intervals of 2 cm in length.

57 2.3.1. Growth parameters

58 In a large number of fish, growth occurs according to the [10] and is described by the following
59 equation: $L(t) = L_{\infty} * (1 - (e^{-k(t-t_0)}))$.

60 The theoretical age (t_0) was calculated using the following equation:

$$61 \log_{10} (-t_0) = -0.3922 - 0.275 \log_{10} L_{\infty} - 1.0381 \log_{10} K \text{ [11]}$$

62 Then the longevity (T_{\max}) of *Sardinella aurita* was determined as follows:

$$63 T_{\max} = 2.9957/K + t_0 \text{ [12]}$$

64 The growth performance index (ϕ') was determined with this equation: $(\phi') = 2 \log_{10} L_{\infty} +$
65 $\log_{10} [13]$.

66 2.3.2. Mortality rates

67 Several methods are used to evaluate total mortality from size distributions. The catch curve
68 method is widely used and gives satisfaction [12]. Indeed, the history of catch
69 curve technique in determining mortalities dates back to the late nineteenth century. The
70 technique relies on assumptions that recruitment and mortalities are constant over the
71 years.

72 The natural mortality (M) was determined by the following equation:

$$73 \log_{10} M = -0.0066 - 0.279 \log_{10} L_{\infty} + 0.6541 \log_{10} K + 0.4634 \log_{10} T$$

74 with T: the mean water temperature in (°C).

75 Fishing mortality (F) was estimated by the equation below

$$76 F = Z - M$$

77 2.3.3. Length at first capture (Lc50) and first sexual maturity

78 The determination of the size at first capture was made par the probability of capture curve and
79 corresponds to the length Lc at which 50% of the individuals are retained by the fishing gear.

80 The left ascending part of the length converted catch curve was used to estimate the probabilities

81 of capture at 50, 75, and 25 which correlates with the cumulative probability at 50, 75 and 25
82 percent, respectively [14]. The age at first capture was then determine as:

$$83 \quad t_{c50} = -1/K * \ln (1-Lc50/ L\infty) + t_0 [15]$$

84 The length at first sexual maturity (lm50) was given by the following equation:

$$85 \quad \text{Log}_{10} L_m = 0.8979 * \log_{10} L\infty - 0.0782 [16]$$

86 The age at first sexual maturity was estimated using the following equation

$$87 \quad t_{m50} = -1/ K * \ln (1-Lm50/ L\infty) + t_0 [17]$$

88 **2.3.4. Recruitment pattern**

89 Automatically, the recruitment pattern was decomposed and reconstructed through FiSAT II
90 routine by the backward projection of the length frequency data. So, one or two pulses can be
91 obtained [18]. The age at first recruitment (tr) was obtained using the following formula:

$$92 \quad t_r = -1/K * \ln (1-Lr/ L\infty) + t_0 [15].$$

93 **2.3.5. Stock assessment**

94 The purpose of fish stock assessment is to provide estimates of the state of a given stock. The
95 prediction of the relative yield and biomass per recruit of the species was made by ~~the~~ analyzing
96 ~~of~~ the knife-edge selection incorporated into the FiSAT II program. In addition, the values of
97 the $L_c/ L\infty$ and M/K ratios were used as input data in the estimation of the reference points $E_{0.1}$,
98 $E_{0.5}$ and E_{max} . These reference points ~~were~~ will afterward then be used to assess the state stock of
99 the studied species.

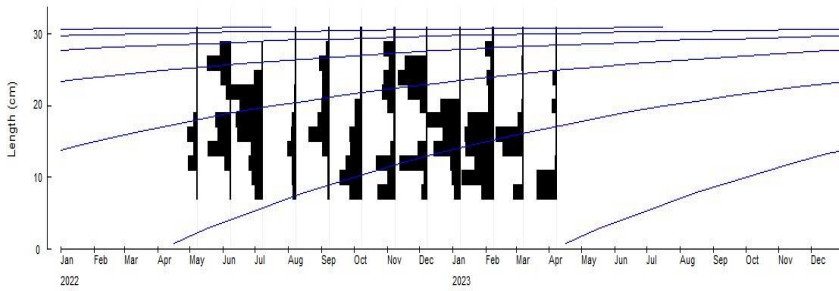
100 Yield isopleth contours which show the stock status were identified as the interception of the
101 exploitation rate (E) and critical length ratio ($L_c50/L\infty$). Yield isopleth was plotted to identify
102 the impact of changes in exploitation ratio (E) on yield (critical length ratio (L_c)= $L_c50/L\infty$).

103 A virtual Population Analysis (VPA) was used to determine the current and historical
104 abundances and the fishing mortality rates by analyzing the catch of cohorts over time to
105 generate an estimate of year-class over time [19]

106 **3. RESULTS**

107 **3.1. Estimation of growth parameters**

108 The ELEFAN routine allowed the estimation of growth parameters such as L_{∞} and K at 31.5
 109 cm and 0.78 respectively. Figure 2 shows the restructured Length frequency data
 110 superimposed with the estimated growth curve which revealed approximately four cohorts. The
 111 others growth parameters the theoretical age, (t_0), the lifespan (T_{max}) and the growth
 112 performance index (ϕ') were estimated as -0.0259, 3.81 year and 2.81 respectively (Table 1).
 113 The Von Bertalanffy growth model equation was: $L_t = 31.5 \{1 - \exp[-0.78(t+0.025)]\}$



114
 115 **Fig. 2.** Reconstructed length frequency distribution superimposed with the growth curve

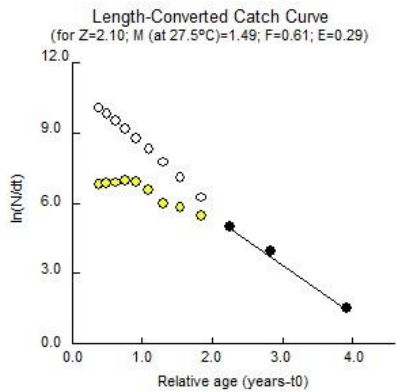
116 Table 1. Growth parameters in *Sardinella aurita* within Côte d'Ivoire's coastal waters. L_{∞} :
 117 Asymptotic length, K : growth rate, t_0 : theoretical age, (ϕ'): growth performance index, T_{max} :
 118 life-span or longevity

Parameters	L_{∞} (cm)	K (year ⁻¹)	t_0 (year)	(ϕ')	T_{max} (year)
Values	31.5	0.78	-0.025	2.88	3.81

119
 120 **3.3. Estimation of mortality parameters (M, F, Z) and Exploitation rate (E)**
 121 Figure 3 shows estimates of mortality parameters and the exploitation rate of the species.
 122 Thus, (Z): the total mortality rate, estimated from the linearized length-converted catch curve
 123 was 2.10 year⁻¹. The natural (M) and fishing (F) mortalities were 1.49 year⁻¹ and 0.61 year⁻¹
 124 respectively. The exploitation rate was estimated at 0.29.

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125

126 **Fig. 3.** Length-converted catch curve in *Sardinella aurita* within Côte d'Ivoire's waters from
127 April 2022 to March 2023.

128 **3.4. Probability of capture and length at first sexual maturity (Lm50)**

129 The estimation of the length at first capture L50%, 23.42 cm corresponding to age 1.03 ~~year~~
130 ~~years~~ is shown in Figure 4 a and ~~table~~ Table II. Further, the length at first sexual maturity
131 obtained was 18.49 cm corresponding to age 1.10 ~~year-years~~ (Table 2).

132 **3.5. Recruitment pattern**

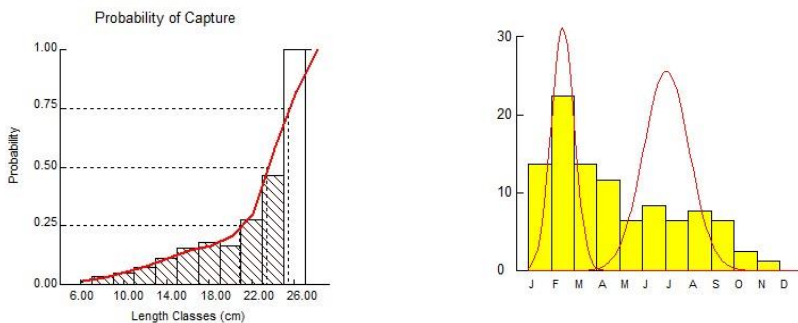
133 Recruitment in *S. aurita* within the Coastal waters of Côte d'Ivoire is represented by ~~the~~ Figure
134 4b. Indeed, recruitment runs from March to October with two pulses in February and June. The
135 length at first recruitment (Lr50) was 8cm with a corresponding age at first recruitment of 0.347
136 year.

137 **Table 2: Length and Age at first capture sexual maturity and recruitment in *Sardinella aurita***
138 **within the coastal waters of Côte d'Ivoire. Lc50 (cm): Length at first capture; Lm50 (cm):**
139 **Length at first sexual maturity; Lr50 (cm): Length at first recruitment. tc50 tm50 and tr50**
140 **(year): age at first capture, age at first maturity and age at first recruitment respectively**

Parameters	Lc50	Lm50	Lr50	tc50	tm50	tr50
Values	23.42	18.49	8	1.78	1.10	0.347

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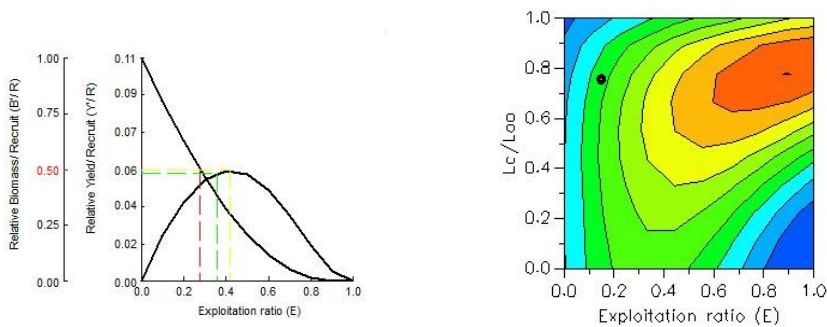
143 **Fig. 4.** Probability of capture (4a) and Recruitment pattern (4b) in *S. aurita* within Côte
 144 d'Ivoire's coastal waters from April 2022 to March 2023

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145 **3.6. Stock prediction: Yield and Biomass per recruit (Y/R, B/R**

146 Figure 5 shows the Beverton and Holt relative yield per recruit model and indicates the indices
 147 which were 0.278 for optimum sustainable yield (E0.5), 0.421 for the maximum sustainable
 148 yield (Emax) and 0.355 for economic yield target (E0.1) (figure 5a). The yield isopleths placed
 149 the fishery in *S. aurita* within Côte d'Ivoire's coastal waters in quadrant A depending on the
 150 interception of ($L_c50/L_\infty = 0.74$) and E (0.29) (Figure 5b)

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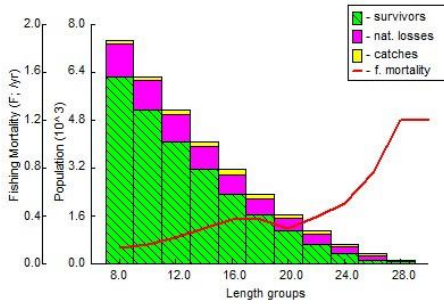


153 **Fig. 5.** Beverton and Holt relative yield per recruit model (5 a) and Yield Isopleth diagram (5
 154 b) in *S. aurita* within Coastal waters of Côte d'Ivoire.

155

156 **3.7. Length structured Virtual population Analysis-**

157 Figure 6 indicates the evolution of several parameters notably natural losses, survivors, catches
 158 and fishing mortality over time. The survivors and the natural losses decreased with an increase
 159 in length.



160
 161 **Fig. 6.** Length-based virtual Population analysis in *Sardinella aurita* within Côte d'Ivoire's
 162 coastal waters from July 202 to June 2023

163 **4. DISCUSSION**

164 The present work gives values of growth parameters notably the length at infinity, the growth
 165 coefficient and the theoretical age different and especially greater than the values obtained by
 166 other studies [20]. According to [21], K measures the exponential rate of approach to the
 167 asymptotic length. The importance of the growth coefficient (K) in fishery science no longer
 168 needs to be demonstrated because it characterizes a given fish stock. However, K can differ
 169 from stock to stock or from species to species. In addition, the value of the growth coefficient
 170 K is linked to the size classes sampled and therefore to the sampling method used including the
 171 fishing gear. *Sardinella aurita*'s stock is supposed to be shared between certain neighboring
 172 countries therefore supposed to have such parameters in common but the differences observed
 173 could have their explanation in the sampling methods used here and there. The K value of the
 174 work is higher [when compared with the regarding](#) values of other studies indicating that *S.*
 175 *aurita* has a fast-growing and short life status within Côte d'Ivoire's coastal waters. Generally,
 176 the rate of growth is high in [short-lived](#) species. The length of [fishes-fish](#) is [a-the](#) best
 177 indicator [for-of](#) the fishing pressure. Because fish length decreases with an increase of fishing
 178 pressure.

179 The length at first capture ($L_{C50} = 23.50\text{cm}$) was higher than the length at first sexual maturity
 180 (18.49 cm) indicating that *S. aurita* within Côte d'Ivoire's coastal waters reaches sexual
 181 maturity before being captured. This constitutes a best alternative for renewing the fish stock.

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182 According to [22], fish should reach sexual maturity before exploitation which allows them to
183 procreate at least once before being captured. The size at first capture mentioned by [20] within
184 Ghana's coastal waters was 5.99 cm, ~~which was very-much low-lower~~ than our result. This
185 significant difference between the results could be due to two essential factors including the
186 fishing pressure and the mesh sizes of the fishing gears used. The estimated age at ~~fst-first~~
187 recruitment (tr_{50}) shows that juveniles of *Sardinella aurita* enter into the stock shortly after
188 birth, approximately three months. The low age at first recruitment (around 3 months) could be
189 explained by the fact that the species has a short lifespan. The study shows two peaks of
190 recruitment as suggested by [23] for tropical fish species. Indeed, favorable environmental
191 conditions, availability of food as well as the presence of a higher percentage of matured
192 *Sardinella aurita* species could ~~explained-explain~~ the recruitment result [24].

193 The continuous recruitment all year round could be explained by a sex-ratio favoring females.
194 Regarding the intercept of the ratio (L_{50}/L_{∞}) and the exploitation rate (E), *S. aurita* falls into
195 quadrant A corresponding to underexploited stock. According to [25], ~~the~~-quadrant A
196 ~~representing-represents~~ underexploited fish with large fish caught at low fishing effort ~~level~~
197 ~~levels~~ and the interception of L_c/L_{∞} with (E) ratio from 0.5 to 1, and (E) from 0 to 0.5. All
198 these indicators indicate that the species is underexploited, but a look at the value of the
199 Beverton and Holt relative yield per recruit model gives a value of E0.5 (exploitation rate of
200 reducing the stock to half of its virgin biomass), lower than the current exploitation rate
201 implying that measures must be taken to contain the species exploitation for sustainable
202 management of the resource. Such sustainable management measures should take into account
203 fishing effort and ~~the~~ mesh size of fishing gears.

204 5. CONCLUSION

205 Regarding the results of the study *Sardinella aurita* is a fast-growing and short live species
206 within Côte d'Ivoire's coastal waters. The recruitment pattern exhibit two peaks with a
207 continuous phenomenon all year round. The exploitation rate (E) obtained shows that the
208 species is underexploited nevertheless, the current exploitation rate is higher than E0.5 at which
209 the stock is reduce to half of its virgin biomass thus inviting us to be more careful and to take
210 appropriate measures.

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