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LENGTH-WEIGHT RELATIONSHIP, GROWTH, MORTALITY AND EXPLOITATION STATUS OF *SEPIA HIERREDDA* (RANG, 1835) IN IVORIAN WATERS, GULF OF GUINEA

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ABSTRACT

Population parameters of the giant African cuttlefish *Sepia hierredda* were estimated from length-frequency data collected in Ivorian waters. A total of 962 individuals were measured. The asymptotic length (L_{∞}) was 32.03 cm and the growth coefficient (K) was 0.69 year⁻¹, giving a growth performance (ϕ') of 2.85. The length-weight relationship was $W=0.20614LD^{2.73634}$, ($R^2 = 0.9023$), and the exponent b was significantly lower than 3 ($p<0.001$), indicating negative allometric growth. Total mortality (Z) for *S. hierredda* was 2.52 year⁻¹, with natural mortality (M) and fishing mortality (F) were 1.31 and 1.22 year⁻¹, respectively. The exploitation rate (E) was 0.48, slightly higher than the E50 reference point (0.466), whereas E10 and Emax were both 1.00. Recruitment pattern was continuous throughout the year, with two major pulses in March-April and August-September; the latter was the stronger pulse and represented 18.78% of reconstructed recruitment. Virtual population analysis showed a progressive decline in population numbers with increasing length and an increase in fishing mortality toward larger length groups. The results indicate that the stock is subject to substantial fishing pressure, although the exploitation rate remains close to the conventional reference level of $E=0.5$ rather than clearly indicating severe overexploitation.

Keywords: *Sepia Hierredda*, Population Parameters, Length-Weight Relationship, Exploitation Rate, Côte d'Ivoire.

1 INTRODUCTION

Cephalopods are important components of marine ecosystems and fisheries, owing to their ecological role as predators and prey and their high commercial value in many coastal regions worldwide. Their relatively rapid growth, short life cycles and sensitivity to environmental and fishing pressures make them particularly relevant for fisheries assessment and management (**Boyle and Rodhouse, 2005**). Among commercially exploited cephalopods, cuttlefish of the genus *Sepia* constitute an important resource for both artisanal and industrial fisheries in several regions of the Atlantic Ocean.

Sepia hierredda (Rang, 1835), commonly known as the giant African cuttlefish, is a large neritic and nekton-benthic cuttlefish distributed along the eastern Atlantic coast of Africa. The species has been reported from the northwestern African coast to the Gulf of Guinea and is currently recognized as a valid species (**Jereb and Roper, 2005; Reid et al., 2005**). It may attain a dorsal mantle length of approximately 50 cm and a body weight exceeding 7.5 kg (**Jereb and Roper, 2005**). It is commercially important in West African fisheries. Regional assessments identify *S. hierredda* as an important component of cephalopod catches in the southern CECAF region (**FAO, 2019**).

In the southern CECAF region, *S. hierredda* has been identified as one of the dominant cuttlefish species in commercial cephalopod fisheries, particularly in Guinea-Bissau, Guinea, Sierra Leone and Ghana. Regional assessments have suggested the existence of geographically distinct stock units, partly because of differences in distribution and apparently limited movements along the coast (**FAO, 2019**). Despite its fisheries importance, biological and population-dynamic information on *S. hierredda* remains considerably more limited than for some other commercially exploited cephalopods. In Ghanaian waters, **Djan et al. (2021)** estimated an asymptotic length of 33.88 cm and a growth coefficient of 0.69 year^{-1} , together with total, natural and fishing mortality rates of 2.88, 1.31 and 1.57 year^{-1} , respectively. The authors also estimated a current exploitation ratio of 0.56, highlighting the importance of assessing fishing pressure on this species. Similarly, regional data from Guinea-Bissau have provided length–weight relationships for *S. hierredda*, with a coefficient of determination of 0.98 for combined sexes and a slope (b) of 2.702 (**García-Isarch et al., 2009; FAO, 2019**).

The length–weight relationship is a fundamental biometric tool in fishery biology because it provides information on the relationship between body size and mass and allows the assessment of growth patterns and changes in body condition. The parameters of the relationship may vary according to sex, developmental stage, season, geographical location and environmental conditions. In addition, length-frequency data can be used to estimate key population parameters, including asymptotic length, growth coefficient, total mortality, natural mortality, fishing mortality and exploitation rate. These parameters are essential for evaluating the demographic status of exploited populations and for providing scientific information for fisheries management. In Côte d'Ivoire, population-dynamic studies have previously been conducted on *Sepia officinalis*, with estimates of growth, mortality and exploitation parameters obtained from length-frequency data (**Akese et al., 2016**). However, comparable information for *S. hierredda* in Ivorian waters remains scarce.

The absence of detailed population-dynamic information for *S. hierredda* in Côte d'Ivoire represents an important knowledge gap, particularly in the context of increasing exploitation of demersal resources in the Gulf of Guinea. Assessing the size structure, length–weight relationship, growth and mortality parameters of this species is therefore necessary to better understand the characteristics of the exploited population and to evaluate the intensity of fishing pressure affecting the stock. Such information can also provide a basis for comparison with populations from neighbouring countries and contribute to regional assessments of *S. hierredda* fisheries.

Therefore, the present study aimed to investigate the **length–weight relationship, growth, mortality and exploitation status of *Sepia hierredda* in Ivorian waters of the Gulf of Guinea**. Specifically, the study aimed to (i) characterize the size structure of the population, (ii) estimate the length–weight relationship and determine the type of growth, (iii) estimate the growth parameters from length-frequency data, (iv) determine total, natural and fishing mortality rates, and (v) assess the current exploitation level of the species using population-dynamic and yield-per-recruit approaches.

2 MATERIALS AND METHODS

2.1 Study area

The study was conducted in the Exclusive Economic Zone (EEZ) of Côte d'Ivoire, in the northern Gulf of Guinea, West Africa (**Fig.1**). This coastal area extends from Cape Palmas (8°W) to approximately 2°30'W and is characterized by a tropical climate influenced by seasonal upwelling events, particularly during the major (July–September) and minor (January–February) cold seasons (**Pezennec and Bard, 1992**). These oceanographic conditions strongly influence marine productivity and the distribution of marine organisms.

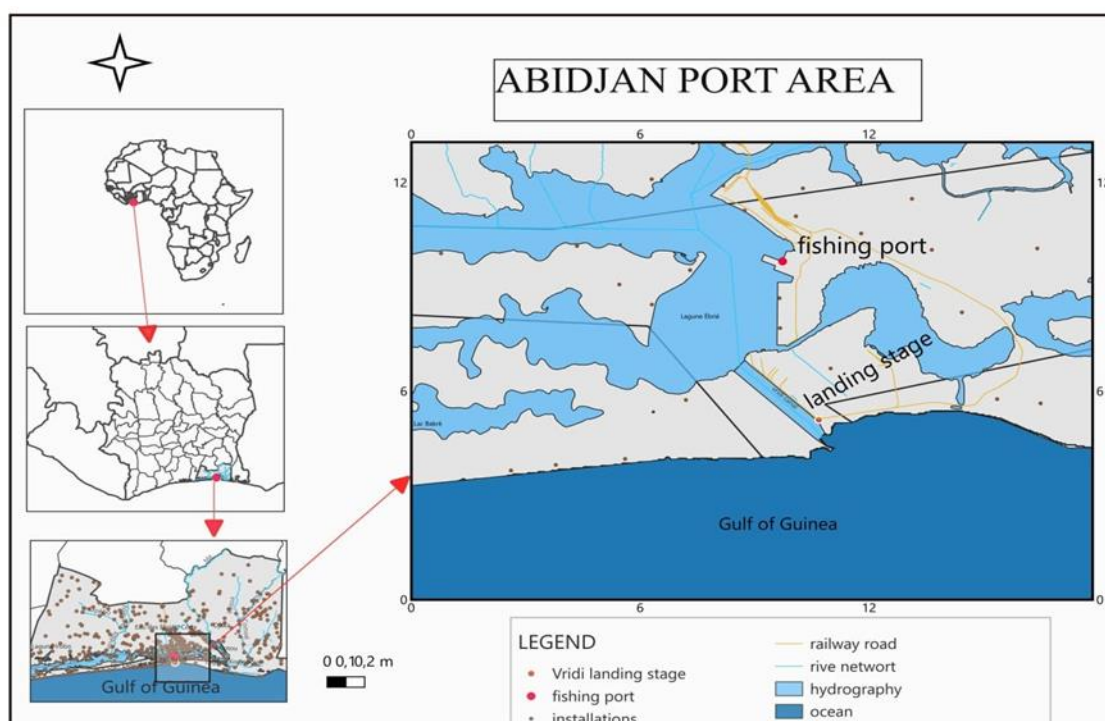


Figure 1: Sampling location in Gulf of Guinea

2.2 Sampling and data collection

Samples of *Sepia hierredda* were collected from January 2016 to December 2016 from commercial trawl catches landed at the Abidjan fishing port and from artisanal fishing catches landed at the Vridi Canal fishing landing site, Côte d'Ivoire. The dorsal mantle length (DML) of 962 individuals was measured to the nearest 0.1 cm. Total body weight was determined using an electronic balance with an accuracy of 0.1 g. The data were then grouped into DML classes by 1cm intervals.

2.2.1 Length-Weight relationship

The length–weight relationship was established using the conventional equation described by **Le Cren (1951)** and **Lagler (1956)**;

$$W = aLD^b$$

where W is the total weight (g), LD is the dorsal mantle length (cm), a is the intercept, and b is the allometric growth coefficient.

The parameters a and b were estimated by linear regression after logarithmic transformation:

$$\text{Log}W = \text{Log} a + b\text{Log} LD$$

The coefficient of determination (R^2) was used to evaluate the goodness of fit. A Student's t -test was applied to determine whether the exponent b significantly differed from the isometric value ($b = 3$).

2.2.2 Growth parameters

Growth parameters were estimated from length–frequency data and the von Bertalanffy Growth Function (VBGF), following the methods described by **Sparre and Venema (1998)** and **Aggrey-Fynn (2009)**:

$$LD_t = L_\infty [1 - e^{-K(t-t_0)}]$$

where LD_t is the length at age t , L_∞ is the asymptotic length, K is the growth coefficient, and t_0 is the theoretical age at zero length.

Parameters (L_∞ and K) were estimated using the ELEFAN I routine implemented in the FAO-ICLARM Stock Assessment Tools (FiSAT II). The growth performance index (ϕ') was calculated as:

$$\phi' = 2 \log_{10} L_{\infty} + \log_{10} K$$

2.2.3 Mortality and exploitation rates

Total mortality (Z) was estimated using the length-converted catch curve method. Natural mortality (M) was computed using Pauly's empirical equation (Pauly, 1980):

$$\log_{10} M = -0.0066 - 0.279 \log_{10} L_{\infty} + 0.6543 \log_{10} K + 0.4634 \log_{10} T$$

where T is the mean annual sea surface temperature ($^{\circ}\text{C}$).

Fishing mortality (F) was calculated as: $F = Z - M$

The exploitation rate (E) was calculated as:

$E = \frac{F}{Z}$ (Gulland 1971). The value of $E \approx 0.5$ is often used as a conventional reference point, but it should not be interpreted as universal stock-specific management target.

2.2.4 Recruitment pattern

Recruitment was reconstructed in FiSAT II from the length-frequency data by backward projection along the length axis, using the estimated growth parameters L_{∞} and K and the assumed t_0 value ($t_0 = 0$). The resulting pattern was used to identify the timing and relative magnitude of recruitment pulses. Because this is a length-frequency-based reconstruction, the estimated peaks are interpreted as periods of entry into the sampled population, not as direct estimates of spawning periods. Normal distribution of the recruitment pattern was determined by NORMSEP (Pauly and Caddy 1985) in FiSAT II. NORMSEP should be mentioned only if it was actually used to separate length-frequency distributions into normal components; it is not, by itself, the recruitment-pattern routine.

2.2.5 Virtual population analysis and yield-per-recruit analysis

Virtual population analysis (VPA) was conducted in FiSAT II to estimate abundance and fishing mortality across length classes, using the length-structured catch information and estimated growth parameters. The specific VPA routine, length-class inputs and terminal fishing-mortality assumption should be reported in the final version according to the settings actually used. Relative yield-per-recruit (Y'/R) and biomass-per-recruit (B'/R) analyses were performed using the selection-ogive approach described by Gayanilo *et al.* (2005). The exploitation reference points E_{10} , E_{max} and E_{50} were obtained from the FiSAT II output. The selection-ogive/probability-of-capture inputs and the exploitation-rate range examined should be specified to make the analysis reproducible. E_{max} denotes the exploitation rate associated with maximum relative yield per recruit; E_{10} is the rate at which the marginal increase in relative yield per recruit falls to 10% of its value at low exploitation; E_{50} denotes the exploitation rate associated with a 50% reduction in relative biomass per recruit relative to the unexploited condition, as defined by the routine used.

3 RESULTS

3.1 Length-weight relationship

The length-weight relationship based on 962 individuals is shown in Fig.2. The fitted equation was $W = 0.20614L^{2.73634}$ ($R^2 = 0.9023$). The allometric coefficient (b) was 2.73634, and was significantly lower than theoretical isometric value of 3 ($t = -9.07$, $df = 960$, $P < 0.001$) indicating significant negative allometric growth.

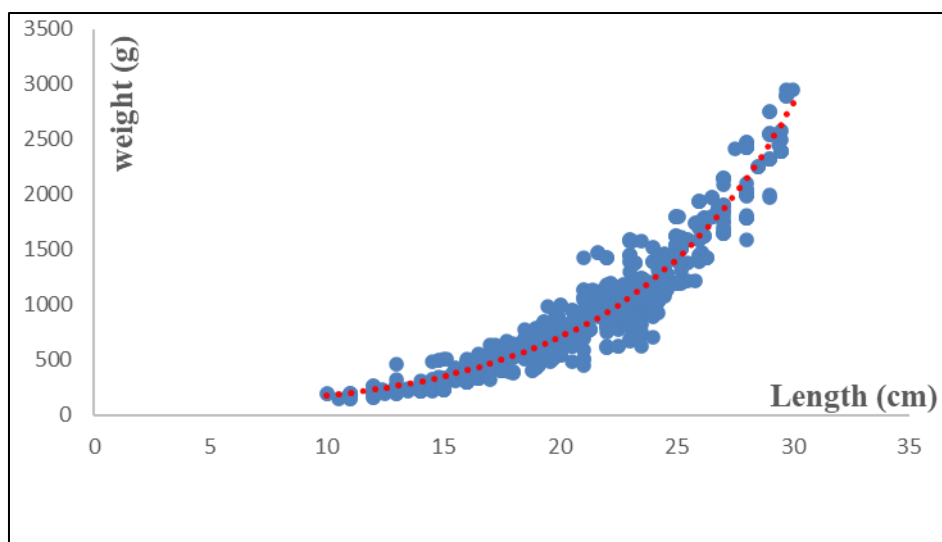


Figure 2: Length-weight relationship of *S. hierredda*

3.2 Growth parameters

The asymptotic length (L_{∞}) of the VBGF was 32.03cm and the growth coefficient (K) was 0.690 year⁻¹ for *Sepia hierredda*. The computed growth curve using these parameters is shown over the restructured length distribution in **(Fig. 3)**. The largest observed individual was 30.0 cm whereas the estimated asymptotic length was 32.03 cm. The best estimated value of K was 0.690 year⁻¹ **(Fig. 4)**. The growth performance index (ϕ') was 2.85 **(Table 1)**.

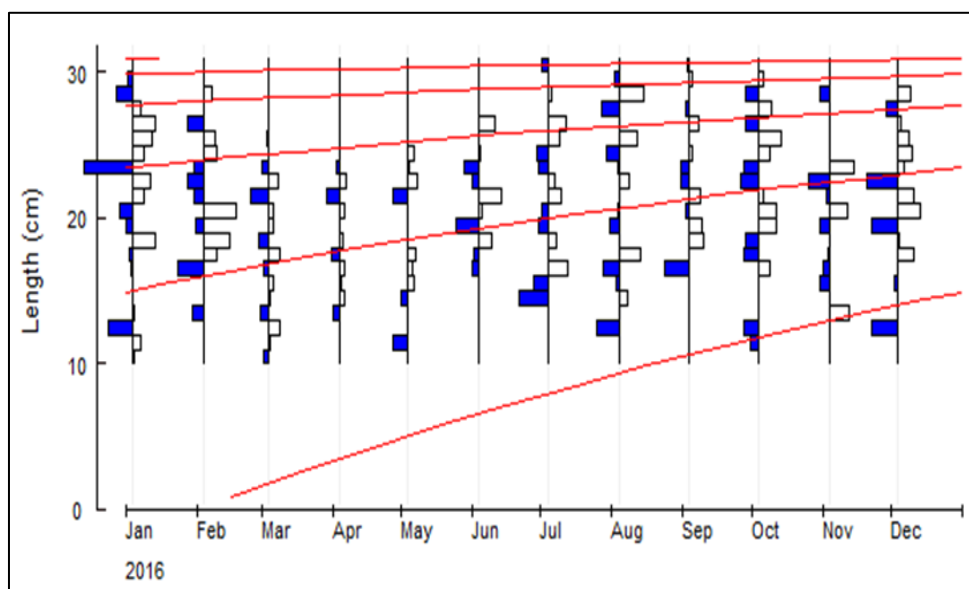


Figure 3: Restructured length-frequency distribution with growth curves superimposed using ELEFAN-1 (L_{∞} = 32.03 cm and K = 0.69 year⁻¹).

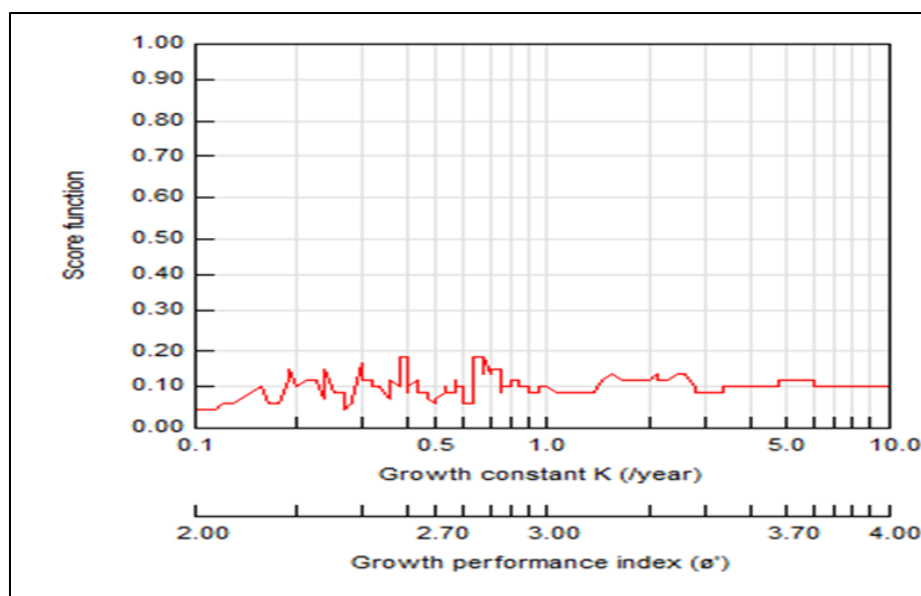


Figure 4: Estimation K of *Sepia hierredda* from Ivorian coastal water

Table 1: Length–weight relationship and growth parameters of *S. hierredda* in coastal waters of Côte d'Ivoire.

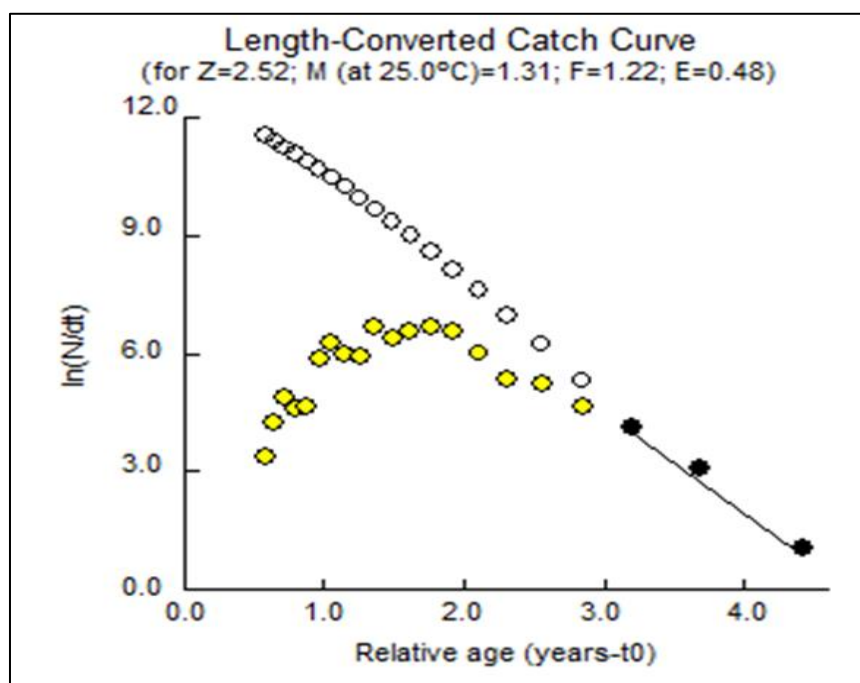
Population parameters	Value
Asymptotic length (L_{∞} , cm)	32.03
Growth coefficient K (year ⁻¹)	0.69
Length-weight coefficient a	0.20614
Length-weight coefficient exponent b	2.73634
Coefficient of determination R^2	0.9023
growth performance index (ϕ')	2.85
Length range (cm)	10-30
Weight range (g)	199-2960
Sample number (N)	962

3.3 Mortality and exploitation

Length-converted catch-curve analysis estimated total mortality (Z) at 2.52 year⁻¹ for *S. hierredda* (**Fig. 5**). Natural mortality (M) was 1.31 year⁻¹ and fishing mortality (F) was 1.22 year⁻¹ (**Table 2**). The Exploitation rate (E) of *S. hierredda* in the coastal water of Côte d'Ivoire was 0.48 (**Table 2**). Natural mortality (1.31 year⁻¹) represented about 52% of total mortality, whereas fishing mortality represented 48%. The current exploitation rate was slightly higher than the E50 reference point (0.466), but remained below E10 and Emax both estimated at 1.00. these results indicate a relatively high fishing pressure close to conventional $E = 0.50$ reference level rather than a clearly under-exploited condition.

Table 2: Mortality parameters and exploitation indicators of *S. hierredda* in coastal waters of Côte d'Ivoire

Mortality and exploitation parameters	Values
Natural mortality, M (year ⁻¹)	1.31
Fishing mortality, F (year ⁻¹)	1.22
Total mortality, Z (year ⁻¹)	2.52
Exploitation level, (E)	0.48
E50	0.466
E10	1.00
E _{max}	1.00

**Figure 5: Length converted catch curve of *Sepia hierredda* in Côte d'Ivoire**

3.4 Recruitment pattern

The reconstructed recruitment pattern of *S. hierredda* was continuous throughout the year, with two main pulses in March-April and August-September (**Fig. 6**). The August-September pulse was stronger and accounted for 18.78% of reconstructed recruitment. Second pulse was stronger and represented 18.78% of reconstructed recruitment.

3.5 Virtual population analysis (VPA)

The VPA indicated a progressive decline in estimated population abundance with increasing length (**Fig. 7**). Estimated abundance was highest in the smallest length groups and declined toward the largest sizes. Fishing mortality was comparatively low in the smaller length classes, increased markedly from approximately 20 cm onward, and reached its highest values among the largest classes.

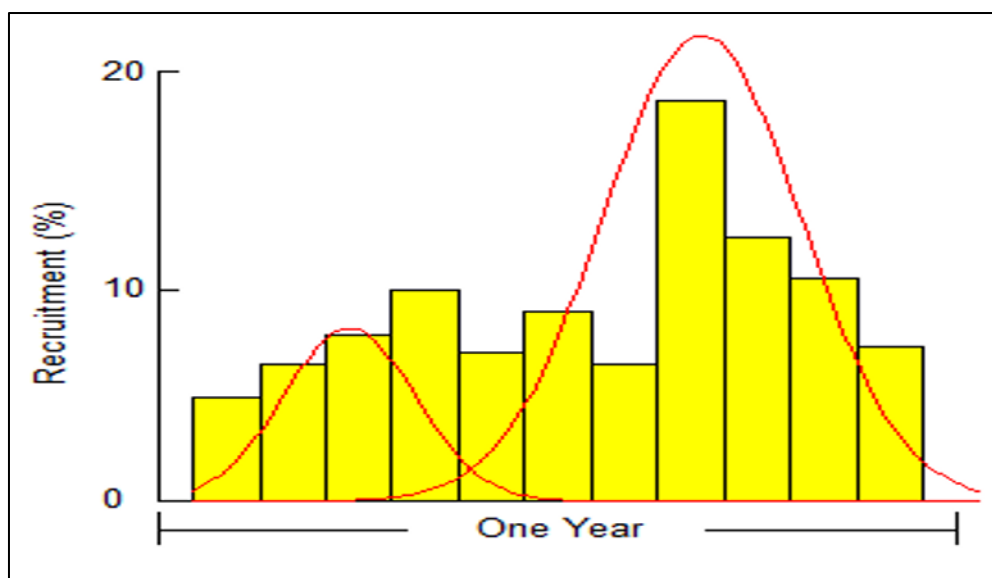


Figure 6: Recruitment pattern of *S. hierredda* from Côte d'Ivoire

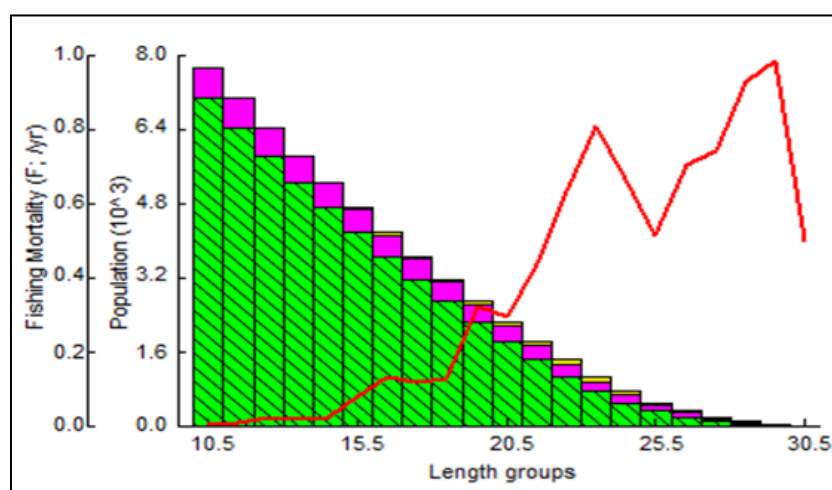


Figure 7: Virtual population analysis of *S. hierredda* from Côte d'Ivoire

4 DISCUSSION

4.1 Length-weight relationship

The size distribution of the 962 sampled individuals covered a broad range of mantle lengths, including small and large individuals, with greatest representation occurring in intermediate size classes. The presence of smaller individuals indicates recruitment to the exploited population, whereas the occurrence of large individuals shows that part of the population survives to advanced size classes. The length-weight relationship yielded $b = 2.73634$, significantly lower than the isometric value of 3 ($p < 0.001$), indicating negative allometric growth. The estimated exponent was close to the value of $b = 2.702$ reported for *S. hierredda* in Guinea-Bissau by **García-Isarch et al. (2009)**. In that study, the relationship was also strongly fitted to the data ($R^2 = 0.98$; $n = 185$). The similarity between the two estimates suggests a comparable overall scaling pattern in *S. hierredda* populations along the West African coast. The present value was also close to that reported for *S. officinalis* in Ivorian coastal waters ($b = 2.77$; **Akessa et al., 2016**). Similar negative allometric relationships have been reported for *S. officinalis* in several geographically distinct populations, including the English Channel ($b = 2.78$ in females and 2.64 in males; **Dunn, 1999**), the Ría of Vigo, Spain ($b = 2.70$ in both sexes; **Guerra and Castro, 1988**), the Ria of Aveiro, Portugal ($b = 2.74$ in females and 2.66 in males; **Jorge and Sobral, 2004**), the coast of Nigeria **Taiwo et al., (2021)** and the Adriatic Sea ($b = 2.773$ for both sexes combined; **Manfrin Piccinetti and Giovanardi, 1984**). These comparisons indicate that negative allometry is common among several *Sepia* populations, although the magnitude of the exponent may vary geographically and between sexes. The coefficient of determination obtained in the present study ($R^2 = 0.9023$) was lower than that reported for *S. hierredda* in Guinea-Bissau ($R^2 = 0.98$). Such differences may result from sample size, size range, sex composition, seasonality, sampling

design or environmental conditions. In addition, studies of *S. officinalis* have demonstrated significant differences between male and female length–weight relationships (Dunn, 1999), indicating that sex composition can influence a pooled relationship. Because the present analysis combines individuals across the study period, the estimated relationship should be interpreted as a population-level relationship rather than as a sex-specific relationship. The negative allometry indicates that weight increased less rapidly than the cube of mantle length. Similar departures from isometry have been reported for *S. hierredda* and related cuttlefish populations, emphasizing that body form and condition can vary geographically and temporally.

4.2 Growth parameters

The von Bertalanffy growth parameters estimated by ELEFAN I were $L_{\infty} = 32.03$ cm and $K = 0.69 \text{ year}^{-1}$, with $\phi' = 2.85$. The asymptotic length was close to the 33.88 cm reported for *S. hierredda* in Ghana by Djan *et al.* (2021), while the growth coefficient was identical ($K = 0.69 \text{ year}^{-1}$). The close agreement in K suggests a similar apparent rate of approach toward the asymptotic size in the two populations, whereas the slightly lower L_{∞} in Côte d'Ivoire may reflect differences in population structure, environmental conditions, fishing pattern, or sampling period. These factors cannot be separated using the present data alone. Comparison with *S. officinalis* from Ivorian waters provides an additional perspective. Akesse *et al.* (2016) estimated $L_{\infty} = 31.50$ cm, $K = 0.50 \text{ year}^{-1}$ and $\Phi' = 2.69$ for *S. officinalis*. The two species therefore showed similar asymptotic lengths, whereas *S. hierredda* exhibited a higher growth coefficient and a slightly higher growth performance index. This difference may reflect species-specific life-history characteristics, environmental conditions, food availability, or differences in population structure. Similar variability in growth has been documented for *S. officinalis*, for which growth can differ between sexes and seasons (Dunn, 1999; Challier *et al.*, 2005). Consequently, comparisons between species should be considered indicative rather than evidence of a direct biological difference unless sampling conditions are fully comparable. The estimated L_{∞} was only slightly greater than the maximum observed length (30 cm), which is consistent with a length-frequency sample containing individuals approaching the upper part of the growth trajectory. The value of $\phi' = 2.85$ provides a useful synthetic measure for comparing the growth performance of this population with populations from neighbouring regions.

4.3 Mortality and exploitation

Total mortality was estimated at $Z = 2.52 \text{ year}^{-1}$, with $M = 1.31 \text{ year}^{-1}$ and $F = 1.22 \text{ year}^{-1}$. Thus, natural and fishing mortality were of similar magnitude, with natural mortality slightly exceeding fishing mortality. Approximately 52% of total mortality was attributed to natural mortality and 48% to fishing mortality. The fishing mortality estimated in Côte d'Ivoire was lower than the $F = 1.57 \text{ year}^{-1}$ reported in Ghana by Djan *et al.* (2021), and the exploitation rate was also lower than the Ghanaian value of $E = 0.56$. This suggests a lower fishing pressure than that reported for the Ghanaian population during the corresponding assessment, although direct comparison should be made cautiously because sampling periods and assessment conditions differ. The exploitation rate of $E = 0.48$ is close to the conventional reference value of 0.5 proposed in the Gulland framework. Moreover, $E = 0.48$ is slightly above $E_{50} = 0.466$, whereas E_{10} and $E_{\max}$ were both estimated at 1.00. Consequently, the present results do not support describing the stock simply as under-exploited. Rather, the population appears to be exploited at a level close to the conventional reference point, with a fishing mortality that is substantial and warrants monitoring. The E_{10} and $E_{\max}$ values of 1.00 should not be interpreted as recommended exploitation targets; they indicate that these model-derived reference points occurred at the upper boundary of the exploitation range examined.

4.4 Recruitment pattern

Recruitment was reconstructed throughout the year, with two main pulses in March–April and August–September; the latter accounted for 18.78% of reconstructed recruitment. This bimodal pattern suggests that individuals entered the sampled population during more than one period of the year. However, the peaks are inferred from length-frequency data and should not be treated as a direct spawning calendar. Environmental or biological factors that might explain the timing of the pulses were not measured in this study and should therefore be discussed only as hypotheses.

4.5 Virtual population analysis

The VPA suggested that estimated abundance declined with increasing length, while fishing mortality increased from approximately 20 cm and was highest in the largest length classes. This indicates that fishing mortality was not evenly distributed across the observed size structure. Similar size-related variation in exploitation has been reported for *S. officinalis* (Dunn, 1999), although differences between species and fisheries warrant caution in direct comparison. The present data do not quantify reproductive output by size class, so the possible consequences for spawning biomass cannot be established. Overall, the study provides baseline estimates of length–weight relationship, growth, mortality, exploitation and recruitment for *S. hierredda* in Ivorian waters. Given the single-year sampling period and the reliance on length-frequency-based assessment methods, continued monitoring and complementary reproductive and fishery-dependent studies are needed before stronger conclusions about long-term stock status can be drawn.

5 CONCLUSION

The present study provides an integrated assessment of the length-weight relationship, growth, mortality, recruitment pattern and exploitation characteristics of *sepia hierredda* in Ivorian coastal waters, based on 962 individuals. The species exhibited significant negative allometric growth ($b=2.73634$), indicating that body weight increased less rapidly than the cube of mantle length. The von Bertalanffy growth parameters estimated by ELEFAN I ($L_{\infty}= 32.03$ cm; $K= 0.69\text{year}^{-1}$; $\phi' = 2.85$) provide baseline information on the growth dynamics for this species in the region. Total mortality was estimated at 2.52 year^{-1} , compared with natural mortality of 1.31 year^{-1} and fishing mortality of 1.22 year^{-1} ; these estimates should be verified against the unrounded outputs to ensure numerical consistency. The exploitation rate ($E = 0.48$) was close to the conventional reference value of 0.5 and slightly higher than the estimated (E_{50}) reference point (0.466), suggesting that the exploitation status should be interpreted cautiously rather than classified as clearly under-exploited or overexploited on the basis of these indicators alone. Length-frequency analysis indicated continuous recruitment, with two main pulses in March–April and August–September, while virtual population analysis suggested that fishing mortality increased toward larger length classes. These findings highlight the importance of monitoring fishing pressure and the size structure of catches. Future management and assessment efforts should prioritize regular monitoring of catches and fishing effort, improved estimates of size at maturity and reproductive parameters, and validation of the mortality and yield-per-recruit estimates to strengthen the scientific basis for sustainable exploitation of *S. hierredda* in Ivorian waters.

COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

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