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Determining the population dynamics of *Istiophorus albicans* (Latreille, 1804) in coastal waters of the Gulf of Guinea using length frequency data

Samuel K.K. AMPONSAH

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University of Energy and Natural Resources, Department of Fisheries and Water Resources, Ghana

ORCID IDs of the author(s):

S.K.K.A. 0000-0001-5559-3139

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Correspondence:
Samuel K.K. AMPONSAH
E-mail: samuelamponsah09@gmail.com

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ABSTRACT

Atlantic sailfish catches in Ghana have declined to levels below historical levels, despite their economic and nutritional significance, raising concerns about a potential collapse of the fishery. This preliminary study aimed to assess the exploitation status of Atlantic sailfish (*Istiophorus albicans*) from the coast of Ghana, utilising FiSAT II software. Of the length distribution of 713 specimens sampled from Dixcove and Tema fishing communities, asymptotic length ($L\infty$), growth rate (K), and age at length zero (t0) were 325.5 cm, 0.59 yr^{-1}, and - 0.13, respectively. Total mortality rate (Z), natural mortality rate (M), and fishing mortality rate (F) were 3.05 yr^{-1}, 0.44 yr^{-1}, and 2.61 yr^{-1}, respectively. The length at capture (Lc_{50} = 186.15 cm) exceeded the length at maturity (Lm_{50} = 150.6 cm). The current exploitation rate (E = 0.86) exceeded the maximum sustainable exploitation rate (E < Emax), indicating a potential collapse of the fishery without effective management measures. Based on the findings, there is an urgent need to implement effective management strategies to sustain the Atlantic sailfish population along Ghana's coast.

Keywords: Growth, Mortality, Exploitation, Ghana, Stock assessment, Atlantic sailfish

Introduction

The Atlantic sailfish (*Istiophorus albicans*, Latreille, 1804) belongs to the family Istiophoridae within the order Carangiformes (ICCAT, 2010). This opportunistic carnivorous species is recognised for its distinctive sail-like dorsal fin, featuring an elongated, pointed rostrum and sharp, small teeth adapted for grasping prey. It can grow up to 315 cm (ICCAT, 2010; Hugi, 2022). The Atlantic sailfish is a pelagic species that inhabits the tropical and temperate waters of the Atlantic Ocean, preferring depths of up to 200 meters (Nakamura, 1985; Hugi, 2022).

In Ghana, Atlantic sailfish are common in fishing communities such as Dixcove, Tema, Sekondi, among others (Kwei & Ofori-Adu, 2005). They are primarily caught by artisanal fishermen using drift gillnets, longlines, and hooks. Individuals of Atlantic sailfish are harvested for fresh, smoked, and frozen consumption, contributing to local nutrition both directly and indirectly (Kwei & Ofori-Adu, 2005). Economically, the Atlantic sailfish is vital to the livelihoods of coastal fishing communities in Ghana. However, the stock has exhibited a sharp decline in recent years, with recorded landings from 693 metric tons in 1993 to 63 metric tons in 2021 (ICCAT, 2023). The alarming decline in Atlantic sailfish catches along Ghana's coast underscores the urgent need for immediate implementation and strict adherence to management measures in alignment with international bodies, such as ICCAT. Without science-based intervention, the continued depletion of this species could have severe ecological and economic consequences, threatening marine biodiversity and the livelihoods of coastal communities.

Despite the reduction in catches, there is a lack of scientific information on the exploitation status of *I. albicans* on Ghana's coast, which limits policymakers' ability to implement effective management strategies (ICCAT, 2023). The lack of scientific information poses a serious risk of overexploitation, potentially leading to the collapse of the fishery and causing further socio-economic challenges (FAO, 2022). This study aimed to assess the population parameters of *Istiophorus albicans* in Ghanaian waters. The findings will provide preliminary information for the sustainable management of the sampled species from the coast of Ghana.

Materials and Methods

Study Site

The study was conducted in two coastal communities, including Dixcove and Tema fishing communities, which are hotspots for sailfish fisheries in Ghana. The artisanal fishing community of Dixcove, located in Ghana's Western Region (N 04.79368°, W 01.94612°), comprises of three landing beaches: Upper Dixcove, Lower Dixcove, and Urom, with over 1,081 fishermen (Dovlo et al., 2016). Tema has two landing beaches, namely Ashamang and Awudun, with over 5167 fishermen (Dovlo et al., 2016) (see Figure 1).

Figure 1. Map showing the sampling sites

Data Collection

Fish samples were collected randomly from local fishermen in Dixcove and Tema fishing communities, where the dominant fishing gears used include drift gill nets (DGNs) and longline gear, over twelve months (once a month) from November 2023 to October 2024. However, no data was obtained in July 2024 due to the closure of artisanal fisheries fishing season in Ghana. Identification of fish species to the species level was done using keys by Fischer et al. (1981) and Kwei and Ofori-Adu (2005). In-situ identified samples were analysed for total length to the nearest centimetre using a 500 m tape measure.

Growth Parameters

Growth parameters that follow the von Bertalanffy Growth Function (VBGF) were estimated using the Electronic Length Frequency Analysis (ELEFAN) option of the FiSAT II Tool. The von Bertalanffy Growth Function (VBGF) is given as follows:

$$L_t = L_\infty [1 - e^{-K(t - t_o)}] \quad \text{(Pauly, 1984)}$$

Where Lt is the average length at time (or age) t, L_∞ is the asymptotic length, K is the growth rate, and t represents the age when the average length was zero.

Estimation of longevity (Tmax) of the species was done using the formula:

$$3/K \quad \text{(Anato, 1999)}$$

The growth performance index was calculated using the formula:

$$2\log L_\infty + \log K \quad \text{(Munro \& Pauly, 1984)}$$

The theoretical age at length zero (t_0) followed the equation:

$$\text{Log}_{10}(-t_0) = -0.3922 - 0.2752 \log_{10} L_\infty - 1.038 \log_{10} K \quad \text{(Pauly, 1979)}$$

Length at First Capture

The ascending left part of the length converted catch curve was used to estimate the probability of length at first capture (Lc50), in addition to the length at both 25% and 75% capture, which correlates with the cumulative probability at 75% and 95%, respectively (Pauly, 1984).

Length at First Maturity

The length at first maturity (Lm_{50}) was estimated as

$$\text{Log}_{10} Lm_{50} = 0.8979 * \text{Log}_{10}(L_\infty) - 0.0782 \quad \text{(Froese \& Binohlan, 2000)}$$

Mortality Parameters

The natural mortality rate of Atlantic Sailfish was computed from the Then et al. (2015) formula:

$$M = 4.118 K^{0.73} * L_\infty^{-0.333},$$

where M is natural mortality in a given stock, and the value of L_∞ is the asymptotic length calculated from the sample.

The fishing mortality coefficient (F) was calculated as:

$$F = Z - M \quad \text{(Qamar et al., 2016)}$$

The exploitation rate (E) was calculated using the formula:

$$E = F/Z \quad \text{(Georgiev \& Kolarov, 1962)}$$

Recruitment Pattern

Recruitment patterns were analysed using the FISAT II program in the recruitment pattern subprogram to construct a time series of recruits from length frequencies, thereby determining the relative peak recruitment per year (Pauly, 1984).

Virtual Population Analysis (VPA)

Input parameters including L_∞, K, M, F, constants of length-weight relationship ($a = 0.0001$ and $b = 3.0$), and annual catch based on single cohort during the exploited phase was used to calculate the abundance and fishing mortality rates of the cohort in each year were used as inputs to VPA analysis for the sampled species (Fry, 1949; Gulland, 1965).

Relative Yield Per Recruit (Y/R)' and Relative Biomass Per Recruit (B/R)'

Relative yield per recruit (Y/R)' and relative biomass per recruit (B/R)' were estimated using the model of Beverton and Holt (1957). The data of probability of capture file M/K values were used to estimate both (E_{max}), which represents the optimum exploitation that may maximize the yield per recruitment and ($E_{0.5}$) the exploitation level at which the biomass is reduced to 50% of the unexploited stock.

Yield Isopleth

Yield contours that indicate stock status were identified as the intersection of the exploitation rate (E) and the critical length ratio ($Lc50/L_\infty$) (Gayanilo et al., 2005).

Data Analysis

The length frequency data was pooled into groups with 20 cm length intervals. The data was then analysed using the FiSAT

II (FAO-ICLARM Stock Assessment Tools) software (Gayanilo et al., 2005).

Results and Discussion

Length Distribution

Overall, a total of 713 samples of *I. albicans* were analysed for growth and exploitation rates from the coast of Ghana. The annual length frequency ranged from 134 to 305 cm, with a mean of 252.5 ± 0.77 cm (Figure 2). The length frequency is illustrated in Figure 2. The mid-length range of 210-230 cm exhibited the highest rate, approximately 70.7%.

Growth Parameters

The results of von Bertalanffy's calculation yielded an asymptotic length ($L\infty$) of 325.5 cm TL, a growth coefficient value (K) of 0.64 per year, and a theoretical length at zero age ($t0$) of -0.13 cm/year. The longevity (Tmax) was estimated at 4.7 years. Figure 3 illustrates the reconstructed length-frequency distribution, along with growth curves (Figure 3).

Length at First Capture and Maturity

From the analysis of probability of capture of each length class, the estimated length at first capture was 186.15 cm TL (Figure 4). The length at 25 % and 75 % was 178.40 cm TL and 193.90 cm TL, respectively. The estimated length at first maturity was 150.6 cm TL.

Mortality Parameters

According to the current study, the estimated total mortality rate (Z), natural mortality (M), and fishing mortality (F) were 3.05 per year, 0.44 per year, and 2.61 per year, respectively. Based on the Z and F values, the exploitation level was 0.86 (Figure 5).

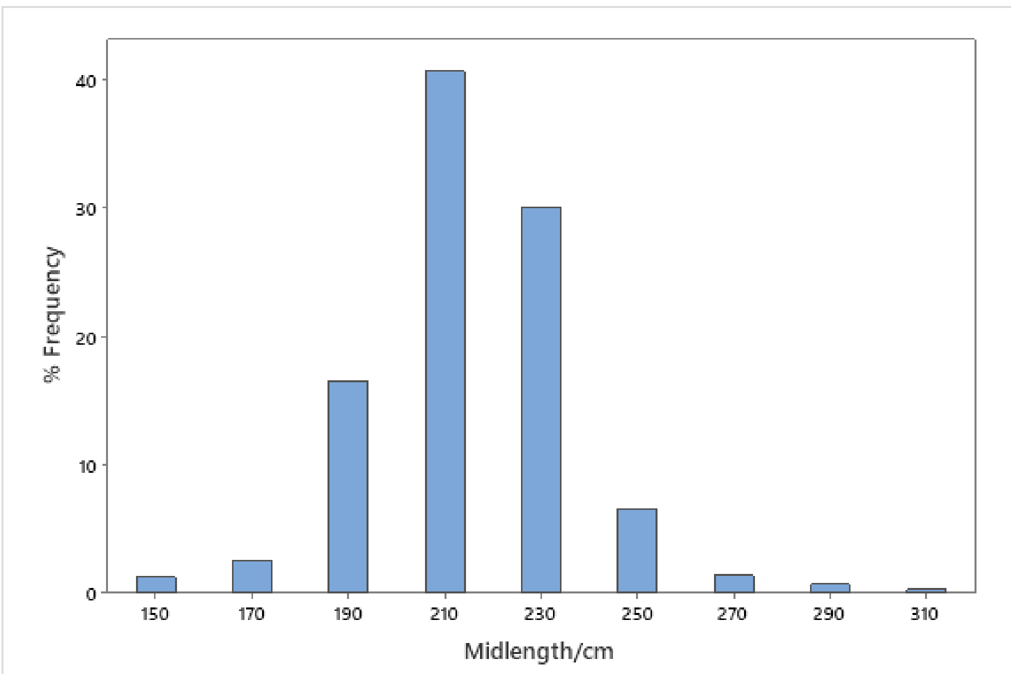

Figure 2. Annual total length frequency distribution of *Istiophorus albicans* on the coast of Ghana

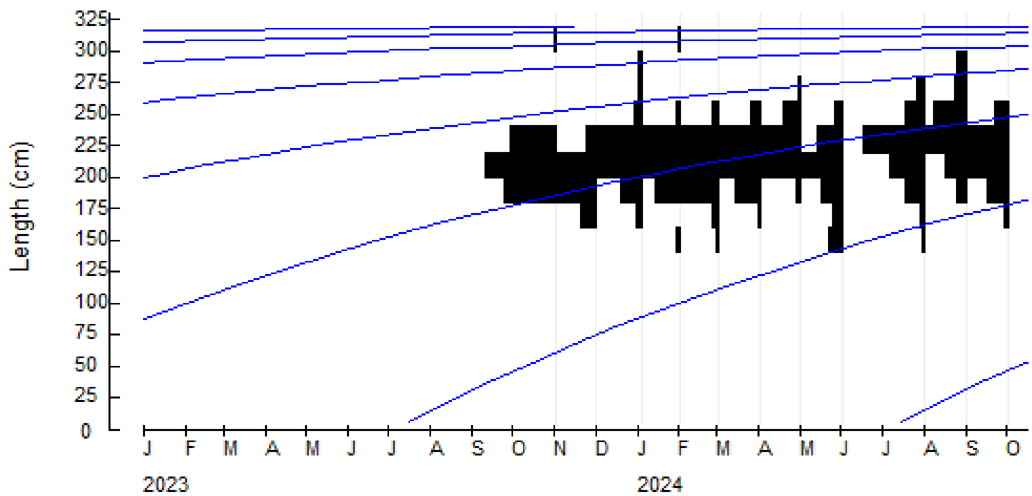

Figure 3. Reconstructed length frequency with growth curves for the Istiophorus albicans

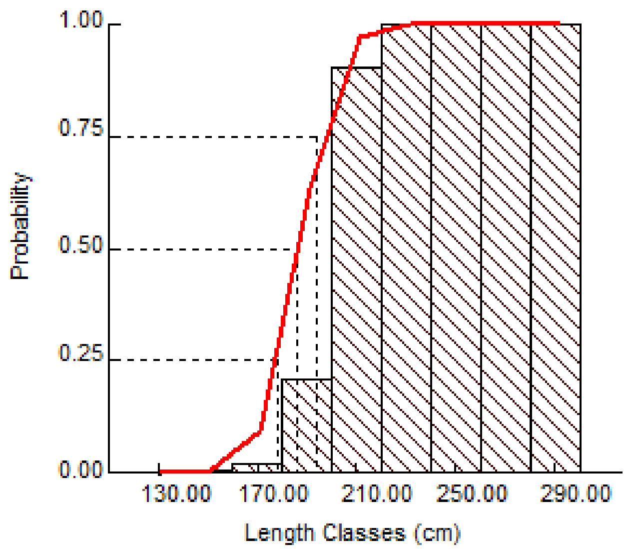

Figure 4. Probability of capture of Istiophorus albicans on the coast of Ghana

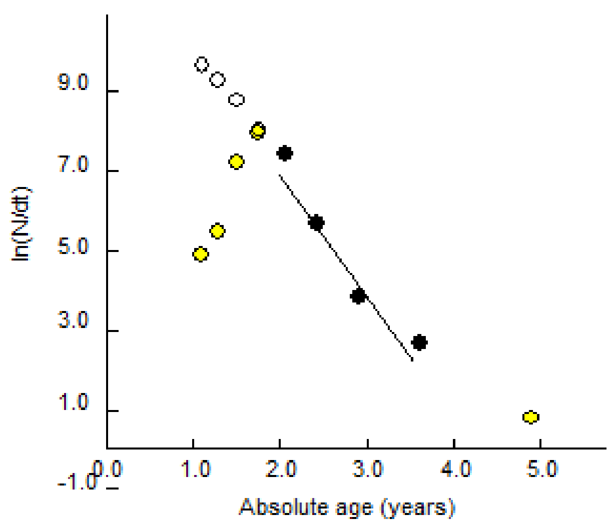

Figure 5. Linearised length-converted catch curve of Istiophorus albicans off the coast of Ghana

Recruitment Pattern

The plot shows a single central pulsed recruitment peak per year in a continuous recruitment pattern (Figure 6). The highest recruitment period occurred from April (10.4%) to September (10.6%), with a prominent peak in June, accounting for 15.8%.

Virtual Population Analysis (VPA)

The virtual population analysis revealed that the minimum and maximum fishing mortalities were recorded for mid-lengths of 150 cm and 230 cm, respectively, at rates of 0.051 and 3.97 per year (Figure 7). The highest fishing mortality for the exploited mid-length fish (230 cm) was 3.97 per year. The catches of fish were highest between mid-lengths of 210 cm and 230 cm.

Yield Per Recruit Analysis

The relative yield per recruit analysis, incorporating probabilities of capture, estimated the exploitation at maximum sustainable yield, at 10% and 50% of yield, as 0.702, 0.614, and 0.392, respectively (Figure 8).

Yield Isopleth

The isopleth yield map of the assessed fish species fell in the third quadrant with a critical length at capture (Lc) of 0.57 and an exploitation rate of 0.86 (Figure 9).

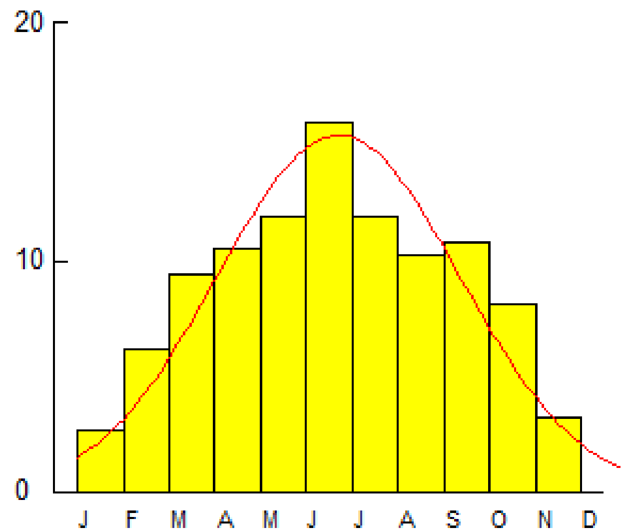

Figure 6. Recruitment of Istiophorus albicans from the coast of Ghana

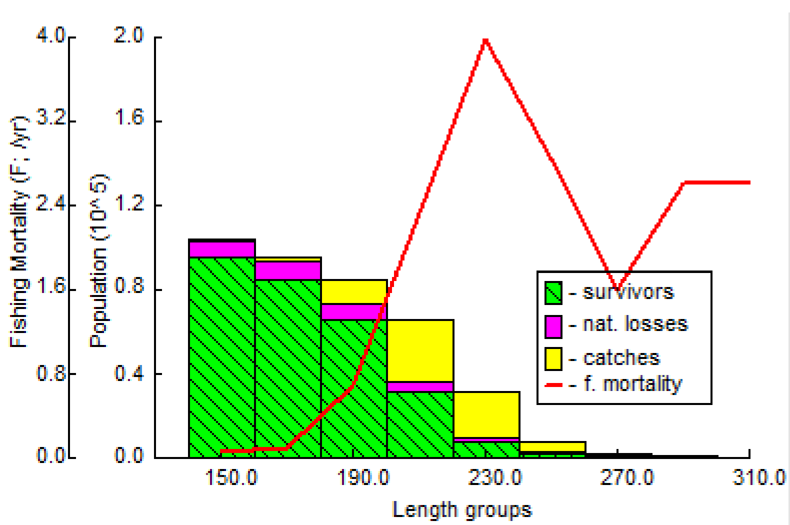

Figure 7. VPA of Istiophorus albicans from the coast of Ghana

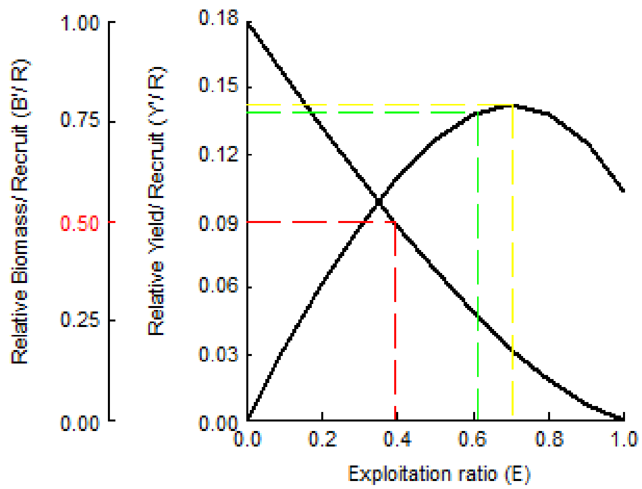

Figure 8. Relative yield per recruit of Istiophorus albicans off the coast of Ghana

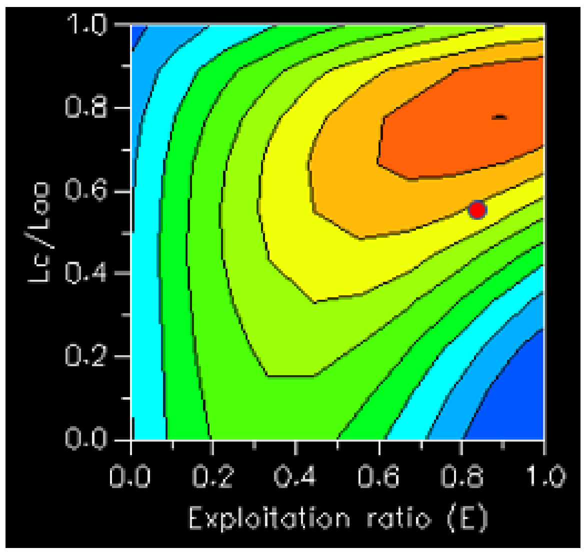

Figure 9. Isopleth plot of Istiophorus albicans from the coast of Ghana

The length interval of the sampled species from the present study varied with estimates from other studies in different locations (Table 1). The use of fishing gears with different mesh sizes across various geographical jurisdictions, differences in fishing intensities, as well as sampling size and methods, and the type of fish length recorded, could be the reason for the varying length estimates between the current study and the aforementioned studies (Amponsah et al., 2021).

The growth rate, theoretical age at length zero (t0), and L∞ values estimated in the current study differed from those estimated by other researchers (Table 2). Variations in sampling techniques, length type recorded, geographic locations, the range of sizes used in the analysis, genetic structure, and density of food may have accounted for the observed differences in growth parameters (Chiang et al., 2004; Morales-Azpeitai et al., 2013; Darvishi et al., 2018).

The recruitment pattern from the study exhibited a continuous pattern, similar to the one documented by Agnissan et al. (2014). This may suggest that environmental conditions of the Gulf of Guinea are conducive for recruitment and functioning of Atlantic sailfish. The highest peak of recruitment for the species occurred in July, which falls within the significant upwelling period in Ghana, characterised by an abundance of feed items.

According to the virtual population analysis (VPA), surviving individuals of the sampled species exhibited a declining trend as the length increased. This observation could be attributed to combined effects of natural and fishing activities. Some scholars (e.g., Agnissan et al., 2014) have noted similar implications. The fishing mortality rate has been widely used to estimate the abundance of commercial fish stocks since its development. Similarly, some scholars (Agnissan et al., 2014) have reported high fishing mortality on large-sized individuals, which may affect future recruitment potential of the species.

The length at first capture was higher than the estimates documented by Agnissan et al. (2014), which may be attributed to the mesh size of the fishing gears used, the sex of the harvested catch, environmental conditions, and the computation procedure applied (Amponsah et al., 2016). Comparatively, the length at capture was higher than the length at maturity, suggesting that the recruitment of the species may be unaffected, as individuals of the sampled species have the opportunity to spawn before becoming vulnerable to the fishing gears (Udoh et al., 2009). However, the size class obtained and the computational procedures applied may have affected the length at first maturity from the study as compared to estimates by Agnissan et al. (2014). The (L_c/L_∞) ratio estimated from the present study was 0.57, which is relatively above 0.5, indicating that the catch marginally comprised matured individuals of *I. albicans* (Pauly & Soriano, 1986). According to Sala et al. (2018), the type of fishing gear used can significantly affect the length and maturity composition of the catch. Hence, enforcing existing fishing gearregulations could help maintain the reproductive capacity of the sampled species.

The fishing mortality rate (F) of the sampled species from the current study was higher than that recorded by other scholars (Table 3), suggesting that *I. albicans* on the coast of Ghana is experiencing high fishing pressure. The exploitation rate estimated was 0.86, which is higher than the optimal exploitation rate of 0.5 (Gulland, 1971), indicating that the species is overexploited. Agnissan et al. (2014) and Surya et al. (2023) have recorded similar implications for the sampled species.

Table 1. Previous records on the minimum, maximum and mean of Atlantic sailfish

References	Location	Min. Length/cm	Max. Length/cm	Mean length/cm
Agnissan et al. (2014)	Ivory Coast	80	220	-
Surya et al. (2023)	Indian	96	284	179.0
This study	Ghana	134	305	252.5

Table 2. Previous records on growth parameters and phi-prime index of Atlantic sailfish

References	Location	K/per year	L∞/cm	Phi prime	to
Agnissan et al. (2014)	Ivory Coast	0.48		4.41	0.49
Surya et al. (2023)	Indian	0.40	231.6		-0.05
This study	Ghana	0.64	325.5	4.831	-0.13

Table 3. Previous records on the exploitation rate, length at capture and length maturity of Atlantic sailfish

References	Location	M/ per year	F/ per year	Z/ per year	E
Agnissan et al. (2014)	Ivory Coast	0.63	0.93	1.56	0.60
Surya et al. (2023)	Indian	0.32	0.69	1.01	0.68
This study	Ghana	0.44	2.61	3.05	0.86

The E_{max} was lower than the current exploitation rate (E), which was in variance with findings from the Ivorian waters, where the current E was lower than the maximum exploitation rate (Table 3). This suggests the species on the coast of Ghana is highly overexploited. In addition, at the eumetric stage, any efforts to increase yield per recruit will lead to reduced stock biomass and potential recruitment failure (Pauly & Soriano, 1986; Abobi et al., 2019). Therefore, it is crucial to reduce fishing pressure to levels closer to the E_{max}, to ensure maximum sustainability of *Istiophorus albicans* fishery and prevent further decline in its population.

Conclusion

This study offers preliminary insights into the population dynamics of *Istiophorus albicans* along Ghana's coast. The sampled species exhibited signs of rapid growth, a strategy used to compensate for the high fishing mortality rate. The recruitment pattern was continuous, with a significant peak in June. The sampled species was placed in the eumetric stage, characterised by a high exploitation rate on matured individuals. Science-based management measures by ICCAT, including gear modification, systematic data collection, catch reduction, and enforcement of minimum landing size, must be mandated and strictly enforced by policymakers in Ghana. These regulations are critical for protecting and ensuring the sustainability of sampled species.

Compliance with Ethical Standards

Conflict of interest: The author declares no actual, potential, or perceived conflict of interest for this article.

Ethics committee approval: Ethics committee approval is not required for this study.

Data availability: The data will be made available upon request from the author.

Funding disclosure: -

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Disclosure: -

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