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Research Article

Population Dynamics of *Ilisha africana* in Coastal Waters of Ghana

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ABSTRACT

The present study was aimed to estimate population parameters including asymptotic length ($L\infty$), growth rate (K), growth performance index (Φ'), natural mortality rate (M), fishing mortality rate (F), exploitation rate (E), and maximum exploitation rate (E_{max}) of *Ilisha africana* in coastal waters of Ghana for effective management measures and utilization using FiSAT. Of the total 804 specimens, asymptotic length, growth rate, and growth performance index were 23.6 cm, 0.48 per year, and 2.428, respectively. The total mortality rate (Z), natural mortality rate, and fishing mortality rate were 1.47 per year, 1.13 per year, and 0.34 per year, respectively. The exploitation rate (E) and maximum exploitation rate (E_{max}) were 0.23 and 0.56, respectively, indicating low exploitation rate of *I. africana* stocks in Ghanaian coastal waters. The induction of recruits into the stock of *I. africana* species was all year round, suggesting no recruitment for the assessed fish species. Although the exploitation of the assessed fish species was optimum, there is the need to ensure continuous monitoring of fishing effort and adherence to mesh size regulations in order to sustain the fishery.

Keywords: Growth; Mortality; *Ilisha africana*; Fishing; Ghana

INTRODUCTION

Sustainable exploitation of fisheries resources requires understanding and information on population dynamics of fish stocks. Population dynamics are the processes responsible for changes in abundance or biomass of a population through time which can provide greater insight into the fish population regarding how a population arrived at its current state and how it might change in the future [1]. Recruitment, growth, and mortality rates are the primary population dynamics (often termed rate functions) that influence the harvestable segment of a fish population [2]. The growth rates of fish in a population are intricately linked with mortality and recruitment rates. The growth rate influences survival and age at sexual maturity. Annual recruitment is typically the most variable factor affecting the dynamics of fish populations but can provide substantial insight into why fish populations may vary in size and structure [3-5]. According to Edmond *et al.* [6], mortality arises mostly through fishing activity (fishing mortality) or by natural mortality scenarios (natural [illegible] cannot be overlooked as they play a key role in expressing the dynamics of the fish population [7].

Fisheries management is changing globally. Fisheries managers have realised the importance of stock and ecosystem-based fisheries management, thus increasing the interest in developing area or stock-specific management practices which require the identification and a better understanding of various groups/stocks/populations [8,9].

Despite the importance of population dynamics to fisheries management, in Ghana, there is paucity of information on the population parameters of many marine fish species. One such species that has received little or no attention from fisheries scientists in Ghana regarding population parameters is *Ilisha africana.* Basic information needed for the management of the stock is lacking. In Ghana, *I. africana* is consumed by a large section of the coastal population, especially the poor, thus providing cheaper source of protein and a significant contribution to the Ghanaian marine fishery. Given this, the objective of the study was to evaluate some population parameters of *I. africana* for sustainable management.

MATERIALS AND METHODS

Description of the study area

Five coastal fishing communities in the Greater Accra Region of Ghana were selected for the current study. The selection of the five coastal fish landing sampling sites was based on the level of fishing

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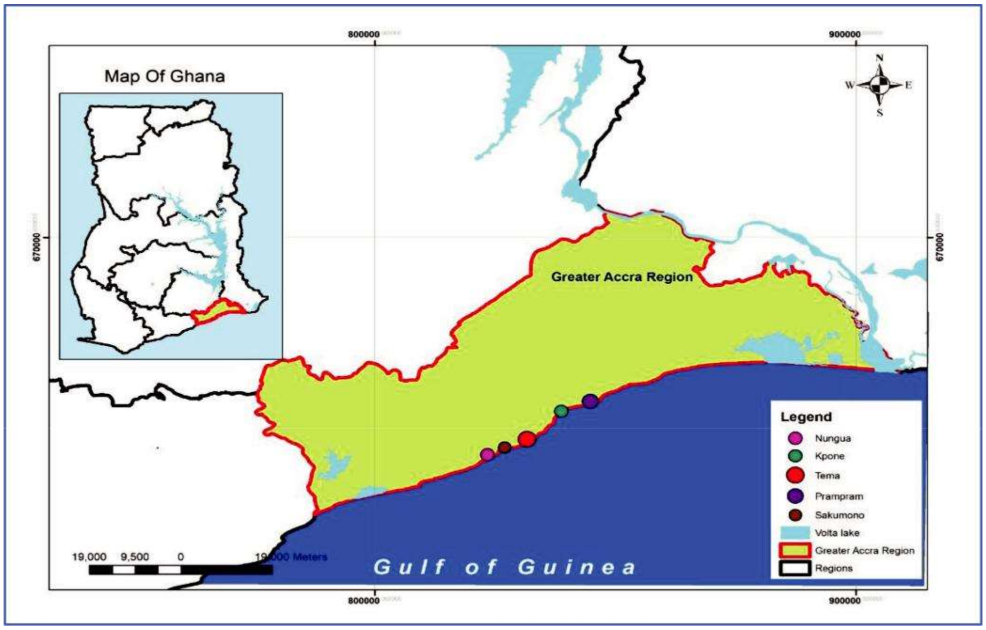

Figure 1: Map showing the fish landing sampling locations.

activities and geographic isolation. These five coastal fish landing sampling locations were Sakumono, Tema, Nungua, Kpone, and Prampram (Figure 1). The primary form of livelihood for the majority of the inhabitants in the selected five coastal fish sampling sites is fishing as well as other activities related to post-harvesting of fish from the wild.

Fish collection

Samples of *I. africana* were obtained from randomly selected fishermen who deployed multifilament fishing gears in their fishing activities from August 2018 to July 2019. Identification of samples at the sampling sites was done using [10] identification keys. The samples were preserved on ice and taken to the laboratory of the Department of Marine and Fisheries Sciences, University of Ghana, for total length and weight analysis. Measurements of length and weight were recorded to the nearest 0.1 cm using a 100 cm graduated wooden measuring board and to the nearest 0.1 g using the digital balance.

ESTIMATION OF PARAMETERS

Growth parameters

Growth parameters, which follow the von Bertalanffy growth function (VBGF) including growth rate (K), asymptotic length ($L\infty$), and the growth performance index (Φ'), were estimated using the Electronic Length-Frequency Analysis (ELEFAN I) option in FiSAT II Tool.

Estimation of longevity ($T_{\max}$) of the species was done using the method:

$$T_{\max} = 3/K \text{ [11]}$$

The growth performance index was calculated using the

formula: $\Phi' = 2\log L_\infty + \log K$ [12]

The theoretical age at length zero (t_0) was calculated using the equation:

$$\text{Log}_{10}(-t_0) = -0.3922 - 0.2752 \log_{10} L_\infty - 1.038 \log_{10} K \text{ [13]}$$

Mortality parameters

Total mortality (Z) was computed using linearized length-converted catch curve [14-15].

The natural mortality rate (M) was calculated as:

$$M = 4.118K^{0.73} L_\infty^{-0.333} \text{ [16]}$$

Fishing mortality (F) was calculated as:

$$Z–M \text{[17]}$$

The exploitation rate (E) was computed as:

$$F/Z \text{ [18]}$$

Length at first capture (Lc_{50})

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 a plot of the probability of capture against length, which was used to derive values of the lengths at capture at probabilities of 25%, 50%, and 75% [19].

Recruitment pattern

The recruitment pattern was derived using the Compleat ELEFAN I computer program [20]. The length at first recruitment (Lr) was taken to be the midlength of the smallest length interval [21].

Virtual population analysis (VPA)

VPA allows for reconstruction of population from total catch data by age or length. The initial step was to estimate the terminal population (Nt), followed by the successive estimation of F values, and finally, the population sizes are computed for each length class (midpoint). These procedures were estimated using the method described in ref. [22].

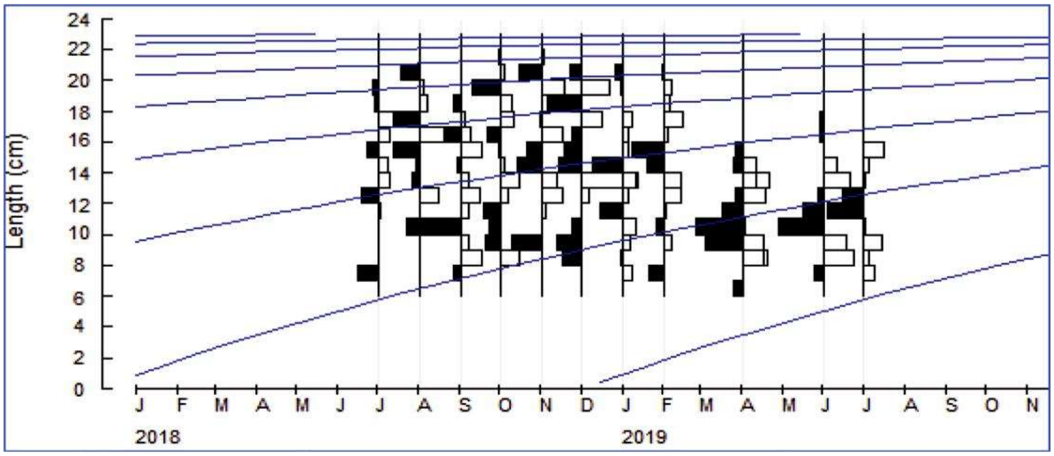

Figure 2: Reconstructed length-frequency distribution with growth curves. The black and white bars are positive and negative deviations from the "weighted" moving average of three length classes, and they represent pseudocohorts. Lines superimposed on the histograms link successive peaks of growing cohorts as extrapolated by the model.

Yield per recruit

The relative yield per recruit(Y/R) was estimated using the knife-edge method [23].

RESULTS

Length distribution

Restructured length frequency of *I. africana* with superimposed growth curves is shown in Figure 2. The asymptotic length (L_∞) was 23.6 cm with a growth rate (K) of 0.48 per year. Growth performance index (Φ′) was 2.428. The longevity (T_{max}) was approximately 6 years. The age at zero length (t_0) was estimated as -0.36 years.

Appendix 1 shows the length-frequency data obtained during the study period. In all, a total of 804 individuals were assessed.

Length at first capture

From Figure 3, the corresponding lengths at capture (Lc) were estimated as Lc_{25} = 9.5 cm, Lc_{50} = 10.32 cm, and Lc_{75} = 11.1 cm.

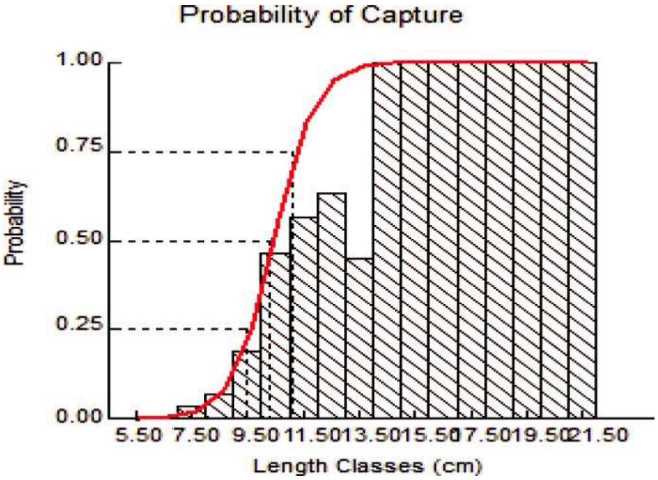

Figure 3: Capture probability of each length class of *I. africana*, Greater Accra, Ghana ($L_{25\%}$ = 8.70 cm, $L_{50\%}$ or Lc = 10.30 cm, and $L_{75\%}$ = 11.80 cm) by logistic transformation. The estimated length at first capture (dotted lines at the middle) is one of the inputs in computing the relative yield per recruit, relative biomass per recruit, and plotting of the yield isopleth.

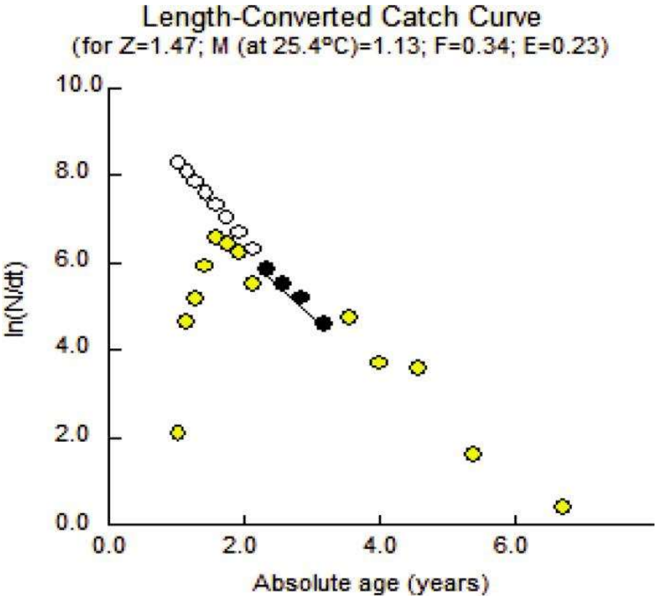

Figure 4: Linearized length-converted catch curve. Dark circles in the figure represent the points used in calculating (Z) through least squares regression lines. The yellow circles represent frequencies of fishes either not fully recruited or approaching (L_∞) and, hence, discarded from the calculation. The expected frequencies of not fully recruited fishes are added as blank circles.

Mortality parameters

The linearized length-converted catch curve was used for the estimation of instantaneous total mortality (Z) as shown in Figure 4. The total mortality rate (Z) was 1.47 year^{-1}. The natural (M) and fishing mortality rates (F) were 1.13 year^{-1} and 0.34 year^{-1}, respectively. The current exploitation rate (E) was obtained at 0.23.

Recruitment pattern

Figure 5 shows a continuous recruitment pattern of *I. africana*. The recruitment of *I. africana* spanned from March to September with its peak in June. The length at first recruitment (Lr_{50}) was 6.5 cm.

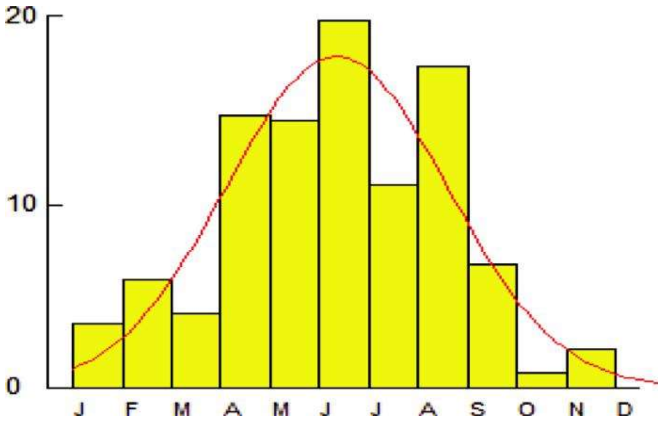

Figure 5: Percentage recruitment calculated round the year in the population of *I. africana*. The recruitment pattern showed one annual pulse of recruitment for *I. africana*, decomposed using NORMSEP routine and fitted with Gaussian distributions.

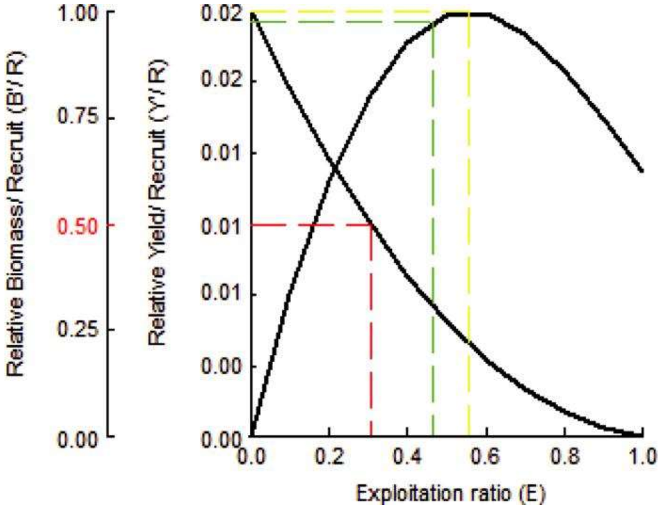

Figure 6: The relative yield plot of *I. africana* in the Ghanaian coast. Yellow line: E_{max}; red line: E_{50}; green line: E_{10}.

Relative yield per recruit

The plot of relative yield per recruit against exploitation ratio showed that the indices for sustainable yield were 0.31 for the optimum sustainable yield ($E_{0.5}$), 0.56 for the maximum sustainable yield ($E_{\max}$), and 0.46 for the economic yield target ($E_{0.1}$) as indicated in Figure 6.

Virtual population analysis

Figure 7 shows the virtual population analysis of *Ilisha africana*. Individuals within the range of 10 to 15 cm experienced the highest level of exploitation (catch = 11,300 per year). Natural losses were highest among individual within the length range of 6 to 7 cm with a value of 114291.4. Surviving individuals in the stock exhibited a declining trend with an increased rate of fishing pressure. The highest number of survivors (997,115) in the stock was observed in the length range of 6 to 7 cm, whereas the lowest number of survivors (1,297) was observed for individuals at a length range of 22 to 23 cm. Fishing effort was highest (*F* = 0.44 per year) on individuals within the length range of 20 to 21 cm and lowest (*F* = 0.001 per year) on individuals at length range of 6 to 7 cm.

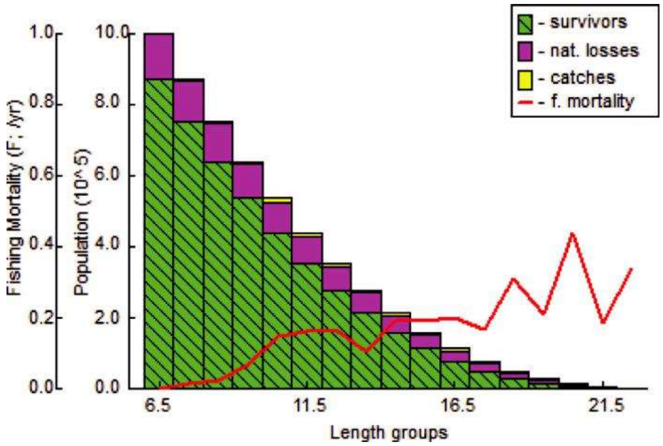

Figure 7: Length-based virtual population analysis of *Ilisha africana*.

DISCUSSION

In comparing findings from the current study to other studies within the same region, the growth rate from the current study (*K* = 0.48 per year) was higher than estimated for Gambia [24] and Senegal [25]. However, estimates of growth rates from other studies [6, 26] were higher than the estimate from the current study. On the other hand, the asymptotic length ($L\infty$) in the current study was greater than estimates reported from Beninese [6] and Nigerian waters [27]. Other studies [5, 23, 28] revealed that growth rates (*K*) are determined genetically and physiologically such as gonad maturity, sex, and growth phase. This may account for the differences in the growth rate obtained within the same sub-region. The growth rate from the present was 0.48 per year, which signifies that *I. africana* in Ghana's waters is a slow-growing species, characterized by its longevity period (t_{max}) of 10 years. Similarly, the growth performance index (Φ = 2.307) obtained in the present study was only higher than estimate by ref. [25]. This variation in growth performance index may be attributed to the heterogeneity of habitat and diversity of genetics [29-31].

The total mortality rate estimated from the current study (Z = 1.34 per year) was found to be greater than estimate by ref. [25] in the Senegalese waters. However, estimates by other studies [6, 24, 32] were higher than the total mortality estimate from the current study. It is assumed that the differences in functionality of environmental parameters in these marine species and the level of fishing effort may be the reasons for the observed variation in total mortality estimates in relation to the current study. The natural mortality rate estimated from the present study was 1.13 per year. Estimate of mortality rate by refs. [6, 24, 32] was higher than the natural mortality rate from the present study. Nonetheless, estimates of natural mortality rate from Gambia [24] and Senegal [25] were lower than estimates from the current study. Pauly [33] also postulated that ideal M should be in the range of 0.2 to 0.3. However, estimate from the current study was outside the range, which symbolizes *I. africana* from the study area was characterized by relatively high M. From the present study, the natural mortality rate (M = 1.13 $year^{-1}$) was greater than the fishing mortality rate (*F* = 0.34 $year^{-1}$). Majority of the studies carried on *I. africana* [6, 24, 25] also observed a similar situation where the fishing mortality rate was lower than the natural mortality rate. This observation could suggest that *I. africana* species in tropical coastal waters are more prone to natural mortality-induced conditions than to fishing gears.

Again, it is plausible to suggest that natural mortality is the most important form of mortality confronting this species, as such these species are not under intense fishing pressure [34]. The exploitation rate from the present study was 0.23, lower than the values provided by refs. [6, 25]. According to refs. [35, 36], the optimal E values for sustainable fishing are 0.5 and 0.4, respectively. The interpretation of these findings suggests that *I. africana* in Ghana is underexploited, which is good for the sustenance of the stock.

From the present study, recruitment into the stock was found to be continuous throughout the year, portraying the absence of recruitment overfishing. The continuous pattern of recruitment within the fishery of *I. africana* from Ghana may be a result of the continuous presence of mature female species. In addition, the unimodal recruitment curve for the *I. africana* may indicate that the assessed species spawns once in their lifetime. The length at first recruitment from the present study was 6.5 cm, which was below the calculated length at first capture (i.e. 10.3 cm). The occurrence of such a situation suggests that individuals of the assessed fish species get the chance to join the stock before becoming vulnerable to capture by any available fishing gear. This condition is good for the stock because issues regarding recruitment failure are non-existent within the *I. africana* stock in Ghana.

The estimated length at first capture from the current study for *I. africana* was 10.3 cm. This estimate was less than the value recorded by ref. [6] from Benin (i.e. 12.9 cm). The potential reason for this variation in estimates could be linked to the use of fishing gears with mesh size lower than that prescribed in Ghana's fisheries regulation instrument. The prescribed mesh size for fishing activities in the marine environment of Ghana is set at 5 cm diagonal stretch (Ghana Fisheries Act, 2002). The critical length at capture (Lc) from the study was estimated as 0.44, slightly smaller than 0.5. This suggests that majority of the catches obtained during the study period were small-sized individuals (i.e. juveniles) of *Ilisha africana*. In view of this, a continuous harvest of juveniles may catalyze the rate of growth overfishing of *I. africana* stocks in Ghana, particularly in the absence of enforcement and proper management measures. Therefore, the mesh size of the fishing gear used in the exploitation of this species should be increased using the length at 75% estimated from the present study. This would enable more matured females to participate in the reproductive activity as well as provide recruits or juveniles the chance to grow and reproduce to ensure resource availability and sustainability [37].

The number of survivors in the stock of *Ilisha africana* in Ghana's coastal waters was 997116 individuals. This high number indicates that the *I. africana* stock is not within the reach of recruit failure, and subsequently, the imminent collapse of the fishery is unlikely. Length-based VPA provides a medium for estimating fishing pressure on various length groups using fish landings from fishing operations [38]. The high fishing mortality on a large-sized individual was experienced by individuals within the interval of 20 to 21 cm. This is sustainable when it comes to management because the majority of these individuals may have undergone spawning and breeding before being captured by any fishing gear. It has been documented that the length at first maturity of *I. africana* from the waters of Ghana is 13.2 cm for the male and 14.7 cm for the female specimen [39]. Natural losses were significantly higher for individuals within the class interval of 6 to 7 cm. It is assumed that individuals with this band of length (i.e. 6–7 cm) are juveniles, and hence, the immune system is strong enough to withstand natural mortality-induced conditions such as predation and variation in environmental factors. However, the number of individuals subjected to natural losses declined as they matured, which is expected because as growth continues, species develop strong immunity against changes in environmental conditions as well as the ability to avoid predators. On the contrary, the fishing mortality rate increased as fish length increased, implying that fishes become vulnerable to fishing gears as they grow. To the relief of fisheries managers in Ghana, the existence of survivors in the stock of this species buttressed the earlier claim that the fishery of *I. africana* is far from recruitment failure within the coastal waters of Ghana.

The *I. africana* stock from the current study has not been subjected to overfishing as the exploitation rate (E = 0.23) is less than the maximum exploitation rate (E_{max}=0.56). Pauly and Soriano [40] used four-quadrant models to describe fish yield related to fish size. Quadrant A represents underfishing where the ratio of fish length at first capture (Lc) to the asymptotic length ($L\infty$) is 0.5:1, and the exploitation rate (E) is 0:0.5. Quadrant B represents eumetric fishing, where $Lc/L\infty$ = 0:0.5 and E = 0:0.5. Quadrant C represents developed fishery where $Lc/L\infty$ = 0.5:1 and E = 0.5:1. Quadrant D represents overfishing where $Lc/L\infty$ = 0:0.5 and E = 0:0.5. In comparison, the fish yield isopleths of this species belong to quadrant A as the ratio between the length at first capture (Lc) and the asymptotic length ($L\infty$) was 0.44 and the exploitation rate (E) was 0.23. Therefore, the population of *I. africana* has not been overexploited. Although the fish stock of *I. africana* has not reached the point of overexploitation, more small fishes were caught in the present study as the yield isopleths $Lc/L\infty$ (0.44) and E (0.23) belong to quadrant A.

CONCLUSION

I. africana from the coastal waters of Ghana is a slow-growing species with a growth rate of 0.48 per year. The recruitment pattern was continuous with a unimodal curve beginning in March and ending in September. As such it is safe to indicate that recruitment overfishing of *I. africana* in Ghana is absent. The exploitation rate (E = 0.23) was far below the optimum level of 0.5 and the exploitation rate at the MSY (E_{max} = 0.56), indicating that this species is not overexploited in Ghana's marine waters. This calls for continuous monitoring and sustainable exploitation to meet food security and nutritional needs of the populace.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicting interest to declare.

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APPENDIX

Appendix 1: Length frequency data for I. africana obtained during the study period

TL (cm)	1/7/2018	1/8/2018	1/9/2018	1/10/2018	1/11/2018	1/12/2018	1/1/2019	1/2/2019	1/4/2019	1/5/2019	1/6/2019	1/7/2019
6.5	0	0	0	0	0	0	0	0	0	1	0	0
7.5	2	0	3	0	0	0	1	1	0	0	5	2
8.5	0	0	2	2	0	8	2	0	1	1	4	5
9.5	0	0	5	7	1	12	3	1	9	2	9	7
10.5	0	0	14	8	0	10	3	2	5	11	44	16
11.5	6	0	5	9	1	0	8	2	6	8	32	33
12.5	14	1	3	5	1	6	6	2	1	6	24	27
13.5	8	3	3	3	2	1	5	3	2	1	5	16
14.5	8	3	5	4	5	19	11	8	3	1	5	9
15.5	9	6	2	4	5	19	5	10	3	0	0	3
16.5	5	1	8	5	2	22	4	5	0	0	2	0
17.5	3	6	4	3	3	11	2	2	0	0	1	0
18.5	4	3	7	3	2	26	0	2	0	0	0	0
19.5	3	3	0	6	1	6	1	1	0	0	0	0
20.5	0	4	0	3	3	13	1	1	0	0	0	0
21.5	1	0	0	3	1	0	0	0	0	0	0	0
22.5	0	1	0	1	0	1	0	0	0	0	0	0