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ASPECTS OF POPULATION DYNAMICS OF *PAGRUS CAERULEOSTICTUS* COLLECTED FROM THE CONTINENTAL SHELF OF SIERRA LEONE AND THE IMPLICATIONS FOR MANAGEMENT

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ABSTRACT

The study evaluated aspects of population dynamics of *Pagrus caeruleostictus* and the implications for management in Sierra Leone, needed to support efficient management plans of its fishery. 12, 729 specimens of *Pagrus caeruleostictus* were collected off Sierra Leone from January-November, 2016 using randomized sampling techniques on-board demersal trawler. Analysis of population dynamics employed methods fitted in FiSAT II software using pooled length-frequencies. Estimated growth parameters were asymptotic length (L_∞ = 34.48cm) and weight (W_∞ = 4693.6g), growth rate (K = 0.29yr^{-1}), growth performance index (ϕ = 2.54), growth exponent (b = 3.09), theoretical age (t_o = -0.8years) and life-span (t_{max} = 9.50years). The instantaneous fishing mortality rate (F = 0.40yr^{-1}) climaxed the optimum fishing mortality rate (F_{opt} = 0.30yr^{-1}) and slightly below the limiting fishing mortality (F_{limit} = 0.51yr^{-1}) whereas natural mortality rate (M) gave 0.76yr^{-1}. Besides, the estimated current exploitation rate ($E_{current}$) exceeded the estimated sustainable level of exploitation (E_{50} = 0.39yr^{-1}) but below the estimated maximum allowable exploitation point (E_{max} = 1.10yr^{-1}). Further, the length (L_{m50} = 23.00cm) and age (t_{m50} = 4.60years) at first maturity climaxed the length and age at first capture (L_{c50} = 21.64cm, t_{c50} = 3.8years,), length and age at first recruitment (L_r = 13.00cm, t_r = 2.4years). Results portrayed slow and isometric growth, median life-span and high survival of a continuously recruited spawning stock of *Pagrus caeruleostictus*. Also, the stock suffered growth overfishing, moderate fishing pressure and overexploition, implying the need for management to recalibrate measures for rational exploitation.

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INTRODUCTION

Pagrus caeruleostictus (Valenciennes 1830) commonly called the “Blue Spotted Seabream” is a demersal species of the Sparidae family that occurs in most part of the Mediterranean Sea (Bauchot and Hureau, 1986; Fischer *et al.,* 1987) at depth ranging from 30m to 200m (Bauchot and Hureau, 1986; Schneider, 1990) with more frequent occurrences in the Eastern Atlantic (Bauchot and Hureau, 1986). *P. caeruleostictus* constitutes one of Sierra Leone’s economically important demersal fish species targeted by both artisanal and industrial fishery sectors (Showers, 1995; Sesay, 2014; Seto *et al.,* 2015). The species contributed 1.77% at 0-30m, 26.30% at 31-50m, 17.70% at 51-100m and 41.10% at 101-200m depth zones of important demersal species in Sierra Leone (Sesay, 2014). Study of fish population dynamics provides insight of the status of stock including age and growth, mortality, exploitation rates, recruitment, vulnerability to capture, relative yield and relative biomass per recruit needed to formulate management measures most appropriate for sustainable exploitation of valuable stocks (Gheshlaghi *et al.,* 2012; Amponsah *et al.,* 2016; 2017; Asadollah *et al.,* 2017; Wehye *et al.,* 2017; Mehanna, 2018).

The objective of the present study was to evaluate aspects of population dynamics of *Pagrus caeruleostictus* collected from the Continental Shelf of Sierra Leone and the implications for management. The study will inform decision makers on the status of the stock for instituting management measures most appropriate for rational exploitation of such invaluable commercial species such as closed seasons and mesh size adjustment. The study will be vital to future researchers owing to scarcity of published work in Sierra Leone and wide.

MATERIALS AND METHODS

Study Area

Sierra Leone lies between latitudes 7°10′ N and longitudes 10°14′ W on the West Coast of Africa, covering an area of 71, 740km^2 (Coutin and Payne, 1989). Sierra Leone has a continental shelf area of about 30 000 km^2, an Exclusive Economic Zone (EEZ) of about 155, 700km^2 and a total area of about 155, 700km^2 (Neiland *et al.,* 2016). The climate in Sierra Leone is characterized by two distinct seasons (Coutin and Payne, 1989): the dry season (November-April) and the rainy season (May-October). Mean monthly temperatures for the open continental shelf area range from 26^{o}C – 27^{o}C and 28^{o}C – 29^{o}C for the wet and dry season respectively (Coutin and Payne, 1989). Figure 1 illustrates the Continental Shelf area of sampling in Sierra Leone.

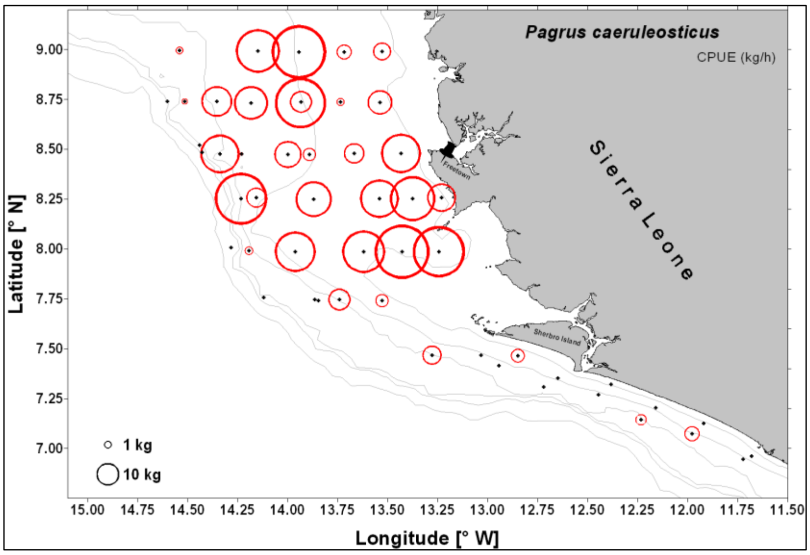

Figure 1. Catch positions of *Pagrus caeruleostictus* in the Continental Shelf of Sierra Leone

Collection of Data

Monthly fish samples were collected from a commercial trawler in the inner (10-50m) and outer (50-100m) shelf of the Sierra Leone coast, and trawl duration was standardized to 6 hrs at night. Fish samples were collected from January-November, 2016 as appropriate for relaible analysis of the dynamics of a fish population (Pauly, 1980).

Pagrus caeruleostictus was identified based on its distinct meristic and morphometric characteristics using a guide for the Gulf of Guinea (FAO, 2010). Once the catch was hauled on deck, sample collection was random, following the on-board demersal sampling methods described in Pauly (1980), and a total of 12, 729 specimens of the assessed species were collected altogether. The collected specimens were frozen and later taken to the laboratory of the Institute of Marine Biology and Oceanography, Fourah Bay College, University of Sierra Leone for measurement of total length (nearest 1cm) and body weight (nearest 1g) using fish measuring board and electronic top-pan weight scale (ADAM-ACBPlus600H) respectively.

Data Analysis

The study on aspects of population dynamics of *Pagrus caeruleostictus* and the corresponding regression analysis utilized time series of length frequencies data grouped by constant class size. Analysis of the aspects of population dynamics of the study species was completed using computerized methodologies fitted in the computerized FAO Fish Stock Assessment Tool (FiSAT II) software (Gayanilo *et al.,* 2005).

Least square regression analysis of length and weight was completed using the MS Excel (Vers. 2010) computer package, whereas the correlation coefficient (r) was calculated by the relation: r = SQRT (R^2), where 'R^2' is the coefficient of determination obtained from the length-weight relationship (Konoyima, 2020; Konoyima *et al.,* 2020).

Estimatation of Parameters

Growth Parameters

The asymptotic length (L_∞) and instantaneous growth rate (K) were respectively computed using the Powell-Witherall method (Powell, 1979; Wetherall, 1986) and method of K-Scan (using L_∞ as input parameter) in ELEFAN 1 fitted in FiSAT II routine (Gayanilo *et al.,* 2005) whereas the growth performance index (ϕ) was estimated from an empirical equation by Pauly and Munro (1984) as implemented in the FiSAT II routine thus:

$\phi = \log10\mathrm{K} + 2\log10\,(\mathrm{L}_\infty)$……… (1)

Also, the asymptotic weight (W_∞) was estimated using the expression by Pauly (1984) thus:

$\mathrm{Log}\mathrm{W}_\infty = \mathrm{LogM} + 0.0066 - 0.6543\mathrm{logK} - 0.4634\mathrm{logT}/-0.279$………. (2)

The length-weight relationship followed the least square regression equation by (Pauly, 1983; 1984) thus:

$W = aL^b$ ……… (3) (Where W = Body weight (g), L = total length (cm), b = regression coefficient/growth exponent and a = intercept).

Following the method of K-Scan in ELEFAN1 (Gayanilo *et al.,* 2005), the restructured length-frequency plots superimposed over the von-Bertalanffy growth curves (Pauly, 1982) were obtained.

Moreover, the special von Bertalanffy growth function (Pauly, 1984) was used to illustrate growth in length of the fish thus:

$L_t = L_\infty\,(1-e^{-K\,(t-to)})$……… (4) (Where L_∞ = asymptotic length, K = instantaneous growth rate. t_0 = age of the fish at length of zero, L_t = length at age t and t = age at length). Also, illustration of growth in weight took the special VBGF for a fish with allometric gowth pattern (b ≠ 3; Pauly, 1984) as follows:

$W_t = W_\infty\,(1-e^{-K\,(t-to)})^b$……… (5) (Where W_t = weight at age t, W_∞ = asymptotic weight, and b = regression coefficient).

The theoretical age at length zero (t_0) was estimated using the empirical model by Pauly (1979) thus:

$\log10(-t_0) = -0.392 - 0.275\log10\mathrm{L}_\infty - 1.038\log10\mathrm{K}$……… (6), whereas the life-span of the fish (t_{max}) was calculated using expression by Pauly (1984) thus:

$t_{max} = \frac{2.9957}{K} + t_0$…… (7)

Modal Progression Analysis (MPA)

The MPA was completed using the Bhattacharya method (Bhattacharya, 1967) fitted in the FiSAT II routine (Gayanilo *et al.,* 2005) that splited the mean length and age groups from the length frequency data based on the relationship:

Ln (N_i+1) - Ln(N_i) = aj + bj * L_i……….. (8), (Where Ni and N_i+1 are uccessive frequencies of the same component of a group of fish in a sample that represents age group j, with L_i representing the upper-class limit of N_i. Thus, the mean of the normal distribution was calculated as:

L_j = -a_j/b_j………… (9). This procedure provided summary estimates of the modal mean lengths, their population sizes (in numbers), standard deviations and separation indexes (SI).

Further, following trends in various methods of estimating age at length (Beverton and Holt, 1957; Goonetileke and Sivasubramania, 1987; Gheshlaghi *et al.,* 2012), the authors of the present study developed a simple model that can be generally used to estimate any age (t_x) at any length given (L_x) thus:

$t_x = \frac{-1}{K} * \text{Ln}\,(1 - \frac{L_x}{L_\infty}) + t_0$ ……… (10); this simple model was applied to estimate the mean age groups of the various modal mean length groups obtained from the Bhattacharya analysis.

Mortality and Exploitation Rates

The instantaneous natural mortality rate (M) was estimated from Pauly's empirical formula (Pauly, 1980) using mean surface temperature (T) of 28°C, L_∞ and K as input parameters thus:

$\text{LogM} = -\ 0.0066 -\ 0.279\ \log L_\infty +\ 0.6543 \log K +\ 0.4634 \log T$ ………… (11)

The total instantaneous mortality rate (Z) was calculated from the method of length converted catch curve fitted in the FiSAT II routine (Gayanilo *et al.,* 2005) using 'M' and 'T' as input parameters. The instantaneous fishing mortality rate (F) and current exploitation ratio ($E_{current}$) were both estimated using formula by Gulland (1971) thus:

$F = Z - M$ …… (12), and

$E = \frac{F}{Z}$ …… (13)

The maximum fishing effort (F_{max}) was calculated using the expression by Hoggarth *et al.* (2006):

$F_{max} = \frac{0.67 * K}{0.67 - (\frac{Lc50}{L\infty})}$ ……. (14), while the optimum fishing effort (F_{opt}) was estimated using the expression by Pauly (1984):

$F_{opt} = 0.4 * M$…… (15). Also, the limiting fishing effort (F_{limit}) was estimated using formula by Patterson (1992):

$F_{limit} = \frac{2 * M}{3}$…… (16)

However, extrapolating probability for the length-converted catch curve as implemented in the FiSAT II routine (Gayanilo *et al.,* 2005) using Z, T and M as input parameters, gave estimates for Z, M, F and E.

Relative Yield per Recruit and Relative Biomass per Recruit

The relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) (Knife-edge selection method) were estimated from the modified model by Pauly and Soriano (1986) fitted in the FISAT II routine using K, M, Z and E as input parameters thus:

$\frac{Y'}{R} = EU^{\frac{M}{K}} \left[1 - \frac{3U}{1+m} + \frac{3U^2}{1+2m} - \frac{U^3}{1+3m}\right]$……… (17) (Where E = current exploitation ratio and

$m = \frac{1-E}{M/K} = K/Z$…… (18)

$U = \frac{1-Lc}{L\infty}$……… (19), and

$B'/R = \frac{Y'/R}{F}$……….. (20)

The procedure for estimating Y'/R and B'/R gave estimates of biological referenced points (E_{10}, E_{50} and E_{max}), where E_{10} = exploitation point at which the related increase in yield per recruit reached 1/10 of the related increase computed at a very devalued exploitation (E) level value), E_{50} = exploitation level at which the stock has been reduced to 50% of its unexploited biomass, and E_{max} = exploitation point that gave the highest yield per recruit.

Length at First Capture and Length at First Maturity

Estimation of the vulnerability of selected length groups (L_{25}, L_{50} and L_{75}) to trawl capture followed the method of length-converted catch curve using the following relationships as implemented in the FiSAT II routine (Pauly, 1984; Gayanilo *et al.,* 2005):

Ln ((1/PL)-1) = S1 - S2 * L …… (21) (Where PL is the probability of capture of length L, and;

$L_{25} = \frac{(Ln(3)-S1)}{S2}$…… (22)

$L_{50} = SI/S2$……….. (23)

$L_{75} = \frac{(Ln(3)+S1)}{S2}$….. (24) (Where L_{25} = length at which 25% entering the trawl net were retained by the gear; L_{50} = length at which 50% of the fish entering the trawl net were retained by the gear, and was taken to be equivalent to the mean length of the fish at first capture (L_{c50}); L_{75} = length at which 75% of the fish entering the trawl net were retained by the gear; S1 and S2 are variables used for estimating the probability of capture under the logistic model).

The corresponding age at first capture (t_{c50}) was estimated using the model by Beverton and Holt (1957):

$t_{c50} = \frac{-1}{K} * Ln(1 - \frac{L_{c50}}{L_\infty}) + t_0$………. (25).

The length at first maturity (L_{m50}) is the length at which 50% of the assessed fish reached first maturity, and was estimated using a plain model by Hoggarth *et al.* (2006) using L_∞ as input parameter:

$L_{m50} = \frac{2 * L_\infty}{3}$.......... (26), and the age at first maturity (t_{m50}) was calculated using the age at length equation by Goonetileke and Sivasubramania (1987) thus:

$t_{m50} = \frac{-1}{K} * Ln(1 - \frac{L_{m50}}{L_\infty}) + t_0$……… (27).

Length-structured Virtual Population Analysis (LVPA)

In this analysis, the modified method (Jones and van Zalinge, 1981; Gayanilo *et al.,* 2005) fitted in the FiSAT II routine was employed. Input parameters were, L_∞, K, M, F and the least square regression coefficients (a and b).

Recruitment Pattern

The normally distributed recruitment pattern of the fish was ascertained by methods inscribed for the FiSAT II routine (Gayanilo *et al.,* 2005; Pauly, 1983) using L_∞ and K as input parameters, and the computed midpoint of the smallest length group of the stock was estimated as the length at first recruitment (L_r) (Gheshlaghi *et al.,* 2012; Wehye *et al.,* 2017).

The age at first recruitment (t_r) was estimated using formula by Beverton and Holt (1957):

$t_r = \frac{-1}{K} * Ln(1 - \frac{L_r}{L_\infty}) + t_0$……… (28)

RESULTS

Growth Parameters

The modified Powell-Wetherall plot (Figure 2) for *Pagrus caeruleostictus* gave a preliminary estimate of asymptotic length (L_∞) and Z/K ratio as 34.48 cm and 4.65 respectively. The mean and cutoff lengths were 20.5cm and 2.52cm respectively, and the linearized equation from the plot was, Y = 6.10 + (-0.177)* X with a very strong negative correlation coefficient, r = -0.979.

Moreover, the asymptotic weight (W_∞) was estimated to be 4.6936 km (4, 693.60g).

The theoretical age (t_0) and longevity (t_{max}) of *P. caeruleostictus* were estimated as -0.8 years and 9.5 years respectively, and the VBGF for length at age was defined as:

$$L_t = 34.48\,(1 - e^{-0.29(t-(-0.8)})$$

Length and weight of the assessed species ranged fom 11cm-31cm and from 18g-462.1g respectively, and the least square regression relationship between total length and body weight was found to be:

$W = 0.01L^{3.09}$

Length and weight positively correlated (r = 0.98) and the growth exponent (b = 3.09) was near-isometric. The special von Bertalanffy growth function for growth in weight of *Pagrus caeruleostictus* was predicated thus:

$$W_t = 4\,693.6\,(1 - e^{-0.29\,(t-(-0.8))})^{3.1}$$

Moreover, the Bhattacharya option for modal progression analysis (Figure 3) gave three modal length groups for the population of *P. caeruleostictus* of mean (±SD) lengths as 12.5 ±0.79cm, 21.12±2.29cm and 28.03±0.98cm with corresponding age groups of 2.40years, 4.10years and 6.60years, respectively. The population sizes of the respective mean length and age groups were 12, 1169 and 35 individuals.

Further the growth rate (K) and growth performance index (ϕ) were estimated at 0.29year^{-1} and 2.54 respectively.

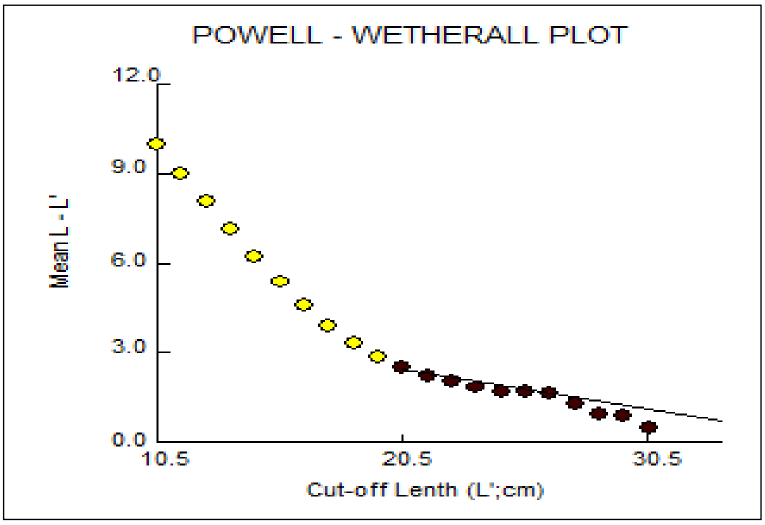

Figure 2. FiSAT II output of Powell-Witherall plot for L_∞ and Z/K ratio of *Pagrus caeruleostictus*

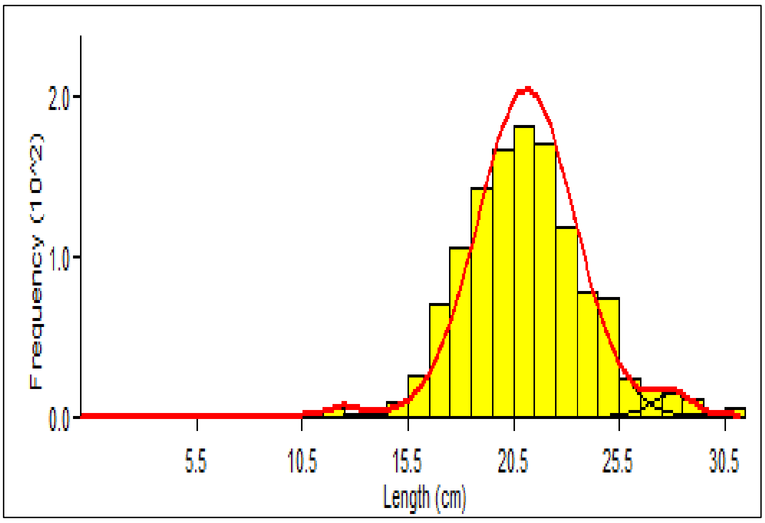

Figure 3. FiSAT II output of the Bhattacharya modal progression analysis of *Pagrus caeruleostictus*

Mortality and Exploitation rates

The total instantaneous mortality rate (Z) was estimated as 1.16year^{-1} (CL = -5.34-7.66). Summary estimate of the instantaneous natural mortality (M), instantaneous fishing mortality (F) and the current exploitation rate ($E_{current}$) are provided in the length converted catch curve (Figure 4). Regression analysis of the length converted catch curve gave mean±SD of the intercept (a) as 12.10±3.64 (95% CL = -34.24-58.34), slope (b) as -1.16±0.51 (95% CL = -7.66-5.34), correlation coefficient (r = -0.92) and coefficient of determination (r^2 = 0.84). Maximum fishing mortality (F_{max}), optimum fishing mortality (F_{opt}) and limiting fishing mortality (F_{limit}) were estimated as 2.04 year^{-1}, 0.30year^{-1} and 0.51 year^{-1}, respectively.

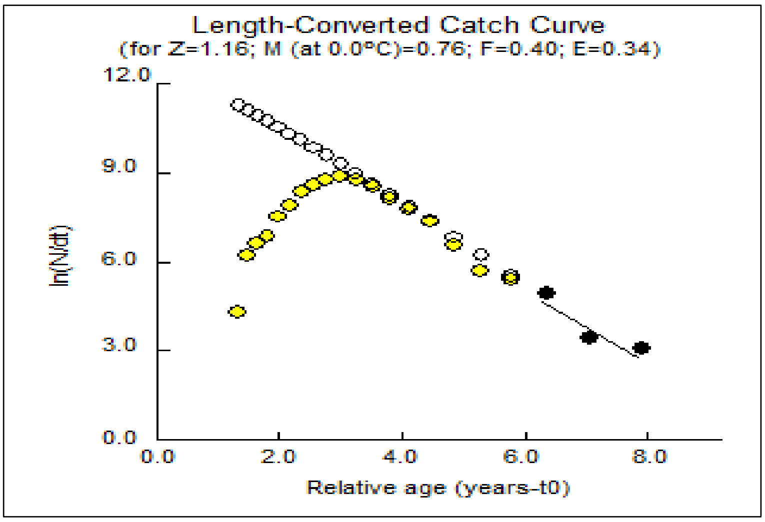

Figure 4. FiSAT II output of length-converted catch curve of *Pagrus caeruleostictus*

Per Recruit Analysis

The estimated biological referenced points of exploitation (E_{10}, E_{50} and E_{max}) of the stock of *P. caeruleostictus* were E_{10} = 1.0, E_{50} = 0.39 and E_{max} = 1.0. The exploitation point that gave the highest Y'/R and B'/R (E_{max} = 1.0) is indicated by the broken yellow line in Figure 5.

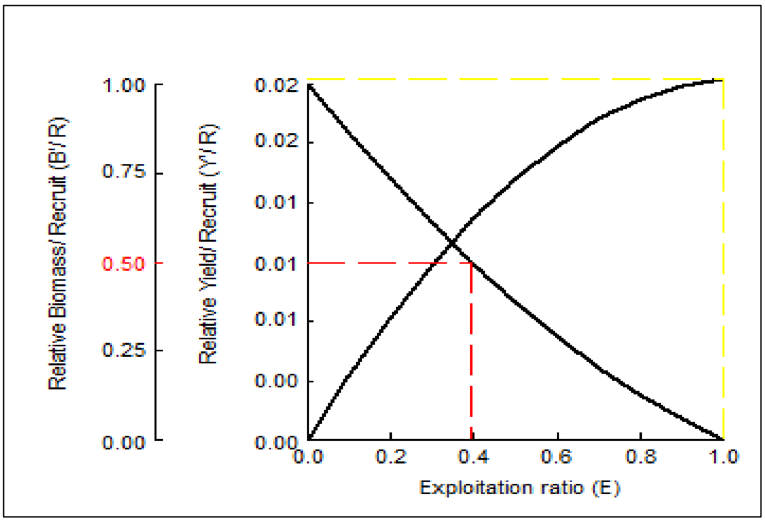

Figure 5. FiSAT II output of relative Y'/R and B'/R of *Pagrus caeruleostictus*

Length at First Capture and Length at First Maturity (L_{m50})

The probability of capture of the estimated lengths, L_{25} = 17.98cm, L_{50} = 19.81cm and L_{75} = 21.64cm were 25%, 50% and 75% respectively (Figure 6). The length at first capture (L_{c50}) was taken to be equal to the length at 50% probability of capture (i.e., Lc_{50} = 19.81 cm) while the age at first capture was estimated to be 3.8years. The length at first maturity (L_{m50}) was modeled to be 23.00cm whereas the age at first maturity (t_{m50}) was 4.6 years.

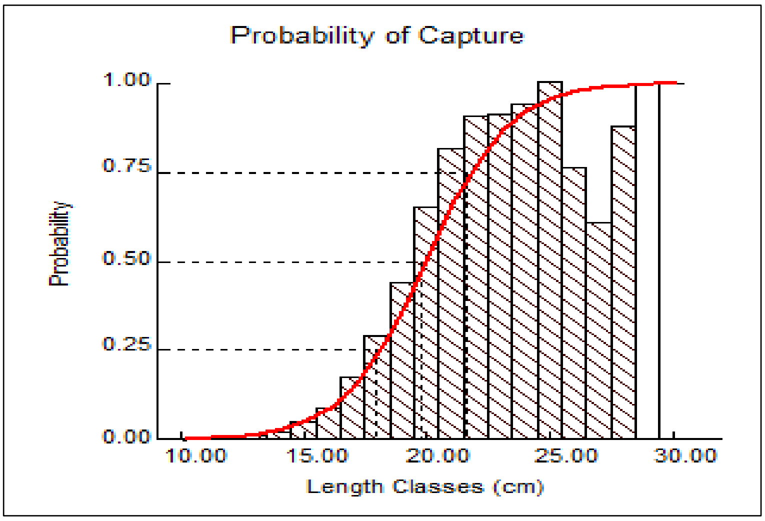

Figure 6. FiSAT II output of probability of capture of *Pagrus caeruleostictus*

Length-Structured Virtual Population Analysis

Table 1 provides the FiSAT II ouput of length-structured virtual population analysis, and there was greater harvest (catch, population and biomass) for midlength ranging from 18cm-23cm at the rate of 0.23year^{-1}-0.75year^{-1} relatively to increase in the steady state biomass (t) of the stock of. *P.caeruleostictus*. Fishing mortality rate increased steadily between 11cm and 25cm midlengths. Figure 7 further provides that natural losses and survivability of the fish population decreased with increase in length and fishing mortality. Terminal harvest rate (0.46year^{-1}) occurred for specimens of midlengths $\geq$ 28.0 cm.

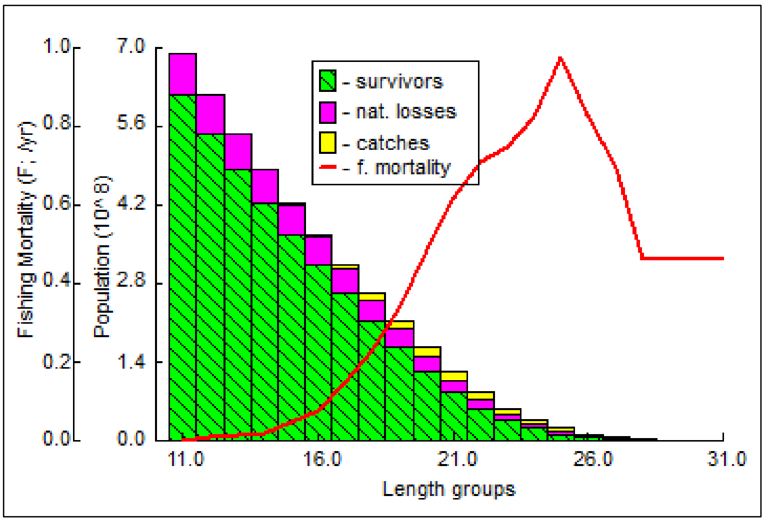

Figure 7. FiSAT II output for virtual population analysis of *Pagrus caeruleostictus*

Table 1. FiSAT II output of virtual population analysis of *Pagrus caeruleostictus*

Mid-Length	Catch (numbers)	Population (N)	Fishing mortality (F)	Steady-state Biomass (t)
11	110000	689264896	0.0011	1786.44
12	790000	616357056	0.0089	2177.81
13	1210000	547777728	0.0146	2587.24
14	1580000	483713280	0.0207	3004
15	3300000	424120480	0.0472	3409.84
16	4950000	367640352	0.0779	3780.41
17	8290000	314414688	0.1459	4079.76
18	11410000	262947232	0.2295	4261.38
19	14180000	213757104	0.3355	4283.79
20	16800000	167456240	0.4867	4100.99
21	16570000	124424648	0.6175	3708.98
22	14050000	87459400	0.7069	3173.13
23	10540000	58303164	0.748	2581.59
24	7840000	37054632	0.8247	1987.34
25	5790000	21989668	0.9756	1407.99
26	2900000	11689185	0.8274	939.04
27	1430000	6125317.5	0.6943	620.28
28	1180136	3129926	0.46	8378.09
29	0	0	0.46	0
30	0	0	0.46	0
31	0	0	0.46	0

Recruitment Pattern

Figure 8 shows a symmetric and continuous recruitment of the stock of *Pagrus caeruleostictus,* and major recruitment occurred in May and June. The length at first recruitment (L_r) and age at first recruitment (t_r) were estimated as 13.0cm and 2.4 years, respectively.

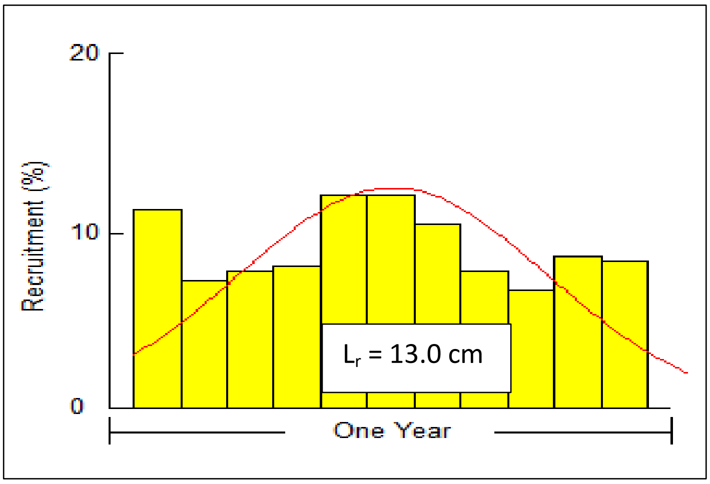

Figure 8. FiSAT II output for recruitment pattern of *Pagrus caeruleostictus*

DISCUSSIONS

Growth

The estimated asymptotic length (L_∞) and weight (W_∞) climaxed the maximum recorded sizes in the samples (L_{max} and W_{max}), suggesting that *Pagrus caeruleostictus* grew in accordance with the special von bertalanffy growth model that requires L_∞,W_∞ > $L_{max,}$ W_{max} (Pauly, 1981; 1984). Nonetheless, the estimated L_∞ (L_∞ < 50cm) placed the study species in the categoty of species not capable of attaining much larger lengths (Pauly, 1984). However, growth pattern of *P. caeruleostictus* was near-isometric (b ≈ 3.0) whereby the fish maintined its dimensional shape during growth as proferred by other scholars (Pauly, 1984; Froese, 2006; Konoyima, 2020; Konoyima *et al.,* 2020). Comparatively, the estimated asymptotic length (L_∞) and/or weight (W_∞) from this study was below that for other Sparidae species such as *Lutjanus chrysurus* (L_∞ = 76.67 cm) *and Lutjanus analis (*L_∞ = 108.2 cm TL, W_∞ = 14.34 kg) recorded off Brazil (Mattos and Maynou, 2009*),* Lutjanus campechanus (L_∞= 67.90 cm cm TL; w_∞ = 9.631kg) off Mexico (Gonzalez *et al.,* 1985), *Argyrops spinifer* (L_∞ = 67.90 cmTL) from the Persian Gulf (Ghanbarzadeh *et al.,* 2015), *Rhabdosargus sarba (*L_∞ = 46.97cm TL) from the Coast of Arabian Sea (Mehanna, 2012)*;* higher than *Lutjanus lineolatus* (L_∞ = 24.45 cm TL) off Egypt (Mehanna, 2003), *Lutjanus chrysurus (*W_∞ = 3.104kg; Mattos and Maynou, 2009) but closely related to *Lutjanus quinquelineatus* (L_∞= 35.5cmTL) off Eypt (Mehanna *et al.,* 2017) and *Lutjanus synagris (*L_∞ = 33.09cm TL) off Columbia (Luckhurst *et al.,* 2000). Other researchers have related variance in asymptotic length to differences in size of the largest fish in samples, period of sampling, depth distribution of the stock, computational methods, geographical locations and environmental factors (Pajuelo and Lorenzo, 1998; Amponsah *et al.,* 2016).

Additionally, the estimated life-span (t_{max}) from this study suggested a median life expectancy for *P. caeruleostictus,* as a much higher age limit has been observed in other sparids*, Lutjanus synagris* (t_{max} = 19 years; Luckhurst *et al.,* 2000) and *Argyrops spinifer* (t_{max} > 20years, Mcilwain *et al.,* 2005 Ghanbarzadeh *et al.,* 2015), and the M/K ratio (M/K = 2.62) beyond hypothetical limit (M/K < 1) for non-tropical fishes (Pauly, 1989) was indicative that the study species was tropical in nature. Besides, the estimated theoretical age (t_0) of the assessed species suggested that the fish spent less than one year in its early-life stages before metamorphosing to the estimated mean length (12.5±0.79cm) and age (2.4years) group of immature individuals, as the older specimens were of estimated mean length, 28.03±0.98cm and age 6.60 years (Figure 3). Similar theoretical age class (t_0) below 1yr has been noted for other Sparids such as *Lutjanus chrysurus (*t_0 = -0.728 yr, Mattos and Maynou, 2009)*, Lutjanus analis* (t_0 = -0.892yr, Mattos and Maynou, 2009) and *Rhabdosargus sarba* (t_0 = -0.83 yr, Mehanna *et al.,* 2012) whereas a little higher theoretical age was observed for *Lutjanus quinquelineatus* (t_0 = -1.3yr; Mehanna *et al.,* 2017) and *Lutjanus synagris* (t_0 = –1.95yr; Luckhurst *et al.,* 2000). Further, the estimated growth rate (K) and growth performance index (ϕ) of *Pagrus caeruleostictus* were just below recommended range for fast growing tropical species (K= 0.33 $year^{-1}$ - 0.67yr^{-1}, Kienzle, 2005) and (ϕ = 2.65-3.32, Baijot *et al.,* 1997; Montchowui *et al.,* 2011). This suggested that *P. caeruleostictus* had slow growth performance but could get better if growth conditions were improved. Aside predation, fisheries managers are adivised to recalibrate water contamination regulatory plans in and around marine zones of Sierra Leone, buttressed by the increased death by natural causes compared to fishing mortality (M >F). Low value of 'K' (K ≤ 0.4) has also been observed in other Sparids such as *Lutjanus chrysurus and Lutjanus analis (*K = 0.16yr^{-1} and 0.17yr^{-1} respectively; Mattos and Maynou, 2009*), Lutjanus campechanus* (K= 0.13yr^{-1}; Gonzalez *et al.,* 1985), *Lutjanus quinquelineatus (*K= 0.35yr^{-1}; Mehanna *et al.,* 2017), *Lutjanus synagris* (K = 0.39yr^{-1}; Luckhurst *et al.,* 2000), *Lutjanus lineolatus (*K = 0.4yr^{-1}; Mehanna, 2003), *Argyrops spinifer* (K = 0.08yr^{-1}; Ghanbarzadeh *et al.,* 2015) and *Rhabdosargus sarba* (K = 0.33 yr^{-1}; Mehanna *et al.,* 2012). Such trend in K-value of the sparids suggested that marginal growth rate may be characteristic of most species of the Sparidae family. Coherently, other studies have shown that sampling, regional hydrographic conditions and seasonal variations may impact growth performance in fish species (Ghanbarifardi *et al.,* 2014; Asadollah *et al.,* 2017; Baset *et al.,* 2020).

Mortality and Exploitation rates

In the present study, the estimated instantaneous fishing mortality rate (F) was above the estimated most favourable fishing effort (F_{opt}) and just below the estimated limiting fishing effort (F_{limit}), indicating that the stock of *Pagrus caeruleostictus* from the shelf area of Sierra Leone suffered moderate fishing pressure. It is advised that fishing effort be reduced to a rate of 0.30yr^{-1} (10 %) in order to at least achieve an optimum fishing mortality rate especially of spawners and juveniles. Such achievement is possible through instituting closed seasons or by reducing fishing hours or fleets. This finding is in agreement with Pauly (1987) who had earlier proposed an optimum fishing effort (F) to be equals 0.4M. However, the instantaneous fishing mortality rate (F) was yet within the greatest possible fishing effort (F_{max}).

Moreover, the estimated current level of exploitation ($E_{current}$) was 12.8% below the estimated relative sustainable yield point (E_{50}) that protects 50% of the biomass of *P. caeruleostictus* (Figure 5) from this study, thus strengthening the hypothesis of a stock that was moderately overfished. This implies that the current exploitation rate ($E_{current}$) should be reduced to a minimum of 0.30yr^{-1} (23.10 % below E_{50}) in order to atleast have a stock that is exploitated within efficient and safer limit that protects 50% of the biomass of *P. caeruleostictus.* According to Amin (2011), staying on the left of the maximum Y'/R value is safe for a stock, and fishing effort must be reduced in order to maintain the sustainability of the resource. Earlier studies have suggested that the optimum exploitation rate for any exploited fish stock is about 0.5, at Fopt = M (Beverton and Holt, 1957; Gulland, 1971). Notwithstanding, the estimated current exploitation rate ($E_{current}$) was lower than that which provides the maximum Y´/R and B´/R (E_{max}) from the current study, implying that the stock is yet within recovery. Other authors have however inferred that in fisheries assessment the maximum Y´/R (E_{max}) is not the target reference point but the maximum constant yield which is the maximum constant catch that is estimated to be sustainable, with an acceptable level of risk, at all possible future levels of biomass (Sissenwine, 1978; Amin, 2011). Further, the estimated Z/K ratio (Figure 2) of *P. caeruleostictus* was extremely greater than the proposed safe limit (Z/K = 2.0, King and Etim, 2004; Wehye *et al.,* 2017; Amposah *et al.,* 2016; 2017), strengthening the postulate of a stock within unsafe limit. More so, according to Johnson (1981) and Pauly (1984), the estimated Z/K ratio from this study further indicated that *Pagrus caeruleosticus* belonged to the category of the r-configured fish species (Z/K > 2).

Lengths at First Capture (L_{c50}) and Length at First Maturity (L_{m50})

The estimated length at first capture (L_{c50}) was lower than the length at first maturity (L_{m50}) from this study, indicative of growth overfishing of the stock of *Pagrus caeruleostictus* whereby immature individuals (TL < 23cm) were retained by the trawl net before they could reach first maturity. Management should ensure that the current mesh size at the cod end of demersal trawl nets be increased by at least 14% in order for juveniles of the assessed fish to survive retention by the gear. Other scholars concur that growth overfishing occurs when the length at first capture exceeds length at fist maturity of a fish species (Amponsah *et al.,* 2016; 2017; Wehye *et al.,* 2017). Buttressing this postulate was the fact that the estimated age at first capture (t_{c50}) was below the age at first maturity (t_{m50}), indicating that young and immature individuals of the study species were collected by the trawl gear before they could reach the age of maturity.

Moreover, the virtual population analysis (Table 1; Figure 7) from this study suggested that the greatest harvest of the population of *P. caeruleostictus* was made from individuals below the length and age of first maturity, and the estimated probability of capture (Figure 6) further indicated that all selected lengths groups (L_{25}, L_{50} and L_{75}) were vulnerable to retention by the trawl gear. This further connotes growth overfishing, and in order to maintain individuals for spawning and recruitment, management is advised to increase the the current mesh sizes probably at the cord end of the demrrsal tawl nets as proposed initially. Other authors agree that the size of fishing nets should be limited to allow the escapement of young fishes and to conserve the reproducible part of fish population (Mehanna *et al.,* 2012; Ghanbarzadeh *et al.,* 2015; Amposah *et al.,* 2016; 2017; Wahye *et al.,* 2017).

Recruitment Pattern

The symmetric recruitment pattern of the spawning stock of *Pagrus caeruleosticus* portrayed an uninterrupted recruitment throughout the sampling periods, and major recruitment in May and June (Figure 8) coincided with the rainy season, probably owing to favourable conditions during such periods. Also, the lower estimated length (L_r) and age (t_r) at first recruitment than the length (L_{c50}) and age (t_{c50}) at first capture, precluded recruitment overfishing of the spawning stock of *P. caeruleostictus,* and that the new recruits survived capture. Notwithstanding, the estimated mean length (L' =20.0cm) of size groups fully recruited into the fishery (Figure 2; Gayanilo *et al.,* 2005) implied that the harvested individuals of the assessed species involved those yet to be fully recruited into the capture fisheries, further emphasizing the need for mesh size adjustment at the cod end of trawl nets of dermersal trawlers operating in the Sierra Leone territorial waters in order to maintain the continuous recruitment of the spawning stock of *Pagrus caeruleostictus*. Several authors have inferred that recruitment overfishing can occur when the length at first recruitment surpasses the length at first capture (Mehanna *et al.,* 2012; Amposah *et al.,* 2016; 2017; Wahye *et al.,* 2017). The continual use of small mesh sized fishing gears alongside high fishing effort could result in diminished catch per unit effort, collapse of the fishery and a consequentially low economic rent in the fishery industry (Pauly and Soriano, 1986; Amponsah *et al.,* 2017).

CONCLUSIONS

Total length and weight of *Pagrus caeruleostictus* grew in accordance with the special von bertalanffy growth model, and the fish had a slow growth but maintained its shape as it grew (isometric growth pattern). Besides, the assessed fish was tropical and r-configured with three mean (±SD) length groups (12.5 ±0.79cm, 21.12±2.29cm and 28.03±0.98cm) and corresponding age groups (2.40 years, 4.10 years and 6.60 years) respectively with a life-span of 9.5 years.

The stock of *P. caeruleostictus* suffered growth overfishing, moderate fishing pressure and overexploition, implying the need for management to recalibrate measures for rational exploitation. This can be achieved by increasing the current mesh size at the cod end of trawl nets by at least 14%, reduce current fishing effort (F) and current exploitation rate ($E_{current}$) to a minimum rate of 0.30yr^{-1} (10 %) and 0.30yr^{-1} (23.10 %) respectively, in order to have immature individuals escape retention in trawl nets, achieve at least an optimum fishing mortality rate and sustainable exploitation limit that protects 50% of the spawning biomass respectively. In addition to fishing pressure, death of individuals by natural causes was eminent (M>F), arousing concerns about environmental quality by management. However, recruitment of the spawning stock was continuous with major peaks in May and June, and the newly recruited individuals survived capture by the gear ($L_{c50} > L_r$).

COMPETING INTEREST

The authors declare that there is no competing interest.

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