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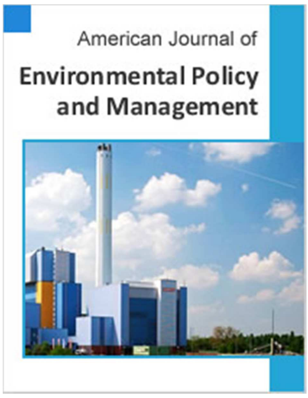

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Stock Assessment of *Chrysichthys nigrodigitatus* in the Mid Cross River Flood System, South Eastern Nigeria: Implications for Fishery Management and Policy

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Abstract
Stock assessment involves the application of statistical and mathematical methods to make quantitative statements about the status of fished populations and predictions about how they are likely to respond to alternative management choices, thus the stock assessment of *Chrysichthys nigrodigitatus* (n = 470) in the mid-Cross River basin was studied. Monthly samples were collected from commercial artisanal fishermen from July 2011 to June 2012. The FAO-ICLARM Stock Assessment Tool (FiSAT II) software was used for data analysis. Growth parameters for *C. nigrodigitatus* were as follows: asymptotic length L_∞ = 29.93 cm TL and growth curvature K = 0.18 yr^{-1}. The mortality parameters for *C. nigrodigitatus* were: total mortality Z = 0.86 yr^{-1}, natural mortality M = 0.59 yr^{-1}, and fishing mortality F = 0.27 yr^{-1}. *C. nigrodigitatus* exhibited a bimodal recruitment pattern. Length at first capture (L_c) was 12.22 cm TL. The selection ogive procedure for relative yield and biomass per recruit showed that E_{max} was 0.59 for *C. nigrodigitatus*. The stock was not overexploited, since $E < E_{max}$. The exploitation rate (E) was 0.32 and given that $E < 0.50$ is considered to be moderately exploited for the fishery. However precautionary management is needed as the M value is high.

1. Introduction

In many developing countries fisheries represent an important contribution towards food security, income and employment globally. There is a major problem in lack of information about many fisheries, resulting in fisheries that are not well managed. At the same time many fisheries may be threatened by degradation of the environment, loss of habitat and by overexploitation of fishery resources. However, data related to this sector are often poor or non-existent. As a result, the available approaches may be limited and resulting estimates, subject to some uncertainty. This may present problems when aggregating capacity measures at the national or regional level, particularly if output-based measures of capacity by species are not available. Stock assessment involves the application of statistical and mathematical methods to make quantitative statements about the status of fished populations and predictions about how they are likely to respond to alternative management choices. Thus, the available knowledge about species biology, populations dynamics and fish community structure will constitute a set of important tools to subsidize not only the sustainable exploration of the fishing resources, but also the regional development policy options, allowing to evaluate and foresee the possible effects on the aquatic ecosystem. The genus *Chrysichthys* belongs to the family Bagridae and has been described by [1] and [2]. The genus exhibits great economic importance and several aspects of its biology have been studied by various authors in Nigerian water bodies: age and growth [3], [4] and [5], condition factor, diet and reproductive biology [6], [7], [8], [9], [10], [11], [12] and diseases [13]. *C. nigrodigitatus* is an important, highly valued and ubiquitous freshwater fish of Nigerian inland waters and is sought after for its flavor and chemical composition [14], [15] and [16]. The acute reduction in the population of this species in Nigerian waters has been mentioned [10]. Therefore, this study seeks to bridge this gap in knowledge by providing information on the stock assessment of *C. nigrodigitatus* necessary for adopting management, conservation policies and in the further development of the fishery. This study further forms a comparison base for the assessment of other stocks that can be incorporated into wider reference systems relevant to current fisheries assessment and management.

2. Materials

2.1. Study Area

The Cross River is a major component of the inland waters of south-eastern Nigeria, and its role to the fishery of the area is quite significant [17]. The Cross River originates from the Cameroon high mountains and flows through Ebonyi State and Cross River State into the Atlantic Ocean. The river (Figure 1) [17] lies in an area between 5°57" – 5°30'20" N and 7°58" – 5°30'20" E. The approximate surface area of the Cross River is 3,900,000 ha [18]. According to [19], the rainy season and the dry season are the two main seasons of the area. The latter occurs between October/November and March, while the former is from April to September/October. During the rainy season, water level increases dramatically in the river. The rise in water levels of the river is brought about by direct precipitation within the catchment areas as well as by inflow from the Afikpo and Cross River flood plains. The inundated soils are sandy with good water retention capacity. During the dry season, water is restricted to the main river channel and some flood plain pools.

2.2. Sample Collection

Samples were collected monthly for twelve (12) consecutive months (July 2011-June 2012). *C. nigrodigitatus* (n = 470) were randomly sampled from the catches of commercial artisanal fishermen. These fish samples were collected from four sampling locations, Ozizza, Ndibe, Enohia, and Uwana in the Cross River basin at Afikpo, Nigeria (Figure 1). Catches were taken using cast nets, lift nets, gill nets, fishing baskets and traps. Catch samples were sorted and identified to the species level using the guides of [20] and preserved in 10% formalin.

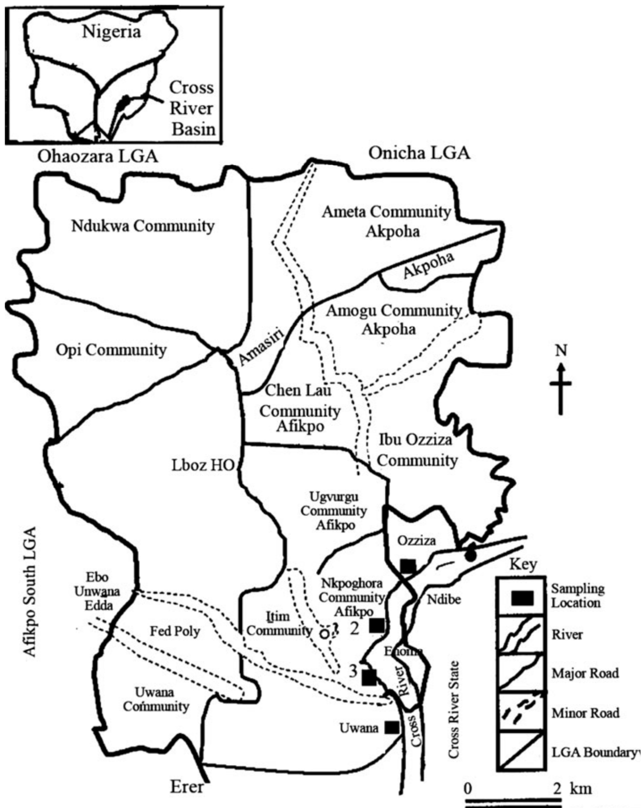

Figure 1. *Map of Afikpo North Local Government Area showing the sampling locations in the Cross River basin (Okoh et al., 2007).*

2.3. Morphometric Measurements

Total length (TL) was measured with a meter rule measuring board to the nearest 0.1 cm. Weight measurement was made with a FEJ-1500A electronic compact weighing balance to the nearest 0.1 g.

2.4. Estimation of Growth Parameters

The length-frequency distribution tables were constructed for the population to determine the dominant size group(s) and its/their percentage composition. The FAO-ICLARM Fish Stock Assessment Tools (FISAT II) software [21] was used to analyse the monthly length-frequency data. The Powell-Wetherall method was employed in the estimation of the asymptotic length (L_∞) of the von Bertalanffy growth function (VBGF) and the ratio of the total mortality to growth coefficient (Z/K) from the linear relationship:

$$\bar{L} - L^1 = a + bL^1$$

Thus, plotting $\bar{L} - L^1$ against L^1 gives a linear regression from which *a* and *b* could be estimated and hence L_∞ and (Z/K) [22].

From the equation above

$$L_\infty = -(a/b)$$
$$Z/K = -(1+b)/b,$$

where a is the intercept on the $(\bar{L}-L^1)$ axis, and b is the slope.

The growth coefficient (K) was estimated from [23]:

$$K = 0.27\exp^{0.038T},$$

where T is the mean environmental temperature °C.

The ELEFAN I procedure in FISAT II was then used to sequentially arrange and restructure the monthly length-frequency data set. The K-scan routine from the FISAT II program provided estimates of L_∞ and K. The ELEFAN I was used to calculate growth parameters for the generalized von Bertalanffy growth function (VBGF) for length L at age t [24]:

$$L_t = [L_\infty (1 - e^{-k(t-t_o)})]$$

where L_∞ is the asymptotic length of fish and K is a growth curvature parameter.

The weight-based von Bertalanffy growth equation was also determined by combining the von Bertalanffy growth equation with the length-weight relationship [25]. The weight-at-age curve was then calculated using the equation:

$$W_t = [W_\infty (1 - e^{-k(t-t_o)})^3]$$

where W_t is the mean weight (g) at age t, W_∞ is the asymptotic weight (g), K is the curvature of the VBGF or growth coefficient (year^{-1}), and t_0 is the hypothetical age (year) at which length equals zero. The asymptotic weight corresponding to the asymptotic length is determined by the equation $W_\infty = aL_\infty{}^b$.

The age-at-length zero (t_0) was derived from the empirical relationship of [26]:

$$Log\,(-t_0) = -0.3922 - 0.2752 Log\, L_\infty - 1.038 Logk.$$

The length-at-age zero (L_0) was estimated according to [25] as:

$$L_o = L_\infty\,[1 - \exp^{(kt_o)}]$$

The individual species' maximum size encountered ($L_{\max}$) and longetivity ($t_{\max}$) [27] was evaluated as

$$t_{\max} = 3/K$$

The length growth performance index ϕ^1 [28] was computed as

$$\varphi^1 = Log\,\mathrm{K} + 2\,Log\,L_\infty$$

2.5. Estimation of Mortality Parameters

The ELEFAN II was used to estimate the instantaneous total mortality coefficient Z via a linearized length-converted catch curve analysis [29] using:

$$In[Ni/\Delta t_i] = a + b.t_i,$$

where N_i is the number of fish in various length classes i; Δt_i is the time needed to grow through length class i:

$$\Delta t_i = [1/k].\, In[\frac{L_\infty - L_i + 1}{L_\infty - L_i}]$$
$$t_i = [1/k].\, In[1 - (\frac{L_i}{L_\infty})].$$

Li is the midpoint of length class i; the value of b with the sign changed provides an estimated value of Z.

The natural mortality coefficient (M) [27] was estimated using the empirical relationship:

$$Log\,M = -0.0066 - 0.279\,Log\,L_\infty + 0.65543\,Log\,K + 0.4634\,Log\,T.$$

The fishing mortality coefficient (F) was computed as:

$$F = Z–M.$$

The exploitation rate (E) was computed from:

$$E = F/Z.$$

2.6. Determination of the Recruitment Pattern

The recruitment pattern of the stock was determined by backward projection on the length axis of the set of available length-frequency data as described in the FiSAT software package [21]. This routine reconstructs the recruitment pulse from a time series of length-frequency data to determine the number of pulses per year and the relative strength of each pulse. Input parameters were L_∞, K, and t_0. The normal distribution of the recruitment pattern was determined by NORMSEP in the FiSAT program.

2.7. Prediction of Relative Yield and Biomass per Recruit Analysis

The model of [30] as modified by [31] was used to predict the relative yield per recruit:

$$\frac{y^1}{R} = EU^{\frac{M}{k}}\left\{1 - \left[\frac{3u}{1+m}\right] - \left[\frac{3u^2}{1+2m}\right] - \left[\frac{u^3}{1+3m}\right]\right\},$$

where $E = F/Z$ is the exploitation rate, i.e. the fraction of mortality caused by fishing activity.

F is the instantaneous fishing mortality coefficient,

$U = 1 - (L_c/L_\infty)$ is the fraction of growth to be completed by the two fish species after entry into the exploitation phase,

$$m = (1 - E) / M/K = K/Z.$$

The relative biomass per recruit was estimated as

$$B'/R = \frac{y'/R}{F}$$

Estimations of E_{max} (exploitation rate which produces the maximum yield), $E_{0.1}$ (exploitation rate at which the marginal increase of y^1/R is 0.1 of its value at $E = 0$), and $E_{0.5}$ (the value of E under which the stock is reduced to 50% of its unexploited biomass) through the first derivative of the [30] function were made. These parameters were compared with the current rate of exploitation (E). The state of the stock was evaluated as follows: in equilibrium ($E = E_{max}$), overexploited ($E > E_{max}$), or underexploited ($E < E_{max}$). Additionally, the yield contours to assess the impact on yields of changes in E and L_c / L_∞ was plotted [21].

3. Result

Length frequency distribution of *C. nigrodigitatus* (n = 470) of the mid Cross River flood system ranging from 10.5-28.5 cm TL showed that the length class 13-14 cm TL (midlength 13.5 cm TL) had the highest frequency (Figure 2). Results of the analysis using the Powell-Wetherall method gave the values of asymptotic length (L_∞) as 29.73 cm TL and Z/K = 0.95 (Figure 3). Analysis of the ELEFAN I in the FiSAT II software yielded the optimized VBG curves with the following parameters using the K scan (Figure 4): asymptotic length L_∞ = 29.93 cm TL, VBGF growth constant K = 0.18 yr^{-1}. The length and weight growth performance index φ^1 and φ were 2.21 and 1.20 respectively.

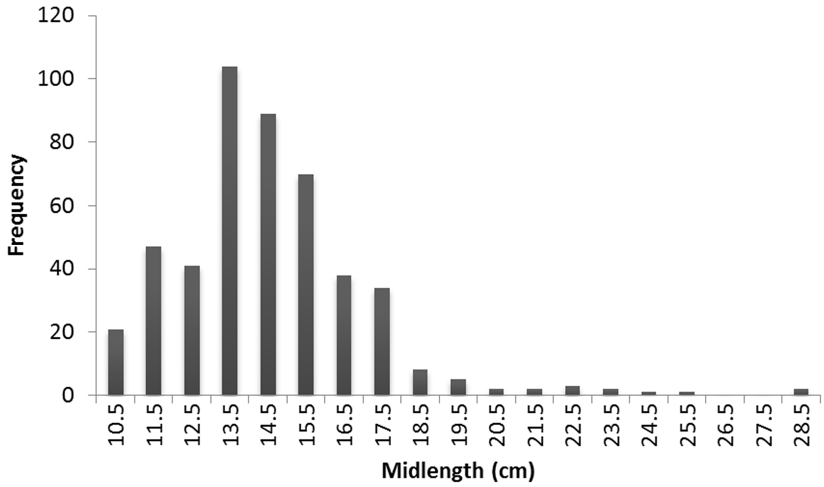

Figure 2. *Length frequency distribution of C. nigrodigitatus.*

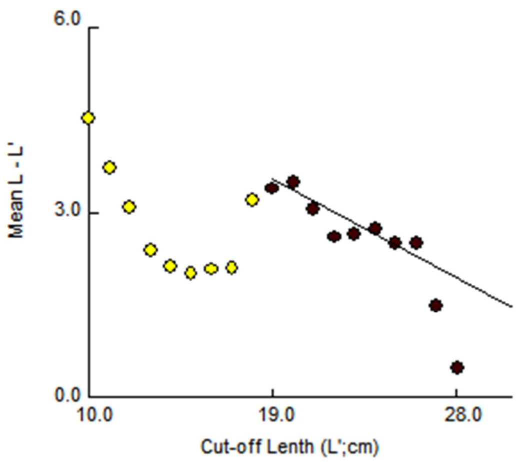

Figure 3. *Powell-Wetherall plot of C. nigrodigitatus.*

Figure 5 shows the length-frequency histograms length-frequency histograms. Figure 6 shows the restructured length-frequency histograms (the black and white bars are positive and negative deviations from the running average of three) with the growth curve. The estimated values for t_0, L_0, and t_{max} were −1.60 yr, −9.95 cm TL, and 16.67 yrs, respectively. The maximum length (L_{max}) encountered was 28.3 cm TL. From these parameters, the von Bertalanffy length (L_t) and weight (W_t) growth function were established as:

$$L_t = [29.93\ (1 - e^{-0.18\ (t+1.60)})]$$

$$W_t = [838.21\ (1 - e^{-0.18\ (t+1.60)})^3]$$

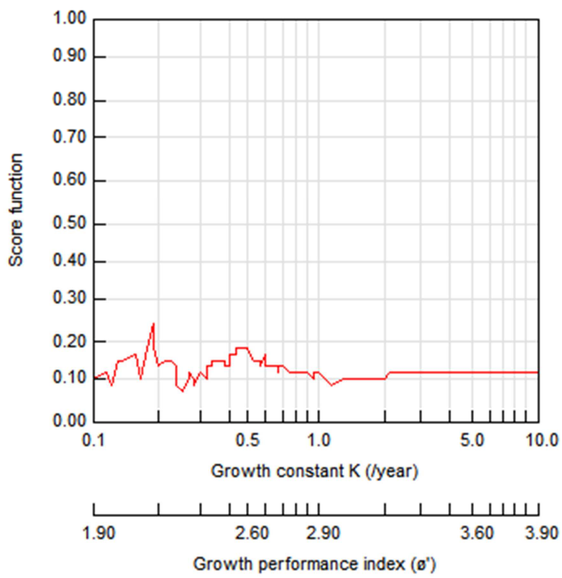

Figure 4. *K scan plot of C. nigrodigitatus.*

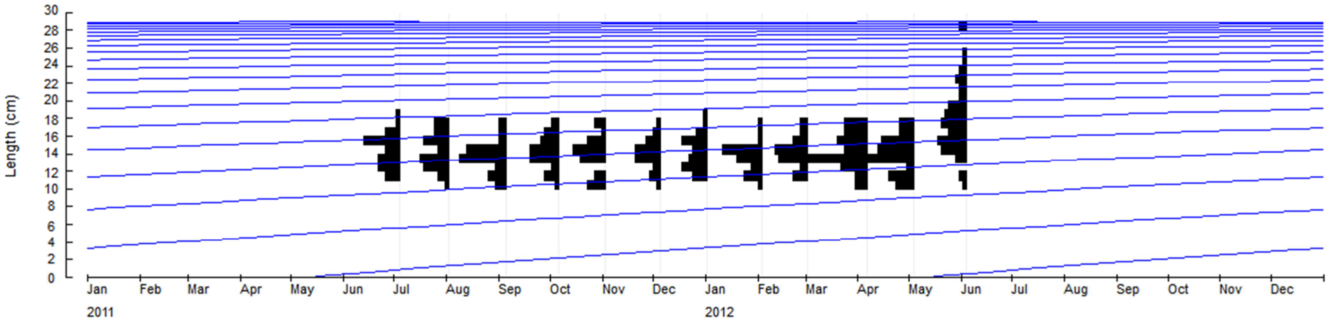

Figure 5. *Length-frequency histograms with the VBGC of C. nigrodigitatus.*

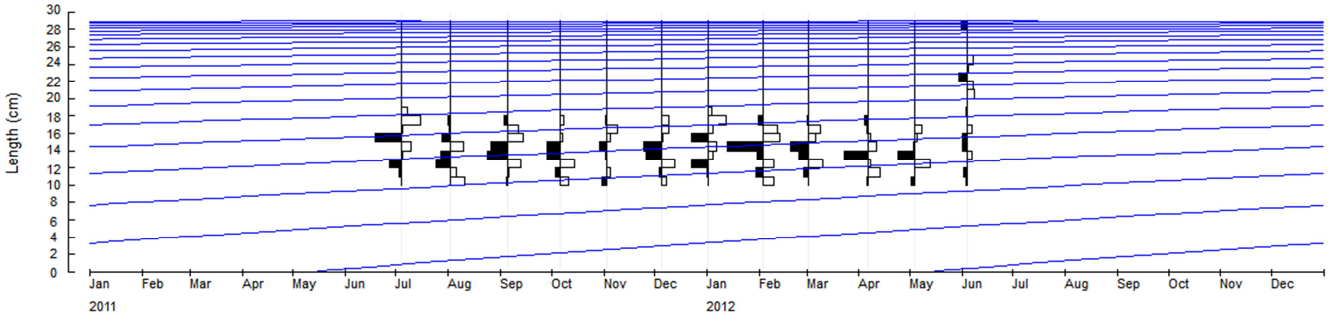

Figure 6. *Restructured Length-frequency histograms with the VBGC of C. nigrodigitatus.*

Using the non-seasonalized length-converted catch curve analysis (Figure 7) in FiSAT II, the computed total mortality (Z) for *C. nigrodigitatus* was 0.86 yr^{-1}. The natural mortality coefficient (M) at 28.5°C was 0.59 yr^{-1}, and fishing mortality coefficient (F) was 0.27 yr^{-1}. E (exploitation rate) was computed to be 0.32.

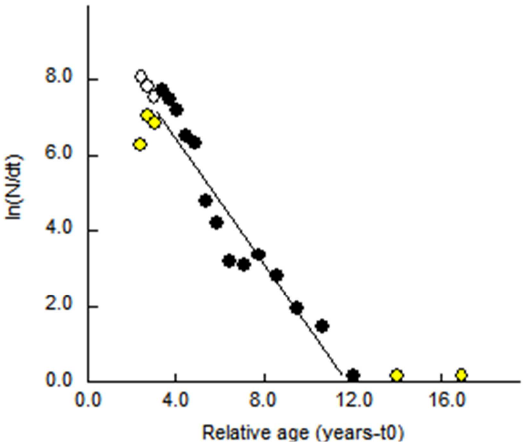

Figure 7. *Length-converted catch curve analysis of C. nigrodigitatus.*

The probability of capture analysis of each size class for *C. nigrodigitatus* was derived (Figure 8). The computed length at first capture L_{50} or L_C (length at which 50% of the fish entering the gear are retained) was 11.86 cm TL. L_{25} (length at which 25% of the fish entering the gear are retained) was 10.82 cm TL, and L_{75} (length at which 75% of the fish entering the gear are retained) was 12.80 cm.

In the population of *C. nigrodigitatus*, there were two recruitment peaks in a year (i.e. bimodal recruitment), and the peaks overlapped in time to give a continuous year round pattern (Figure 9). The first mode was from March to May with 11.07%, 10.16% and 9.51% recruitment respectively. The second mode was in August and September with 14.05 and 14.00% recruitment respectively. VPA results for *T. zilli* indicated one peak (Figure 10) of fishing mortality (F). The peak of F occurred in the length class 28.0 to 29.0cm TL with midlength of 28.5cm.

Using the knife-edge selection procedure for the analysis of relative yield and biomass per recruit of *C. nigrodigitatus* (Figure 11 and 12) gave an E_{max} (the value of exploitation rate E giving the maximum relative yield per recruit) of 0.817, $E_{0.1}$ (the value of E at which increase in the Y^1/R is 10% of its value) of 0.665, and $E_{0.5}$ (the value of E at 50% of the unexploited relative biomass per recruit) of 0.349. Figure 13 shows the selection ogive procedure of *C. nigrodigitatus* with E_{max} as 0.591, $E_{0.1}$ as 0.510, and $E_{0.5}$ as 0.331.

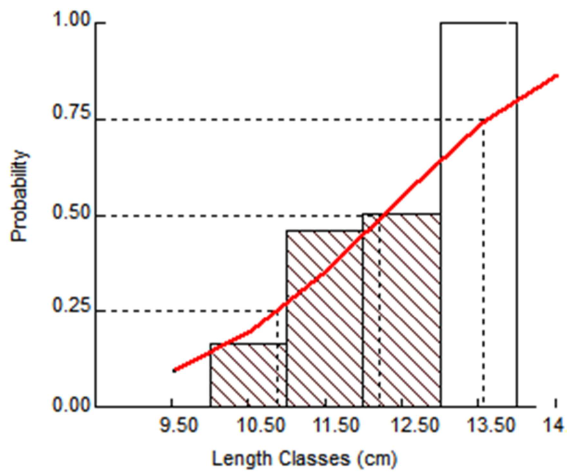

Figure 8. *Probability of capture analysis of C. nigrodigitatus.*

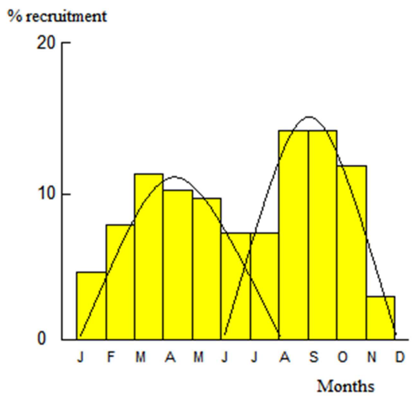

Figure 9. *Continous bimodal recruitment pattern of C. nigrodigitatus.*

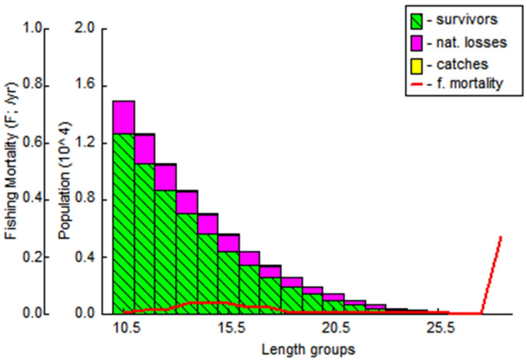

Figure 10. *Virtual population analysis of C. nigrodigitatus.*

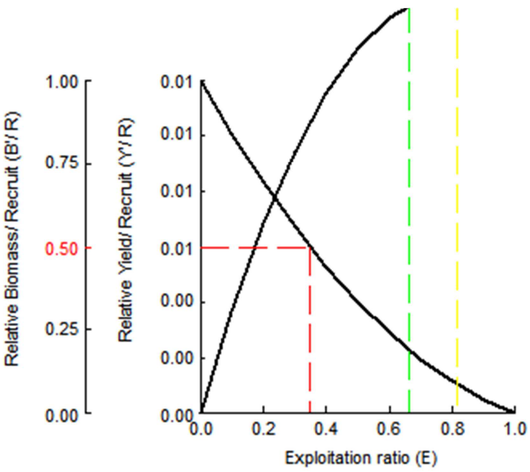

Figure 11. *2D Knife-edge selection procedure for the analysis of relative yield and biomass per recruit of C. nigrodigitatus.*

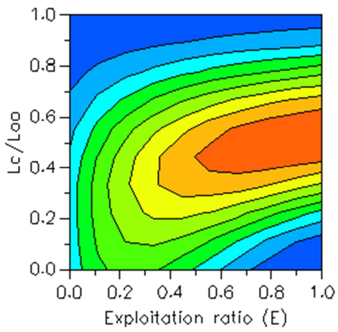

Figure 12. *Knife-edge selection procedure for the analysis of relative yield and biomass per recruit of C. nigrodigitatus.*

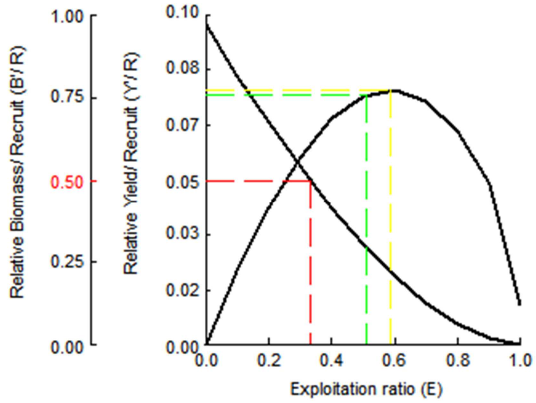

Figure 13. *Selection Ogive procedure for the analysis of relative yield and biomass per recruit of C. nigrodigitatus.*

4. Discussion

In this study, *C. nigrodigitatus* had L_∞ as 29.93 cm TL and is indicated as a slow growing fish with K value of 0.18. t_0, L_0, and t_{max} were -1.60 yr, -9.95 cm TL, and 16.67 yrs, respectively. The length and weight growth performance index φ^1 and φ were 2.21 and 1.20 respectively. The predictive von Bertalanffy growth parameter of *C. nigrodigitatus* from Lake Akata, Nigeria was $L_{t\ =}$ 37.28 [1-exp $^{(-0.530\ (t-0.85))}$] and growth performance index (φ^1) was 2.87 [32]. According to [33], fishery biology of Catfish (*Chrysichthys auratus*, Family: Bagridae) from Damietta branch of the River Nile, Egypt had estimates of the von Bertalanffy growth parameters as L_∞ = 26.53 cm, K = 0.214 and t_o = -1.569. Also the individuals of this species live for about 4 years and the first age dominates the population. The growth performance index in length (φ^1) and weight (φ) were estimated as 2.18 and 1.11 respectively. From the above findings, there are differences in the values of the growth parameters. VBG parameters have been proven to be the most useful in assessing fish stocks and effectively regulating fisheries. These differences in the growth of this species in different areas may be caused by factors, such as temperature, habitat, availability of food, metabolic activity, and reproductive activity [34].

The mortality parameters of *C. auratus* from Damietta branch of the River Nile, Egypt were computed as: Total mortality, Z = 1.44yr^{-1}, natural mortality, M = 0.60yr^{-1} and Fishing mortality, F = 0.84yr^{-1}. The exploitation rate was estimated as E = 0.58 [33]. As stated by [32], total mortality (Z) as estimated from FISAT II using Hoenig's Model I was 1.432yr^{-1}. Instantaneous fishing mortality (F) was 0.379yr^{-1} while instantaneous natural mortality was 1.053yr^{-1} with an exploitation rate of 0.266 suggesting that exploitation is not excessive for *C. nigrodigitatus* from Lake Akata, Nigeria. This is in line with this study indicated high values of Z and M. The stock of this study is not overexploited with an E value of 0.32. According to [35], a stock is considered to be overfished if E exceeds 0.50. According to [36], if the Z/K ratio is < 1, the population is growth-dominated; if it is > 1, then it is mortality-dominated; if it is equal to 1, then the population is in the equilibrium state where mortality balances growth. The stock of this study is thus mortality-dominated. In a mortality-dominated population, if Z/K ratio = 2, then it is a lightly exploited population. In this present study, Z/K is 4.78, showing a mortality-dominated population which is though moderately exploited. However, M value is high, indicating deaths due to natural occurrences such as diseases, predation, adverse environment conditions etc. This may be connected with a high level of anthropogenic activities (washing, bathing, dumping of refuse and even defecating) along the river system.

Probability of capture analysis for *C. nigrodigitatus* was 13.57 cm TL. This is also in line with the results of the population structure in which 13–14 cm TL size groups were numerically dominant and constituted 22.12% of the nineteen (19) size groups of the population.

In the population of *C. nigrodigitatus* of this study, there were two recruitment peaks in a year (i.e. bimodal recruitment). [25], who reported that when a population is being fished, it has an effect on other factors, e.g. there will be a greater rate of recruitment, a faster growth. This is because fishing creates ‘room’ for more new recruits; it removes slow-growing fish, which are replaced by smaller fast growing fish.

The findings of this study show the knife-edge selection and selection ogive procedures for the analysis of relative yield and biomass per recruit of *C. nigrodigitatus* gave E_{max} as 0.82 and 0.59 respectively. This revealed that the stock is not overexploited since E (current exploitation rate) computed as 0.27 is less than the E_{max} values.

5. Conclusion

In conclusion, *C. nigrodigitatus* has a slow growth rate (K = 0.18 yr^{-1}), maximum size (L_∞ = 29.93 cm TL), long life span ($t_{max} \approx$ 16.67 yr), high natural mortality (M = 0.59 yr^{-1}). *C. nigrodigitatus* exhibits a bimodal recruitment pattern. The predicted E_{max} of knife-edge selection and selection ogive procedure of *C. nigrodigitatus* is greater than their current exploitation rates revealing that the stock is not overexploited. Immediate management intervention is not required in the present status of the *C. nigrodigitatus* stock. Mortality was not fishery dependent but management is warranted, because open-access fisheries are prone to overcapitalization or overexploitation. Due to the high natural mortality value, management intervention should be focused on environmental pollution and degradation, anthropogenic activities (washing, bathing, dumping of refuse and even defecating) which may be connected to the high M value due to natural occurrences such as diseases, predation, and adverse environment conditions etc. of this study.

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