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Growth, Mortality, Recruitment and Yield of *Pellonula leonensis* Boulenger, 1917 (Osteichthyes: Clupeidae) in a Tropical Flood River System

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Abstract: The population dynamics of *Pellonula leonensis* the target clupeid in the Anambra flood river system was studied with samples collected from commercial artisinal fishers. About 13 consecutive months length-frequency data was analysed using the FiSAT program to obtain the following parameters: growth parameters were as follows: asymptotic Length (L_∞) = 9.98 cm TL, growth curvature (K) = 1.3 $year^{-1}$. The mortality parameters were: total mortality Z = 4.03 $year^{-1}$, natural mortality M 2.77 $year^{-1}$ and fishing mortality F was 1.26 $year^{-1}$. Exploitation rate E was 0.31. T he fish exhibited the bimodal continuous recruitment pattern. The Knife-Edge selection and Selection Ogive procedures for relative yield/biomass per recruit showed that E_{max} were 0.641 and 0.630, respectively. The stock was not overexploited, since $E<E_{max}$.

Key words: Reproduction, growth, mortality, recruitment, yield, *Pellonula leonensis*, Nigeria

INTRODUCTION

The pellonuline clupeid fishes are important icthyofaunal component of freshwater and brackish ecosystems. They are important ecologically and commercially and are widely exploited. Clupeids e.g., herrings and sprats provide the largest single source of raw material for production of fish meal and oil. Sardines contain vitamins A and D, also vitamin B groups are found in their flesh.

The bones of sardines provide us with calcium and phosphorus (Aidos, 2002). These are abundant and inexpensive and easily affordable by the rural poor. The family Clupeidae has a world wide distribution, occurring in almost all or all of the continents of the world (Etnier and Wayne, 1993).

P. leonensis popularly known as the small toothed pellonula is predominantly found in Africa in lagoons, lakes, lower and upper reaches of river from Senegal to Cameroon also in the lower reaches of coastal river basins from Cameroon to Democratic Republic of Congo (Gourene and Teugels, 1991).

Biological studies have been done on pellonuline clupeids (Ikusemiju *et al.*, 1983; Kunzel and Lowenberg, 1990; King, 1996; Anon, 1997; Ezenwaji and Offiah, 2003). According to Ezenwaji (2004), *P. leonensis* is the dominant species, by number 35.3% and weight 23.1% in the fishery of Anambra River where it sustains artisanal fisheries and fetches good income on account of its tasty characteristics (Ezenwaji, 2004). Although, *P. leonensis* is an economically important fish, till date there is limited information on the species.

Thus, this study seeks to bridge this gap in knowledge by providing information on the reproduction, growth, mortality, recruitment and yield of *P. leonensis* in the flood river system (South-Eastern Nigeria) which is necessary in adopting management and conservation policies as well as in the further development of the fishery for this species.

Furthermore, the population parameters estimated for *P. leonensis* forms a comparison base for other population studies of small-sized fish species of tropical environments bridging the information gap about tropical small fishes. The results also provide baseline information (as well as reference points) that can be incorporated into wider reference systems relevant to current fisheries assessment and management in the tropical region.

MATERIALS AND METHODS

In this study, samples of the fish *P. leonensis* (Clupeidae, Osteichthyes) with varying sizes were studied. The study was conducted in the river port at Otuocha (70 8^{1}N, 70.15^{1}E) (Fig. 1) of the Anambra flood river system, in South-Eastern Nigeria. The river system has a length about 207.4 km with many tributaries which

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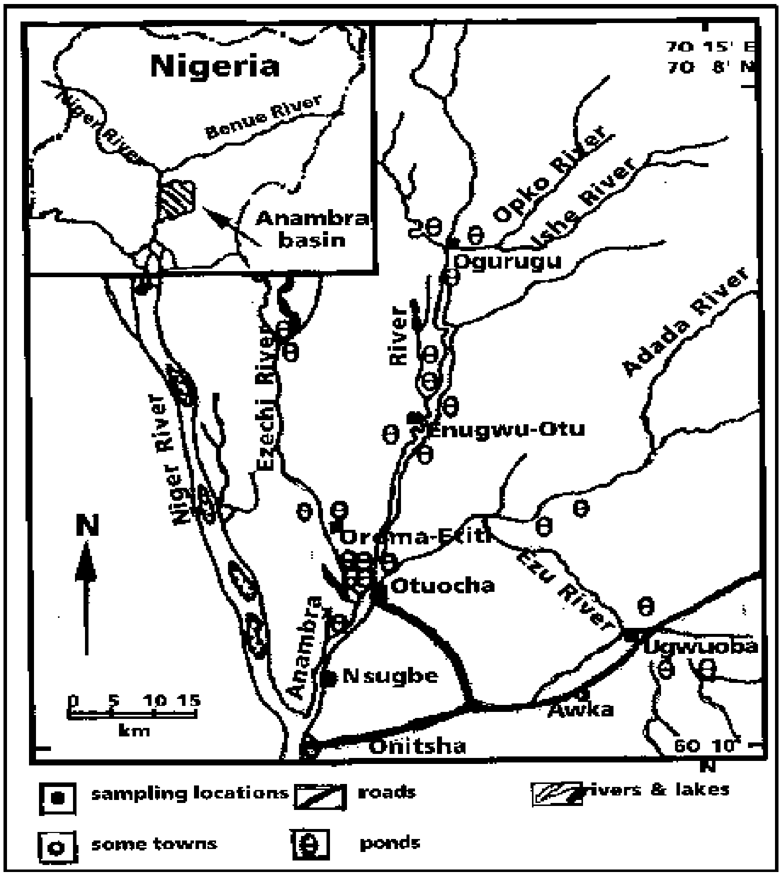

Fig. 1: Map of Anambara flood river system showing the sampling location (Otuocha)

is characterized by floodplain lentic water bodies mainly small sized (<500 m^2) and medium sized (<5,000 m^2) ponds and lakes which are fringed by riparian shrubs and forests. The vegetation is the rainforest/Guinea mosaic and it is typical of this area and areas north of it (Ezenwaji, 2004).

The rainy season and the dry season are the two main seasons of the area. The latter occurs between October/November-March while the former is from April to September/October. Samples were collected monthly for 13 consecutive months. The monthly samples were made by random samples of the catch of the commercial artisinal fishers. Samples were collected from every other fisher landing at the river port at Otuocha. Sampled were preserved in 10% formalin until they were processed.

Total Length (TL) was measured to the nearest 0.1 cm with a meter rule measuring board. Weight measurement would be made for both species with a Mettler PC 2000 electronic weighing balance to the nearest 0.1 g. The FiSAT 11 software (Gayanilo *et al.*, 1996) was used to analyse the monthly length-frequency data. First the Powell-Wetherall method as modified by Pauly (1986) 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:

$$L-L^1 = a + bL \quad (1)$$

Where L^1 is cut off length of the smallest fully recruited fish for each size class, $L = (L_\infty + L^1) / [1 + (Z/K)]$ which is mean length of all fishes = Lt. Thus, plotting L B L^1 against L^1 gives a linear regression from which a and b could be estimated and hence L_∞ and (Z//K). From Eq. 3, a preliminary L_∞ as a/b and Z/K as -(1 + b) / b. The ELEFAN procedure in FISAT was then used to sequentially arrange and restructure the monthly length-frequency data set.

Then with preliminary L_∞ from Eq. 1 as a seeded value, ELEFAN procedure was used to fit the seasonalized Von Bertalanffy Growth Function (VBGF) (Eq. 2) proposed and later modified by Somers (1988) to the length frequency data:

$$L_t = L\infty\,[1 - \exp - K\,(t - t_0) + (CK/2\pi)\sin(2\pi\,(t - t_s)) - (C/K2\pi)\sin 2\pi\,(t - t_0)] \quad (2)$$

Where:

L_t = Length at age t (in years)
L_∞ = Asymptotic length (cm)
K = Von bertalanffy growth coefficient ($year^{-1}$)
C = Amplitude of growth oscillations
t_0 = Age of the fish at zero length
t_s = Time from birth to onset of first growth oscillations

Here, t_s was replaced with WP (Winter Point which is the period when growth is slowest) as $WP = t_s + 0.5$. Equation 2 reverts to the original VBGF if C is zero, i.e., if there is no seasonality of growth.

The single negative exponential mortality model (Eq. 3) was used to quantify total mortality in the fish population:

$$N_t = N_0 e^{-zt} \quad (3)$$

Where:

Z = Instantaneous total mortality coefficient
N_0 = Initial numbers
N_t = Numbers after time t (in years)

Z in Eq. 3 was estimated using the seasonalized length-converted catch curve (Pauly 1990; Pauly *et al.*, 1995) method according to Eq. 4:

$$\text{In } N = a + bt^1 \quad (4)$$

Where N is number of fishes sliced by growth curves of Eq. 4 as generated by the ELEFAN routine in FISAT, t^1 is relative age of fish in that pseudo-cohort, b with sign changed gives Z with seasonality. Equation 5 was used to compute Z without seasonality:

$$\text{In } (N_i/\Delta t_i) = a + bt_i \quad (5)$$

Here, N_i is number of fishes in length class i , Δt_i is (1/K ln [(L_∞-L_1)/(L_∞-L_2) is time needed for the fish to grow through length class I, L_1 and L_2 being the lower and upper limits of length class I, t_i is (1/K)ln [(1-(L_t/L_∞)] is relative age corresponding to the class mid-point of length class I and b with sign changed gives Z without seasonality. Additionally, the Beverton and Holt = s>mean length in the catch method (Eq. 6) was used to estimate Z without seasonality:

$$Z = [K\,(L\infty\text{-}L)]/(L-L^1) \quad (6)$$

Whereby all symbols are as already defined in Eq. 1 and 2. The empirical model of Pauly (1980) was used to estimate the instantaneous natural mortality coefficient M:

$$\text{Log } M = -0.0066 - 0.279\log L\infty + 0.6543\log K + 0.4634\log T \quad (7)$$

Here, T was 25.7°C (the mean annual surface water temperature in the river).

The overall growth performance index φ^1 was quantified using the model of Pauly and Munro (1984):

$$\varphi^1 = 2\log L\infty + \log K \quad (8)$$

While, the potential longevity of the fish was estimated according to Eq. 9 (Taylor 1958; Pauly, 1980):

$$t_{max} \approx 3/K \quad (9)$$

The ascending left arm of the non-seasonalized length- converted catch curve was used to compute the probability of capture (P) of each size class i. This involves dividing the number of fishes actually sampled by the expected numbers (obtained by backward extrapolation of the straight portion, i.e., the descending part of the catch curve) in each length class of the ascending part of the catch curve.

By plotting the cumulative probability of capture against class mid- length, a resultant curve was obtained from which the length at first capture Lc was taken as corresponding to the cumulative probability at 50%.

The recruitment pattern of the fish was constructed using the entire length frequency data set. This involved projecting backward, along a trajectory described by the computed VBGF, all length frequency data onto a 1 year time scale (Pauly, 1987).

Then, employing the maximum likelihood method, the distribution was resolved into its Gaussian components using the NORMSEP (normal separation) procedure of Hasselblad (1966). The model of Beverton and Holt (1956), as modified by Pauly and Soriano (1986) was used to predict the relative yield per recruit (Y^1/R) of the species to the fisheries:

$$(Y^1/R) = EU^{M/K}[1-(3U)/(1+m)+(3U^2)/(1+2m) - (U^3)/(1+3m)] \quad (10)$$

Where, $E = F/Z$ is current exploitation rate, i.e., the fraction of death caused by fishing activity, F is the instantaneous fishing mortality coefficient, $U = 1 - (Lc/L_\infty)$ = the fraction of growth to be completed by the fish after entry into the exploitation phase, $m = (1-E)/(M/K) = K/Z$. The relative biomass per recruit (B^1/R) was estimated as:

$$B^1/R = (Y^1/R)/F \quad (11)$$

Then, E_{max} (exploitation rate producing maximum yield), $E_{0.1}$ (exploitation rate at which the marginal increase of Y^1/R is 10% of its virgin stock) and $E_{0.5}$ (the exploitation rate under which the stock is reduced to half its virgin biomass) were computed through the first derivative of the function. Yield contours were plotted to assess the impact on yield of changes in exploitation rate E and critical length ratio Lc/L_∞.

RESULTS AND DISCUSSION

The length-frequency distribution (Fig. 2) of *P. leonensis* (n = 1627) showed that the smallest and largest specimens were 2.3 and 9.3 cm TL, respectively (mean 5.9 cm ± 0.95). The 4-6 cm TL size groups were numerically dominant and constituted 61.9% of the population. There was only one mode at 4-5 cm TL (Fig. 2). The weight ranged between 0.1 and 7.3 g (mean 2.2 g±1.67).

Analysis using the Powell-Wetherall's method (Fig. 3) gave the results of L_∞ as 10.24 cm TL and Z/K = 2.92. The ELEFAN 1 analysis in FiSAT 11 software yielded the optimized VBG curves with the following parameters using the K scan: Asymptotic length (L_∞) = 9.98 cm TL, VBGF growth constant (K) = 1.3 year^{-1}. Also the growth and weight performance index φ^1 and φ were 2.112 and 0.748, respectively.

These curves were superimposed over the length-frequency histograms (Fig. 4) which show the normal length-frequency histograms and the restructured length-frequency histograms (the black and white bars are positive and negative deviations from the running average of three) (Fig. 5). Estimated values for t_o, l_o, t_{max} were − 0.11 year, 1.33 cm TL and 2.31 years, respectively.

Maximum length (L_{max}) encountered was 9.3 cm TL. From these parameters, Von Bertalanffy length (L_t) and weight (W_t) growth functions were established:

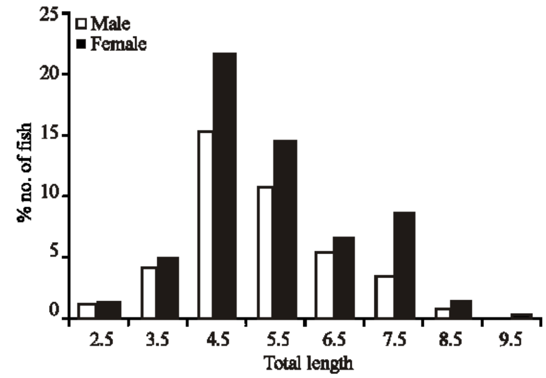

Fig. 2: Lenght-frequency distribution of male and female *P. leonensis* with one mode at 4-5 TL

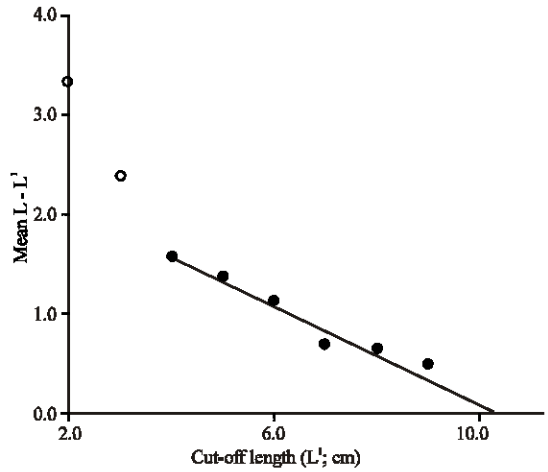

Fig. 3: Powell-Wetherall plot of *P . leonensis* showing L_∞ as 10.24 cm TL and Z/K = 2.92

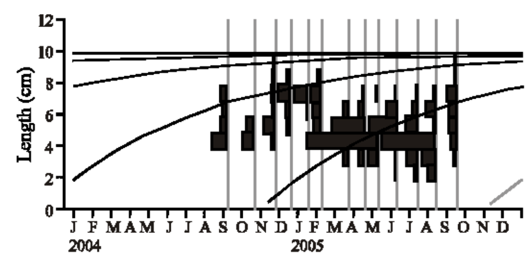

Fig. 4: VBG curve of *P. leonensis* with normal length-frequency histograms (L∞ = 9.98 cm TL and K = 1.3 year^{-1})

Where:

$$L_t = 9.98\,[1 - \exp^{-1.3\,(t + 0.11)}]$$
$$W_t = 8.95\,[1 - \exp^{-1.3\,(t + 0.11)}]^{2.781}$$

Using the non-seasonalized length-converted catch curve (Fig. 6) in FiSAT, computed Z for *P. leonensis* was 4.03 year^{-1}. Estimated Z obtained from the Beverton and Holt Z equation based on length data

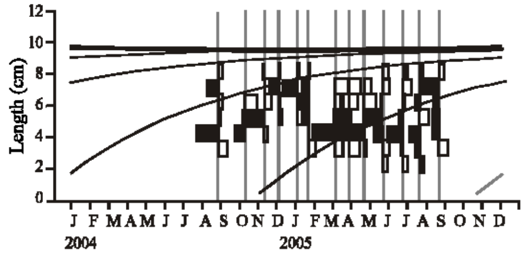

Fig. 5: VBG Curve of *P. leonensis* with restructured length-frequency histograms(L∞ = 9098 cm TL and k = 1.3 year^{-1})

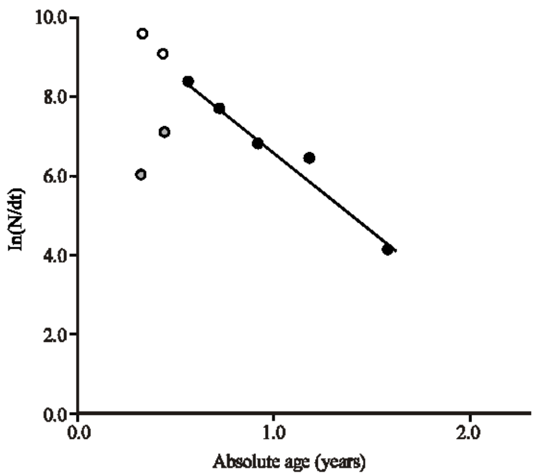

Fig. 6: Lenght-converted catch curve of *P. leonensis* Z = 4.03 year^{-1}, M at 25.7°C = 2.77 year^{-1}, F = 1.26 year^{-1} and E = 0.31

= 2.16 year^{-1} while it was 1.76 year^{-1} based on length-at- first lenght-frequency histograms (L_∞ = 9.98 cm TL and K = 1.3 year) capture. The natural mortality coefficient (M) at 25.7 °C was 2.77 year^{-1}. Fishing mortality coefficient F was 1.26 year^{-1}. E (exploitation rate) was computed as 0.31. Recruitment pattern is demonstrated with a graph which displays variation in intensity of recruitment with time. In the population of *P. leonensis*, 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 (Fig. 7). The first mode was between March, April and May with 14.37, 19.63 and 11.39% recruitment. The second mode was September with 10.36% recruitment. Probability of capture analysis of each size class for *P. leonensis* as derived from the ascending left arm of the catch curve (Fig. 6). The computed length-at-first capture L_{50} or L_C (length at which 50% of the fish entering the gear are retained) was 3.84cm. L_{25} (length at which 25% of the fish entering the gear are retained) was 3.08 cm and

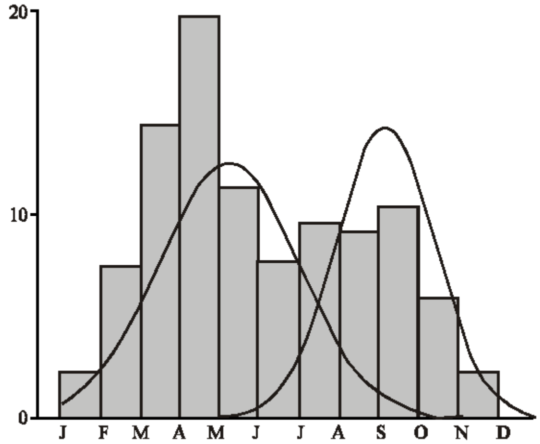

Fig. 7: Continuous bimodal recruitment pattern of *P. leonensis*

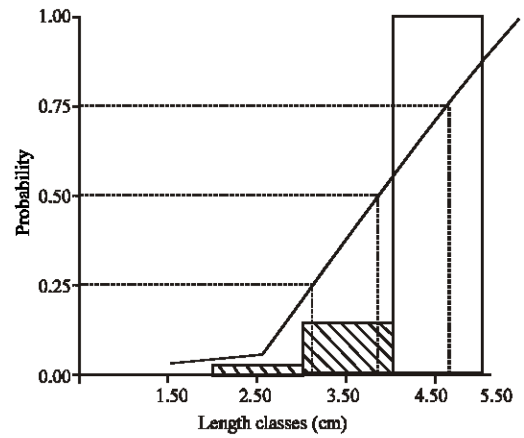

Fig. 8: Probability of capture ananlysis for *P. leonensis* (L_{50} or L_C = 3.84 cm, L_{25} = 3.08 and L_{75} = 4.62 cm

L_{75} (length at which 75% of the fish entering the gear are retained) was 4.62 cm (Fig. 8). Using the Knife-Edge selection procedure for the analysis of relative yield and biomass per recruit of *P. leonensis* (Fig. 9) gave an E_{max} (the value of exploitation rate E giving the maximum relative yield per recruit) of 0.641, $E_{0.1}$ (the value of E at which increase in the Y^1/R is 10% of its value) of 0.502 and $E_{0.5}$ (the value of E at 50% of the unexploited relative biomass per recruit) of 0.331.

Figure 10 shows selection ogive procedure of *P. leonensis* with E_{max} as 0.630, $E_{0.1}$ as 0.511 and $E_{0.5}$ as 0.328. Although, *P. leonensis* is not the only clupeid present in the Anambra flood river system, their abundance by number and weight in the liftnet fishery is notable and significant. The target clupeids

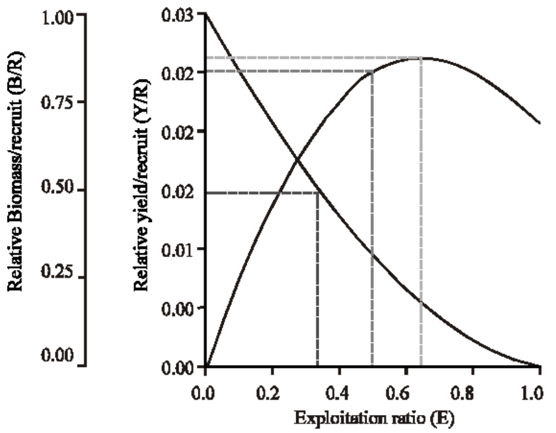

Fig. 9: Relative yeild and biomass recruit of *P. leonensis* using Knife Edge selection produre (E_{max}= 0.641, $E_{0.1}$ = 0.502 and $E_{0.5}$ = 0.331)

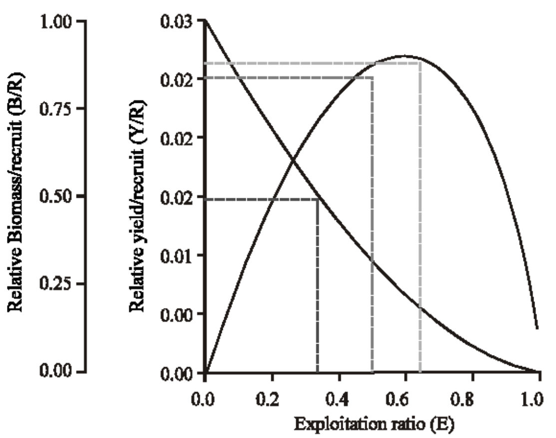

Fig. 10: Relative yeild and biomass recruit of *P. leonensis* using selection ogive produre (E_{max} = 0.630, $E_{0.1}$ = 0.511 and $E_{0.5}$ = 0.328)

constituted over 35 and 23% by number and weight, respectively of the overall catch (Ezenwaji, 2004). According to Ezenwaji and Offiah (2003), this abundance may not be unconnected to a number of factors such as early sexual maturity, all year round breeding, food availability, high growth rate, short life span, high natural mortality and environment. In this study, the size range of 2.3-9.3 cm TL and its preponderance at 4-6 cm TL is a good reflection of its population structure in that the fish grows fast, becomes recruited into the fishery with high fishing and natural mortality. Such range of fish must have been adequately sampled. This is in agreement with the report of Ezenwaji and Offiah (2003). Whitehead (1985) and Gourene and Teugels (1991) reported maximum size of 10 cm TL for *P. leonensis*, corresponding with L_∞ values of 9.98 and 10.24 cm TL of the ELEFAN I analysis and Powell-Wetherall's method, respectively of this study. These results are, however, in contrast with the finding of Kunzel and Lowenberg (1990). Reported values of K (0.960) and φ^1 (2.37) however corresponded with the values of this study (K = 1.3 and φ^1 = 2.112). This indicates relatively high growth performance for *P. leonensis*.

The sandy sprat Hyperlophus vittatus (Clupeidae) found in the Indo-Pacific and southern Australian had Von Bertalanffy growth parameters as k = 1.83 year^{-1} and L_∞ = 7.81 cm (Rogers and Ward , 2007) this is similar to the values of *P. leonensis*.

Computed values of Z, M and F were high. This is in agreement with mortality rates of other clupeids, such as *S. tanganicae, L. miodon* and three *Sardinella* sp. (Mambona and Michael, 1993; Mubamba, 1993). This is evident as clupeids are forage species for other piscivores; they are also known to exhibit cannibalism (Ezenwaji and Offiah, 2003). According to Gourene and Teugels (1991), *P. leonensis* is preyed upon by *Clarias, Schilbe niloticus, Cynothrissa mento* and *Elops lacerta* and deaths due to diseases.

This leads to high natural mortality even deaths due to old age. This fish occurs in the artisanal fishery with frequent fishing due to their rich and cheap source of animal protein for the rural poor (Ezenwaji and Offiah, 2003). This leads to high fishing mortality.

This in turn results in high total mortality. As stated by Barry and Tegner (1989), as a general rule, if 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 an equilibrium state where mortality balances growth. In a mortality-dominated population, if Z/K ratio = 2 then it is a lightly exploited population.

In this investigation, the Z/K ratio for *P. leonensis* was 2.92 thus indicating a lightly exploited population. Bimodal recruitment pattern demonstrated in this study with peaks overlapped in time to give a continuous year-round pattern.

This conforms to the pattern of *Sardinella aurita* which also presented a continuous and bimodal recruitment (Guzman and Gomez, 2001). Thus, recruits are released into the fishery throughout the year, although, with two modes. The presence of ripe individuals in most of the months of this study period shows that the fish is in reproductive pulse all the year round. Ezenwaji and Offiah (2003) also reported an all year gonad recrudescence of *P. leonensis*, implying that there would be recruits throughout the year. It is also important to note that *P. leonensis* grows fast, reaching maturity early as indicated by the length of the smallest mature male and female (3.9 and 4.1 cm TL, respectively). High mortality recorded in this study is also responsible for the continuous year-round pattern.

This agrees with Sparre and Siebren (1998) who report 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. Computed value of L_C of 3.84 cm TL is in close range to the smallest sampled individual of 2.3 cm TL. The Knife-Edge selection procedure assumes that fishes less than L_C are not captured by the gear while the selection ogive procedure (which used the computed probability of capture of each size class) assumes that the chance of capturing any fish is a function of its length.

The predicted E_{max} of knife-edge selection and selection ogive procedure of 0.641 and 0.630, respectively are greater than the current exploitation rate (E = 0.31). This means that the stock is not overexploited, corroborating with the earlier deduction made from the Z/K ratio.

The present situation of *P. leonensis* stock does not call for management intervention. However, considering that open-access fisheries are prone to over capitalization (or overexploitation) in the absence of proper management then mesh size should be increased in the event of any increase in effort.

It is important to note that *P. leonensis* in the Anambra flood river system has a very rapid growth rate ($K = 1.3\ year^{-1}$), small maximum size ($L\infty$ =9.98 cm TL), short life span ($t_{max} \approx 2$ years), early sexual maturity ($l_m/L\infty = 0.58$) and high natural mortality ($M = 2.77\ year^{-1}$). These are all r-selected traits. Thus, ecologically *P. leonensis* could be regarded as r-selected species. According to Ezenwaji (2004), reproduction of this fish species is successful.

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