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POPULATION DYNAMICS OF MUDSKIPPER, *Periophthalmus barbarus* (LINNEAUS 1766) (TELEOSTEI : GOBIIDAE) IN THE ARTISANAL FISHERY OF IMO RIVER ESTUARY, SOUTHEAST NIGERIA

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Abstract- The population dynamics of *Periophthalmus barbarus* in the Imo River Estuary, southeast Nigeria, were obtained from a twelve month length composition data ranging 6.0- 14.00cm total length TL (mean = 9.2225cm±0.1425; n=2160) corresponding to 1.67- 26.79g Total weight TW (mean = 8.4717g±0.40196). The growth was exponential. The asymptotic length (L_∞) of the Powell-Wetheral plot (L_∞ = 13.36cm) was seeded into FiSAT II software to obtain best estimates of von Bertalanffy growth parameters as: L_∞ = 19.9cm*TL*, growth curvature (*K*) = 1.0 year^{-1}; age-and-length-at-age zero years, t_0 = - 0.75; L_o= 10.50 cm*TL*; longetivity, t_{max} = 3 years. The estimated growth performance index, φ' = 2.59. Other FiSAT II growth parameters were the amplitude of growth oscillation, *C* = 0.9 and the Winter Point, *WP* = 0.6, R_n = 0.368. The computed total mortality, *Z* = 9.57 year $^{-1}$, natural mortality, *M* = 2.04 year^{-1} and fishing mortality, *F* was 7.53 year^{-1}. Results indicate the fishery is highly exploited with current exploitation ratio, E_{cur} = 0.79 > E_{max} = 0.644 > E_{opt} = 0.5 which suggests stock over-exploitation; corroborated by *Z/K* ratio (2.396). The rate of exploitation, μ = 0.787 year^{-1} = E_{cur}, 79% of the available stock being fished annually. The length-at-first capture L_c=7.76cm cm*TL* and L_c/L_∞ was 0.39, indicating the fish was yet to complete 61% of growth as at the time of capture at L_c; hence, L_{opt} = 11.85cm*TL*, which provides least impact and confers better condition factor on the stock should be adopted.

Keywords- Fishery policy, length-frequency distribution, mortality, overfishing, potential yield

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Introduction

Fish are limited but renewable resources, hence, sustainability requires that their rate of exploitation balances the renewability capacity of the stocks. Fish stock assessments grants us insight into the dynamics of a fish stock, and provide baseline information/input for proper management of fish stock to ensure intergenerational access and sustained livelihood of locals who depend on it. Interestingly, the sustainability of the mudskipper and other tropical artisanal fisheries are ill-managed [1-3]. Mudskipper, *Periophthalmus barbarus* Linnaeus 1766 (= other used names: *Gobius barbarus*, *Gobius koelreuteri*, *Periophthalmus koelreuteri*, *Periophthalmus papilio*, *Periophthalmus papillon*, *Periophthalmus gabonicus* and *Periophthalmus erythronemus* is the only species of genus Periophthalmidae in West Africa [4]. The species inhabits burrows in intertidal saline swamps in estuaries, creeks and lagoons. In the Imo River estuary as in other parts of Nigerian coastal waters, they are exploited and used as baits, consumed as protein source, or in traditional medicinal purposes due its aphrodisiac values [3, 5]. Mudskipper meal was found to be rich in protein (55.87%); other constituents include: fat (5.12%), fibre (1.07%), ash (18.26%), dry matter (89.65%) and carbohydrate (9.33%) and advanced as a possible replacement to fish meal to produce a cheaper fish feed [6]. The demand for *chewa* (mudskipper meal, CP of 44-52%) in Bangladesh and Asia far exceeds supply and only few companies are able to utilize this source in fish feed production [7].

Several studies on the mudskipper fishery have been undertaken. Such include its ecophysiology, behaviour and environmental biology [5,8-10], orientation and distribution [11,12], breeding biology [3], morphometric relationships [2,13,14] and its reproductive characteristics in the Imo River estuary, Nigeria [2]. The mudskipper is a reliable aquarium or ornamental fish suitable for export to Europe and the United States [4] and abundant in Nigeria's coastal mudflats and mangroves [15]. Its population dynamics in Nigeria has been reported in the Cross River [16,17], Cross River estuary [3,17] and New Calabar river [18]. This paper reveals the exploitation level and state of the stock in the Imo River estuary, Nigeria vis-a-viz earlier report of overfishing [3].

Materials and Methods

The length-frequency data of varying sizes of *P. barbarus* (n = 2160) were randomly sampled bimonthly from the landings of the artisanal fishery of the Imo River estuary, at Ikot Abasi, Southeast, Nigeria (4°25'N - 6°25' N, longitude 6° 50' E - 7°40' E), over a period of 12 months (December to November). The fishers employed nonreturn valved traditional basket traps set on the mudflats at low tide and retrieved just before high tide [2]. Length-based assessment of fish stocks require a minimum sample size of 1500 length-frequency data accumulated within a period ≤ 6 consecutive months [19]. Our data meets this criterion. Fish samples were identified [20] and measured to the nearest 0.1cm total length (TL) and 0.1g total weight (TW) for each specimen and preserved in 10% diluted formaldehyde.

The Fish Stock Assessment Tool (FiSAT II) software [21] was used to analyse the monthly length-frequency data [Table-1]. The ELEFAN procedure in FiSAT was then used to sequentially arrange and restructure the monthly length-frequency data set from which a preliminary L∞ value was seeded. The ELEFAN procedure was used to fit the Von Bertalanffy Growth Function (VBGF) using [Eq-1] [22]:

$$L_t = L_\infty[1-\exp^{-k(t-t_0)}] \quad (1)$$

where:

L_t = Length at age t (in age)

L_∞ = Asymptotic length (cm),

K = Von bertalanffy growth coefficient (year^{-1})

t_0 = Age of the fish at zero length.

The t_o was estimated empirically [23]:

$$Log_{10}(-t_0) = -0.3922-0.2752\ Log_{10}L_\infty - 1.038\ Log_{10}K \quad (2)$$

The optimum length L_{opt} was estimated as:

$$L_{opt} = L_\infty[3/(3+M/K)] \quad (3)$$

where L_∞ and *K* are parameters of the von Bertalanffy growth function, and M is the instantaneous rate of natural mortality [24]. The potential longevity of the fish was estimated as [23]:

$$t_{max} \approx 3/K \quad (4)$$

The overall growth performance index *φ'* was quantified [25]:

$$\varphi' = Log\ K + 2\ Log\ L_\infty \quad (5)$$

The instantaneous rate of natural mortality (M) as estimated empirically [23]:

$$Log\ M = -0.0066-0.279\ Log\ L_\infty + 0.6543\ Log\ K + 0.463\ Log\ T \quad (6)$$

where, *T* was 29.0°C (the mean annual surface water temperature in the study area).

The overall length frequency (L-F) distributions (all fishing methods pooled monthly) were first converted to relative frequency and then plotted as histograms for estimation of the instantaneous rate of total mortality (Z) using the length-converted catch curve procedure [21]. The slope with the sign changed gave an estimate of Z. The instantaneous rate of fishing mortality (*F*) was estimated by subtracting the value of natural mortality from the total mortality as :

$$F = Z-M \quad (7)$$

while exploitation ratio:

$$E = F/Z \quad (8)$$

and $$F = M (\text{i.e., } E = 0.5) \quad (9)$$

The exploitation rate (μ) was calculated empirically [26]:

$$\mu = F/Z(1-e^{-z}) \quad (10)$$

where *F* = Fishing mortality, *Z* = Total Mortality and *E* = 2.7182. A relative yield-per-recruit analysis was performed [21,27]. The probability of capture was computed by the selectivity ogive, S, of each length class of *P. barbarus* against the mean total length from the left ascending arm of the length-converted catch curve [23].

Result

The monthly length-frequency data of 2,160 specimens collected for 12 months used to estimate growth and mortality parameters of *P. barbarus* are provided in [Table-1]. The collection indicate variations in the size (length cm) and weight (g): 6.0 - 14.00 cm*TL* (mean = 9.2225cm±0.1425; n=2160) corresponding to 1.67 - 26.79 g*TW* (mean = 8.4717g±0.40196). The length-frequency distribution [Fig-1] showed that the 8-9 cm*TL* size groups were numerically dominant (the only mode) and constituted 24.63% of the population while the least value of 0.09% was observed at the length class 14-15cm.

The length - weight relationship [TW = $0.01533TL^{2.8}$] [Eq-1] indicates that *P. barbarus* is allometrically negative [Table-2].

Table 1- Length-frequency data for P. barbarus from artisanal landings of the Imo River estuary, Nigeria (n = 2160)

ML	D	J	F	M	A	M	J	J	A	S	O	N	Total
5.5	3	5		3	3		4		7		3	5	33
6.5	22	16	9	8	24	22	24	15	17	3	22	16	198
7.5	26	24	32	28	60	57	51	43	30	33	26	24	434
8.5	30	36	33	47	50	63	53	47	44	63	30	36	532
9.5	21	37	43	45	49	42	43	39	46	60	21	37	483
10.5	18	28	18	43	17	15	27	24	32	30	18	28	298
11.5	12	18	7	25	7	3	6	12	22	9	12	18	151
12.5	1	5		7			2		2	2	1	5	25
13.5				2				2					4
14.5				2									2
Σ	133	169	142	210	210	202	210	182	200	200	133	169	2160

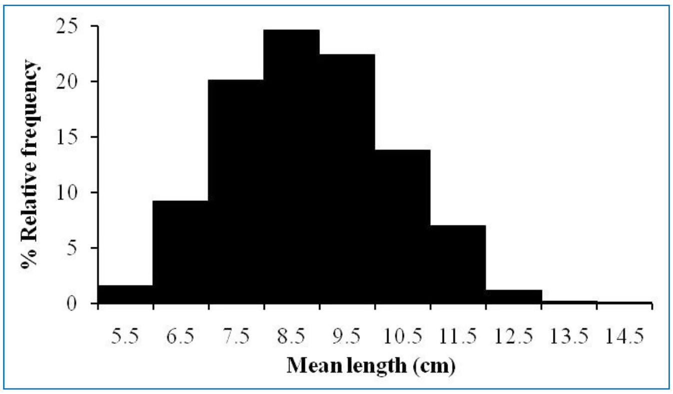

Fig. 1 - The length-frequency distribution of *P. barbarus* from artisanal landings of the Imo River estuary, Nigeria (n = 2160)

Analysis of the L-F data by the Powell-Wetherall method gave: L_∞ = 13.36 and *Z/K* = 2.396. This initial L_∞ value was seeded into the ELEFAN of FiSAT II to obtain the best estimates of the optimized von Bertalanffy growth parameters as: L_∞ = 19.9 cm, *K* = 1.00 yr^{-1}, growth oscillation, C = 0.9, Winter Point (period when growth is slowest) *WP* = 0.6, R_n = 0.368); and the seasonalized growth curves was superimposed on length frequency histogram [Fig-2]. The theoretical age, t_0, was - 0.75 [Eq-4]. From these parameters, Von Bertalanffy length (L_t) and weight (W_t) growth functions for the species were established as:

$$L_t = 19.9\ [1-\exp^{-1.0(t-(0.75))}] \quad (12)$$

$$W_t = 65.56\ [1-\exp^{-1.0(t-(-0.75))}]^{2,8} \quad (13)$$

where L_t and W_t are the mean length and weight predicted at age (*t*) if they grew as predicted by the equation. Here asymptotic length (L_∞) is the maximum theoretical average length a species could attain in its natural habitat although fish grows throughout life, and *K* parameter indicates the speed at which the species grows in size in its years. The growth performance index φ' was also estimated [25]: φ' = 2.59 [Table- **3**]; the amplitude of growth oscillation, C = 0.9 and the Winter Point, *WP* (period when growth is slowest) is 0.6, i.e., between June and July.

Table 2- Length-weight relationship of mudskippers in the study area compared with others

Water body	a	b	r	n	Species/Min-max
Imo River estuary, Nigeria [This study]	0.01513	2.8	0.9054	2160	*P. barbarus* 6.0 - 14.00 cmTL
Imo River estuary, Nigeria [14]	0.1533	2.9	0.921	1079	*P. barbarus* 1.6 - 15.6 cmTL
Cross River estuary, Nigeria [16]	0.012	2.94	0.969	415	*P. barbarus* Not stated
Lagos Lagoon, Nigeria [28]	0.0000785	2.552	0.9385	185	*P. barbarus* 30.0 - 190.0mmTL
Coastal Areas of Selangor, Malaysia [30]	0.000065	2.56	0.982	315	*P. chrysospilos* 18.2 - 83.2 mmSL
	0.000033	2.8	0.974	110	*P. gracilis* 20.5 - 42.7 mmSL
	0.000051	2.67	0.989	299	*P. novemradiatu* 8.3 - 70.2 mmSL

Table 3- Parameters of von Bertalanffy equation of of Periophthalmus barbarus in Imo estuary estimated from length frequency distribution and compared to others

Location/Reference	L_∞ cmTL	K, yr^{-1}	t_0, yr	φ'	t_{max}*
Powel-Wetherall (This study)	13.36				
Imo River (This study)	19.9	1	-0.75*	2.59	3
Imo River [3]	21.6	0.55	-0.49*	2.28	5.5
New Calabar [18]	10.73	3.57	-1.25*	2.181	0.8
Cross River [16]	19.6	0.51	-0.44*	2.28	5.9
Cross River [17]	17.8	0.36	-0.28*	2.06	8.3
Qeshm Island, Iran [33] **	14.15	0.46	0.79	1.96*	6.5
Bandar-Abbas, Iran [33] **	16.68	0.42	0.62	2.07*	7.1

**Deduced empirically for purpose of comparison*
*** Age was determined using the second pectoral radial bone of Periophthalmus waltoni*

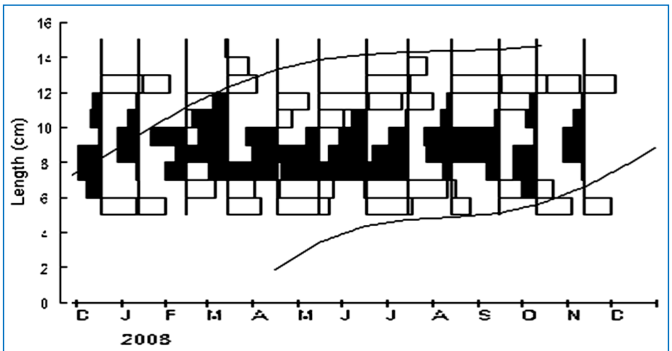

Fig. 2 - Restructured length-frequency histogram for *P. barbarus* with superimposed growth curve (L_∞ = 19.9 cm, K = 1.00 yr^{-1}, C=0.9, WP = 0.6, R_n = 0.368)

The effect of fishing on *P. barbarus* stock in the Imo River estuary was estimated [23] as Z = 9.57year^{-1}, natural mortality coefficient, M = 2.04 year^{-1} while fishing mortality coefficient, F, was estimated as (Z – M =) 7.53 year^{-1} [Fig-3]; the current exploitation ratio, E_{cur} was computed as 0.79, while the rate of exploitation, μ, gave 0.78868 yr^{-1} [26].

Table 4- The estimated population parameters of P. barbarus in Imo estuary, Nigeria, compared to others in different water bodies in southeast Nigeria

Population Parameters	Rates of population parameters in different water bodies in southeast Nigeria				
	Imo River (This study)	Imo River [3]	Cross River [16]	Cross River [17]	New Calabar [18]
Total Mortality (Z)	9.57 yr^{-1}	4.21	2.208	0.836	2.03
Total Mortality (Z)	9.57 yr^{-1}	4.21	2.208	0.836	2.03
Natural Mortality (M)	2.04 yr^{-1}	1.35	1.34	0.72	1.68
Fishing Mortality (F)	7.53 yr^{-1}	2.86	0.868	0.116	0.35
Exploitation Ratio (E)	0.79	0.68	0.393	0.139	0.17
Rate of Exploitation (μ)	0.787 yr^{-1}	-	-	-	-
E_{max}	0.306	0.151	-	-	0.421
$E_{0.1}$	0.252	0.465	-	-	-
$E_{0.5}$	0.236	0.296	-	-	-
L_c	7.76	7.69	-	-	0.76
L_c/L_∞	0.38995	0.356	-	-	0.05
L_{25}/L_∞	0.35126	0.318	-	-	-
L_{75}/L_∞	0.43015	0.395	-	-	-
M/K	2.04	2.45	2.63	2	0.47
Z/K	2.396	7.65	4.33	2.32	0.57

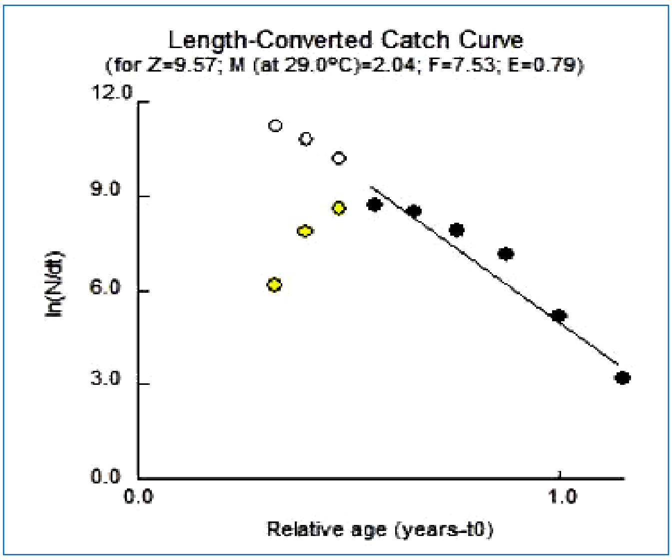

Fig. 3 - FiSAT output of linearized length converted catch curve for *P. barbarus* caught from the Imo River estuary, Nigeria

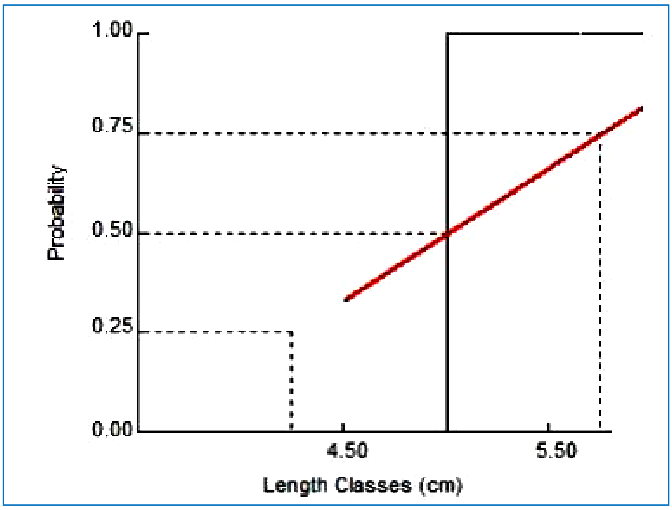

Fig. 4 - Probability of capture of *P. barbarus* in the Imo River estuary (L_c = 7.7 cm, L_{25} = 6.99cm and L_{75} = 8.56 cm)

The estimated population parameters of *P. barbarus* in Imo estuary, Nigeria, compared to others in different water bodies in southeast Nigeria are summarized in [Table-4]. The computed length-at-first capture, L_{50} or L_c (length at which 50% of the fish entering the gear are retained) was L_c = 7.76 cm*TL* [Fig-4] and L_c/L_∞ ratio was 0.39 while L_{opt} = 11.85cm*TL*. The relative yield per recruit (*Y′/R*) based on the assumption of the knife-edge selection: E_{max} = 0.306, $E_{0.1}$ = 0.252 and $E_{0.5}$ = 0.236 [Fig-5] while the selection ogive option gave: E_{max} = 0.644, $E_{0.1}$ = 0.516 and $E_{0.5}$ = 0.333 [Fig-6].

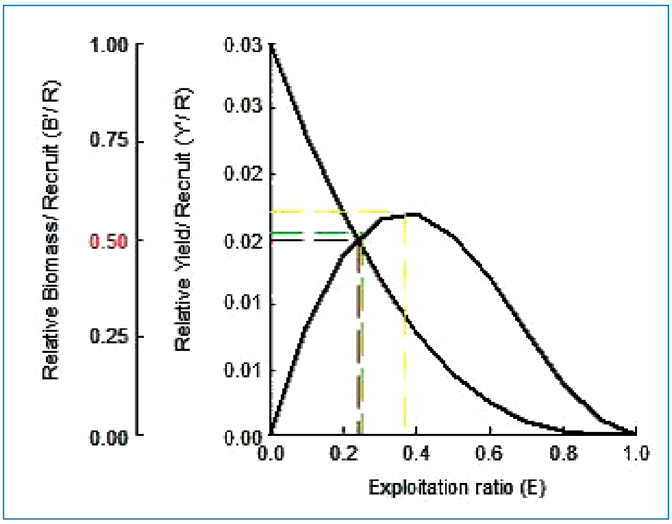

Fig. 5 - Relative yield-per-recruit *P. barbarus* using Knife Edge selective procedure (E_{max} = 0.306, $E_{0.1}$ = 0.252 and $E_{0.5}$ = 0.236)

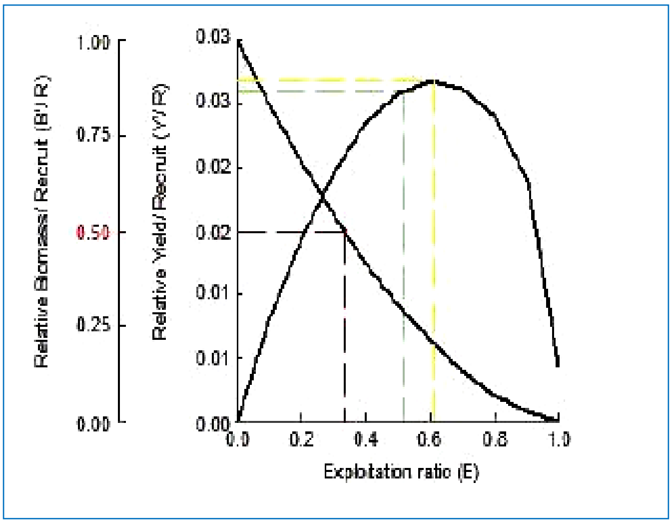

Fig. 6 - Relative yield-per-recruit P. *barbarus* using ogive selective procedure (E_{max} = 0.644, $E_{0.1}$ = 0.516 and $E_{0.5}$ = 0.333)

There were two recruitment peaks (i.e., bimodal recruitment) overlapped in time to give a continuous year-round pattern [Fig-**7**] in the population of *P. barbarus*. The first mode was between the months of July and August and the second was in February.

Discussion

The catch data presents *P. barbarus* of wide variations in sizes with the *b* value estimator of length - weight relationship (b = 2.8) indicating negative allometry [Table-2] similar to other reports from Southeast Nigeria [14,16] but different from the report for the same species in southwest Nigeria [28]. The value falls within the valid limits reported for fish: 2.0-3.5 [29], 2.5-3.5 [29], 2.5-4.0 [24]; and 2.56 - 3.50 for eleven species of mudskippers caught in the coastal areas of Selangor, Malaysia [30]. In multi-species fisheries *b* < > 3 is typical but confirmed the expected range as 2.5 < *b* < 3.5, with median *b* = 3.03 being significantly larger than 3.0, across species [24], indicating a tendency towards slightly positive-allometric growth (increase in relative body thickness or plumpness) in most fishes. Within-species variance in weight–length relationships and condition factor can be substantial, depending on the time/season, the population, and stomach fullness, developmental state of the gonads or annual differences in environmental conditions. As a result, differences in weight estimated from length can be two-fold or more, depending on which relationship is chosen. However, growth of fish is isometric at the early age (t_o) and allometric at later age (t_{max}) [31].

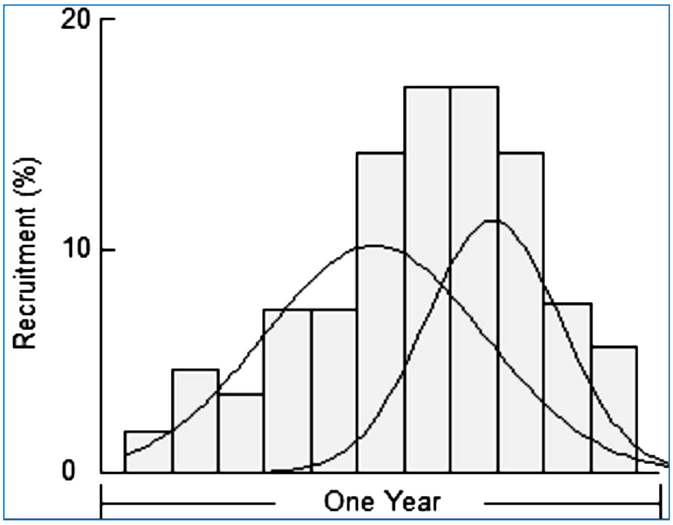

Fig. 7- Recruitment pattern of *P. barbarus* from the Imo River Estuary, Nigeria.

The *P. barbarus* in the present study follows exponential growth pattern and the von Bertalanffy growth parameters (L_∞ = 19.9, *K* = 1.00 yr^{-1}) are within range and compares (though higher) to studies reported for Imo and Cross River species [3,13,16] but different for that of New Calabar [18] for the same species [Table-3]. However, since the growth of fish is not linear, comparing above coefficient do not make any biological meaning as one species or stock can grow faster than the other when young or slower when old. Generally, L_∞ values for fishes range from 1 cm in short-lived fishes like gobies to around 14 m in long-lived fishes like whale sharks. However, in reverse, *K* values range from 8.5 year^{-1} for small-sized, fast growing species such as herring, to 0.02 year^{-1}, for the Adriatic halibut, *Hippoglossus hippoglossus*. Thus, in tropical fish, low L_∞ values often have high *K* values as obtained in this study [32].

The growth performance index in this study (φ' = 2.59), was higher than in other studies [Table-3]. Fishes of a certain genotype will either have a low *K* and a high L_∞ or vice versa; but will have the same φ' [34]. The longevity of this species [Table-3] in the present study is about 3 years (t_{max} = 3 years) and contradicts higher values obtained [3,17,33]. The amplitude of growth oscillation (*C* = 0.9) and Winter Point (*WP*= 0.6) in this study indicate seasonality in growth with growth slowest between June and July. Generally, growth seasonality is prominent in aquatic organisms in temperate region during winter when growth slows down or is completely retarded. But in the tropics, the environmental water temperature is high all year, except for a slight variation. Therefore, temperature change may not be a major factor to growth retardation in this environment. The poorest growth of the fish in June – July may be associated with their reproductive activities in the period, such as spawning stress or to trade-off between growth and breeding during the peak of wet season in the estuary.

The effect of fishing on *P. barbarus is* predicted from mortality values: Z = 9.57year^{-1}, M = 2.04 year^{-1} and F = 7.53 year^{-1} [Fig-3]. The current exploitation ratio, E_{cur} = 0.79, indicates that about 79.0% of the total mortality of the available stock was caused by exploitation; while the rate of exploitation, μ = 0.78868 yr^{-1} indicates that about 79% of the available stock was fished annually (at equilibrium with the exploitation ratio, E_{cur} = 0.79). These results indicate intense pressure on this stock at a rate greater than earlier studies [3,16-18]. The optimum yield of a fishery is taken when the fishing mortality (F) is about equal to the natural mortality (M) i.e. $F = M$ or $E = F/Z = 0.5$; i.e., $E_{cur} > 0.5$, indicates overfishing [35]. Consequently the species are under excessive and high fishing pressure. This is probably because the species is a food fish sought-after by the inhabitants around Imo River; unlike, in the Cross River Estuary where it is largely exploited as fish-food or bait.

The interaction of the fish with gear indicated that current L_c = 7.76 cm*TL* [Fig-4] is similar to 7.69cm*TL* earlier obtained [3] for this stock in the same estuary. The L_c/L_∞ ratio of 0.39 indicates the fish was yet to complete 61% of growth as at the time of capture at L_c; the value is also similar to, but better than an earlier value of 0.356, as at 2002 [3]. The L_{opt} = 11.85cm*TL* provides least impact and confers better condition factor on the stock. The relative yield per recruit (Y'/R) is a function of different values of exploitation ratio (E) and length at first capture L_c. The Y'/R based on the assumption of the knife-edge selection assumes that specimens < L_c are not retained by the trap, while the selection ogive procedure assumes that the probability of capturing any specimens is a function of its lengths. Therefore, the selection ogive is much realistic. In this study, computed current exploitation rate (E_{cur} = 0.79) is greater than the predicted values (E_{max} = 0.644) which suggests stock over-exploitation. This is also true of Z/K value from the Powell-Wetherall plot. As a general rule, when $Z/K > 1$, mortality dominates the stock; if it is equal to 1, then the population is in an equilibrium state where mortality balances growth and if <1, the population is growth-dominated. In a mortality-dominated population, if Z/K ratio = 2, then it is a lightly exploited population. The Z/K values of *P. barbarus* in different water bodies in southeast Nigeria are greater than 2 [Table- 4], indicating impact of both human and natural factors. Z/K = 2.396 in our study and shows a lower level of exploitation compared to others. The ratio of natural mortality (M) to intrinsic growth rate (K), for mudskipper fishery in the southeast Nigeria ($M/K > 2$) falls within the range of 1.0 to 2.5 (for fish) indicating a good environmental state [36]. The M/K ratio is an indirect method used by scientists to examine the accuracy of growth parameters and is supposed to be constant for a group of species or closely related families or taxa [37].

The two recruitment peaks obtained in this study agrees with earlier observations of the monthly variation in gonadosomatic index, GSI [3], suggesting the fishery recruits once a year in the study area. The present situation of *P. barbarus* stock calls for optimal management. However, considering the multi-species open-access nature of the fishery and to ensure ecosystem-based fisheries management, the optimal length-at-capture L_{opt} = 10.50 cm*TL* creates the least impact on the stocks because the product of its survivors times mean individual weight reaches a maximum and offers better condition, i.e., more weight per specimen than at L_c or L_{75} [32,38,39].

Conclusions

P. barbarus in the Imo river estuary, Nigeria, is highly exploited for food; it has a very rapid growth rate (K = 1.00 year^{-1}), small maximum size (L_∞ =19.9 cm*TL*), short life span ($t_{max} \approx 3$ years) and high natural mortality (M = 2.04 year^{-1}), making the species ecologically a short lived, high productive, *r*-selected species.

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Conflicts of Interest: None declared.

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