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The Population Dynamics of the Mudskipper, *Periophthalmus barbarus* (LINNEAUS 1766) (TELEOSTEI, GOBIIDAE) and the Implication for Conservation and Management in the Mangrove Swamp of Iko River Estuary, Southeastern Nigeria

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Authors' contributions

This work was carried out in collaboration with both authors. Author NOA performed the statistical analysis, managed the analyses of the study, managed the literature searches and wrote the final draft of the manuscript. Author MTU designed the study, wrote the protocol, and wrote the first draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

The population dynamics of *Periophthalmus barbarus* in the mangrove swamp of Iko River estuary, southeast of Nigeria were obtained from a twenty four month length composition data ranging 4.6 – 14.5 cm total length (TL) (mean 9.1841± 1.6346: n = 2,876) corresponding to 1.16 – 50.6 g total weight (TW) (mean = 9.9626 ± 5.4796) the growth was exponential. The asymptotic length (L∞) of the Powell-Wetheral plot (L∞ = 15.03 cm) was seeded into FSAT II (FAO-ICLARM Stock Assessment Tools II) software to obtain best estimates of vonBertalanfy growth parameters as L∞ = 16.22 cm TL, growth coefficient (K) = 1.2 year^{-1}, age of fish at zero length, t_o = 0.071; longevity, t_{max}

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= 2.5 years. The estimated growth performance index, φ' = 2.449. Other FISAT II growth parameters were the amplitude of growth oscillation, C = 0.6 and the winter point, WP = 0.6, Rn = 0.3127. Mortality parameters were total mortality, Z = 479 $year^{-1}$, natural mortality, M = 2.39 $year^{-1}$ and fishing mortality, F was 2.40 $year^{-1}$. Result indicate the fishery is optimally exploited with current exploitation rate, Ecur = 0.50 < Emax = 0.668 > Eopt = 0.5 which suggests stock optimal exploitation; corroborated by Z/K ration (3.184). Ecur (0.5) means that 50% of the available stock is being fished annually. The length-at-first capture Lc = 7.33 cm TL and Lc/L∞ was 0.45, indicating the fish was yet to complete 55% of growth as at the time of capture at Lc; hence *P. barbarus* in the ecosystem is at the optimal level of exploitation as well as the presence of growth overexploitation. Thus to circumvent the consequences of growth overfishing, sustainable fisheries measures such as monitoring of fishing effort, use of selective gears and increase in mesh size should be encouraged, implemented and enforced.

Keywords: Population dynamics; Periophthalmus barbarus; mangrove swamp; growth; mortality; exploitation.

1. 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 sustainable livelihood of aborigines/locals who depends on it. Interestingly, the sustainability of the mudskipper and other tropical artisanal fisheries are ill-managed [1,2,3,4]. Mudskipper, *Periophthalmus barbarus* (Linnaeus 1766) which is also known as *Gobius barbarus, Gobius koelreuteri, Periophthalmus koelreuteri, Periophthalmus papilio, Periophthalmus papillon, Periophthalmus gabonicus* and *Periophthalmus erythronemus* is the only species of genus *Periophthalmidae* in West Arica [5,6]. Other related species reported in some parts of the world include: *Periophthalmus chrysospilos* which was reported in Singapore [7] *P. koelreuteri* in East Africa, *Boleopthalmus boddaerti* and *B. woberi* are found inhabiting estuaries of Pasir Ris in Singapore. A new species, *Periopthalmus takita* was recently discovered in Australia [8,9].

The species inhabits burrows in intertidal saline swamps in estuaries, creeks and Lagoons. In the Mangrove Swamp of Iko 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 to their aphrodisiac values [5,10,3]. 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 [11,4]. 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 [12,4]. The mudskipper is a reliable aquarium or ornamental fish suitable for export to Europe and the United States [6] and are abundant in Nigeria's coastal mudflats and mangroves [2,13,4]. The term ''mangrove'' is used to refer to a habitat comprised of a number of halophytic (salt tolerant) plant species, of which there are more than 12 families and 50 species worldwide [14]. Mangroves grow in intertidal or estuarine areas, they are found in warmer areas between the latitude 32 degree north and 38 degree south, along the tropical and subtropical coasts of Africa, Australia, Asia, and North and South America. In U.S. (United State), mangroves are commonly found in Florida [15]. Mangrove plants have a tangle of roots which are often exposed above water, leading to the nickname ''walking trees.'' The roots of mangrove plants are adapted to filter salt water, and their leaves can excrete salt, allowing them to survive where other land plants cannot [16]. The mangrove swamp (biome or mangal), is a distinct saline woodland or shrubland habitat characterized by depositional coastal environments, where fine sediment, often with high organic content collect in areas protected from high-energy wave action. Mangroves are excellent candidates of productivity, they offer various ecosystem services such as shoreline stabilization, habitat, nursery and breeding ground for many fish species and other fauna [16,17,18]. Mangrove also provide wood for fuel wood, timber, and poles; other functions are establishment of restrictive impounds that offer protection for maturing offsprings, filtering and assimilation of pollutants from upland run-off, stabilization of bottom sediments and are excellent candidates in carbon capture and sequestration among other products [18]. Mangrove swamp is found along the coastline of Nigeria. It straddles states such as Lagos, Ondo, Delta, Bayelsa, Rivers, Akwa Ibom, and Cross River.The Nigeria mangrove habitat is said to be the eight largest in the world [19].

Considering the ecological importance of the *Rhizophora* mangrove ecosystem to the Nigerian coastal waters/shoreline, there is a dire need for government and organized private sector to enforce: exploitation of mature *Rhizophora* plant leaving the young vegetation to attain adult forest, limited restriction to the *Rhizophora* mangrove wood extraction and sales of *Rhizophora,* environmental restoration of degraded mangrove *Rhizophora* by development of nurseries and replenish those lost *Rhizophora* macrophyte areas through generational replacement and sensitization and education of the natives and interested groups through public lectures, seminars, film shows and hand-bills should be carried out [14,15]. Fisheries conservation and management are the activities of protecting fishery resources so that sustainable exploration is possible, drawing on fisheries science and including the precautionary principles [72]. Modern fisheries management is often referred to as a governmental system of appropriate management rules based on defined objectives and a mix of management means to implement the rules which are put in place by a system of monitoring, control and surveillance [42]. A popular approach is the ecosystem approach to fisheries management [1,5]. This involves, monitoring and maintaining habitats to ensure that fish have food and shelter, protection of critical habitats such as mating areas, spawning grounds, nurseries, young juveniles and breeding adult grounds, habitats that are affected by fishing and human activities should be restored, and consideration should be given to establishing sanctuary through fishing exclusion zones [1,57]. Other measures include control of catch and fishing effort, control of fishing gear, by-catch reduction and maintenance of an ''old growth'' structure in fish populations, since big, old and fat female fish have been shown to be the best spawners [3]. Fisheries conservation and management are aimed at promoting and maintaining of the quality, diversity and availability of fishery resources in sufficient quantities for present and future generations in the context of food security, poverty alleviation and sustainable development [1,51].

Several studies on the mudskipper fishery have been undertaken. Such include its ecophysiology, behavior and environmental biology [10,20,21,22], length–weight relationship, condition factor and size composition [23], Inter sexual plasticity in aspect of biology and morphometric relationships and reproductive maturation [2,24], breading biology [3] morphometric relationships [25,26]. It population dynamics in Nigeria has been reported in the Cross River [3,27], New Calabar river [28] and Imo River estuary [4]. In Nigeria, factors such as poor fisheries data collection, limited resources, conflicts and IUU (illegal, unregulated and unreported) fishery do not only make it difficult to estimate the status of almost all the marine biodiversity but also present a great challenge to fisheries managers. Furthermore, the paucity of information on population parameters and biology pertaining to commercially important fish species within Nigeria (in general) and Akwa Ibom State (in particular) coastal waters cripple any management interventions geared towards sustainable fisheries in Nigeria. It is against this backdrop that the present study sought to estimate some population parameters of the mudskipper, *P. barbarus* residing in the mangrove swamp of Iko River Estuary, Nigeria.

2. MATERIALS AND METHODS

2.1 The Study Area

The mangrove swamp of Iko River Estuary in Eastern Obolo LGA (Local Government Area), of Akwa Ibom State, Nigeria, is located within the petroleum belt of the Niger Delta, Nigeria.It is located in the Eastern part of the Niger Delta between latitude 4°30'' N and 4^{o} 45'' N and longitude 7°35'' and 7°40'' E . (Fig. 1) [29,30,31] The river has a shadow depth ranging from 1.0 metre to 7.0 metres at flood and ebb tide and an average width of 16 metres.Iko River takes its rise from the Qua Iboe River catchment and drains directly into the Atlantic Ocean at the Bight of Bonny [29]. Iko River has many adjoining tributaries and creeks, and part of it also drains into Imo River estuary, which opens into the Atlantic Ocean at the Bight of Bonny. The mangrove swamp of Iko River is characterized by soft-dark mud flats, usually exposed during low tide, with mangrove trees, shoals and sand bars. The river has semi-diurnal tides and has a length of more than 30 km. The climate of the area is characterized by distinct wet and dry seasons [32,33]. The wet season begins in April and lasts till November, while the dry season begins in November till March. A short period of draught is usually experienced in July and August, while a period of harmattan characterized by cold dry winds and lower temperatures normally occurs between December and February [29,33,31]. Iko area is characterized by a humid tropical climate with rainfall reaching about 3000 mm per annum. The mean annual daily evaporation of the area is 4.6 mm per day [33]. The hydrology of Iko River is affected by tides, although seasonal influences which are related to the climatic regime, are evident. Iko River is directly influenced by processes in the Atlantic coastal waters [29]. Sediments in the mangrove swamp of Iko River become well sorted, composed of mainly coarse quartz sand, shell debris, faecal pellets, silts and clay trapped within the luxuriant mangrove prop roots and impregnated with decaying mangrove leaves and branches [34]. The macrophytes are composed of the native red mangrove; *Rhizophora racemosa*, *R. harrizonii*, *R. mangle*, black mangrove (*Avicenia africana*) and *Laguncularia racemosa* [34,35].

2.2 Sample Collection

Monthly samples of *P. barbarus* were collected between November, 2011 and October, 2013. The samples were collected by means of 6 - 20 non-return valve-basket traps (baited with ground crabs) set on the mudflat at low tide and retrieved just before high tide. The traps were 42 – 50 cm in length, 14 - 17 cm diameter of opening and had mesh sizes of 0.2 - 0.5 cm. Each trap was fitted with two separate valves which separate the inside chamber into two compartments [36]. Services of local fishers were employed in setting up the traps and collection of

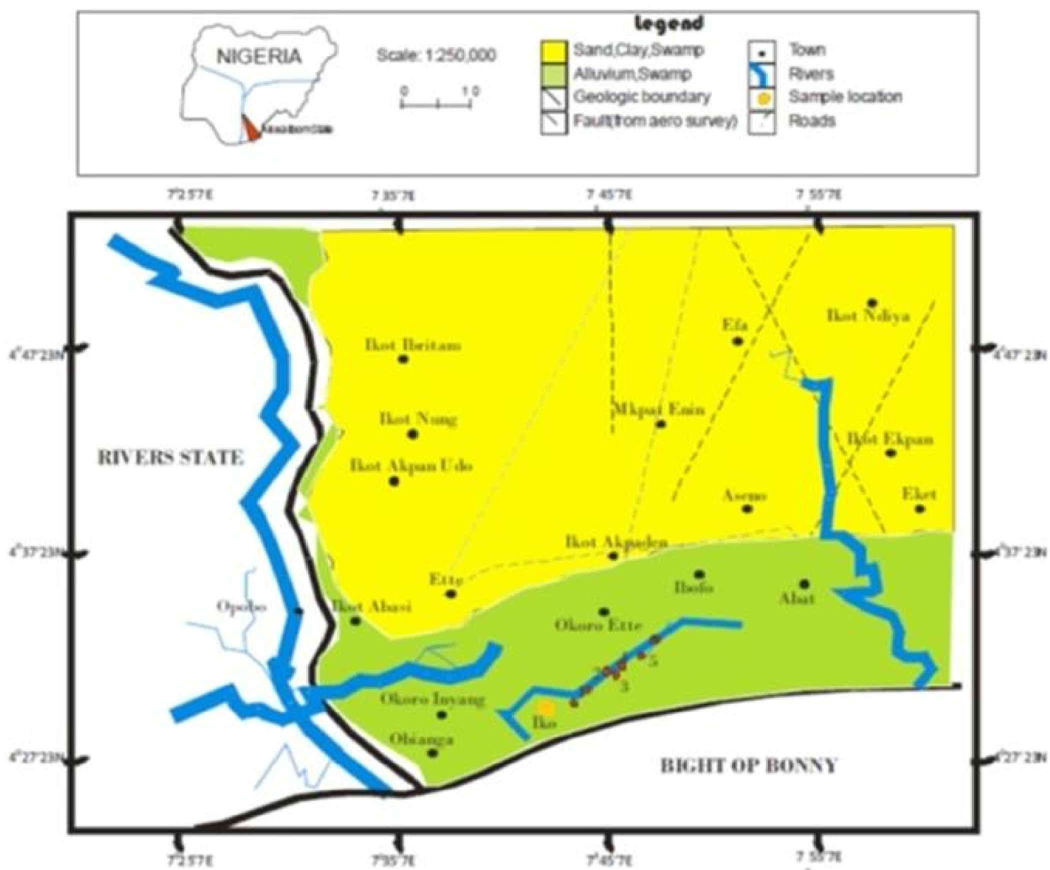

Fig. 1. Location of sampling site on the map of Eastern Obolo, Akwa Ibom State, Southeastern Nigeria

the fish. Specimens were killed using chloroform, pooled together and preserved in 10% formaldehyde solution in plastic container and transported to the laboratory, Fisheries and Aquatic Environmental Management Department, University of Uyo. In this study, efficient sampling was carried out to include the widest possible range of lengths, which were generally obtained using non-selective fishing techniques (non-return valve-basket traps) which did not select the size of fish caught. The variation in fish sizes indicated that the fish population ranged from immature specimens to fully matured ones.

2.3 Data Collection

Fish samples were rinse with water, identified and measured to the nearest 0.1 cm total length (TL) using a measuring board and 0.1 g total weight (TW) using an electronic metler balance for each specimen [37]. Length-based assessment of fish stocks require a minimum sample size of 1500 length-frequency data accumulated within a period of ≤ 6 consecutive months [38]. Our data meets this criterion.

2.4 Data Analysis

2.4.1 Estimation of the seasonalized von bertalanffy growth parameters

The Fish Stock Assessment Tool (FiSAT 11) software [39,40] was used to analyse the monthly length-frequency data (Table 1). The ELEFAN (Electronic Frequency Analysis) procedure in FiSAT 11 was then used to sequentially arrange and restructure the monthly length-frequency data set from which a preliminary asymptotic length (L∞) was seeded.

To estimate growth of each of the mudskippers, the ELEFAN procedure was used to fit the von Bertalanffy growth function (VBGF) using [41].

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

Where L_t = predicted length at age t (in age), L_∞ = the asymptotic length (cm), K = von Bertalanffy growth coefficient (yr^{-1}), t_o = age of the fish at zero length (year) [41]. The age at zero length (t_o) was obtained using Pauly's [42,43] empirical equation as follows:

$$Log_{10}(-to) = -0.392 - 0.275 \times \log_{10} L_\infty - 1.038 \times \log_{10} k \quad (2)$$

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 VBGF and M is the instantaneous rate of natural mortality [44].

2.4.2 Potential longevity (T_{max})

The potential longevity (t_{max}) of the fish was estimated as [45,43].

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

2.4.3 Growth performance index (φ')

The overall growth performance index (φ') was calculated from the formula given by Pauly and Munro [46].

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

Where K and L∞ are parameters of VBGF.

2.4.4 Estimation of mortalities

The rate of natural mortality (M) was estimated (empirically) using the empirical model of Pauly [47].

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

Where, L∞ was expressed in cm (TL) and T is the mean annual surface water temperature (in °C) in the study area which was measured using a mercury in glass thermometer; it ranged from 28.5 to 31.5°C (29.8 ± 0.86).

Total mortality was estimated by the conversion of the overall length-frequency distribution to relative frequency [47,48] and then plotted as histograms, using the length-converted catch curve procedure [40,49]. The slope with the sign changed gave an estimate of Z. The attainment of reasonable estimates of M and Z could lead to an accurate estimate of fishing mortality (F).

The rate of fishing mortality (F) was estimated by subtracting the value of natural mortality (M) from total mortality (Z) based on the equation [50,51,52].

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

2.4.5 Estimation of exploitation

The exploitation rate (E) defined as the fraction of mortality of the fish (F) caused by fishers divided by the fraction of total mortality (Z) was estimated [51,53,54]:

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

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

The exploitation ratio(μ) was calculated empirically [55].

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

Where F = fishing mortality, Z = total mortality and e = 2.7182.

2.4.6 Probability of capture

The probability of capture P of each size class i was estimated from the ascending left arm of the length-converted catch curve procedure developed by Pauly [38]. The method involves dividing the numbers actually sampled by the expected numbers obtained by backward extrapolation of the straight portion or the right 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 mid length, a resulting curve was obtained. From this curve, the length at first capture Lc was taken as corresponding to the cumulative probability at 50% in addition to the length at both 25 and 75 captures which corresponded to the cumulative probability at 25% and 75% respectively. The probability were smoothed using the logit transformation.

2.4.7 Estimation of recruitment patterns

The seasonal recruitment pattern of the fish species was reconstructed using the entire restructured length-frequency data set. This involved projecting backward along a trajectory described by the computed von Bertalanffy growth function (VBGF). Then using the maximum likelihood approach, the Gaussian distribution was fitted to the back-projected data through NORMSEP (Normal Seperation) Procedure [56].

2.4.8 Relative yield-per recruit (Y/R) and biomass-per recruit (B/R) analyses

The yield per recruit model [57] is a principal steady state model that describes the state of stock and the yield in a situation when fishing pattern has been the same for a long time so that all fish are vulnerable to capture after recruitment [58]. The model, as modified by Pauly and Soriano [59] was used to predict the relative yield-per-recruit (y/R) and biomass-per-recruit (B/R) of the goby fishery.

The yield per recruit (Y/R) was estimated by the Berverton and Holt [57]; Froese, Lourdes, Palomares and Pauly [60] function:

$$Y/R = y^1/R^* \,[L\infty\ e - (M\,(tr - t_o)] \quad (11)$$

Where:

Y =yield; R = Recruitment; y^1 = Relative yield; M = Natural mortality; t_r= Age at recruitment; t_o = Age of fish at length zero

Relative biomass per recruit (B/R) was from the relationship:

$$(B/R) = y^{-1}/R/F \quad (12)$$

Where y^1/R is yield per recruit and F is instantaneous fishing mortality coefficient. From the analysis, the expected values of E_{max} (the value of exploitation level E giving the maximum relative yield-per-recuit) was estimated. Also, $E_{0.1}$ (the exploitation level at which the marginal increase in yield per recruit is 10% of the virgin biomass at E = 0) and $E_{0.5}$ (the exploitation level at which the stock is reduced to half(50%) of it virgin biomass) were estimated through the first derivation of the Berverton and Holt [57] function.

2.4.9 Yield isopleth

The yield isopleths were constructed to assess the impact on yields created by change in exploitation rate E (an aproxy for effort) and variation in length at first capture and asymptotic length ratio Lc/ L∞.

2.4.10 Length at first maturity (L_m)

To estimate the length at first maturity (L_m) for the assessed species, the procedure by Hoggarth et al. [61] was used. The input parameters for the model included asymptotic length only (L_∞).

Length at first maturity

$$(L_m)=L_\infty * 2/3 \quad (13)$$

3. RESULTS

The monthly length-frequency data of 2876 specimens collected from the mangrove swamp for 24 months that was used to estimate growth

Table 1. Length frequency distribution of *P. barbarus* from mangrove swamp of Iko river estuary, Southeastern Nigeria between November, 2011 and October, 2013; n = 2,876, Class interval = 1 cm

ML	2011		2012												2013										Sum
	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	
4.45	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
5.45	0	0	3	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	2	0	1	**9**
6.45	0	6	11	12	1	11	4	4	0	1	2	0	17	8	3	3	14	2	2	7	4	15	7	11	**145**
7.45	4	16	22	28	5	22	14	19	6	5	9	10	33	9	12	11	40	14	34	27	13	8	22	25	**408**
8.45	7	25	25	24	28	28	29	18	55	23	28	34	10	21	26	23	32	30	24	26	28	24	26	33	**627**
9.45	10	25	18	28	35	28	29	18	55	23	28	34	10	21	26	23	32	30	24	26	28	24	26	33	**634**
10.45	15	20	22	20	22	24	29	19	32	36	31	26	21	20	26	15	8	24	16	14	30	21	17	17	**525**
11.45	16	18	14	6	21	8	9	7	20	17	12	22	17	24	23	26	3	17	7	8	12	12	9	6	**334**
12.45	5	7	4	1	3	5	5	3	7	4	1	15	7	21	9	4	5	15	2	3	2	14	9	4	**155**
13.45	0	0	0	1	0	0	0	0	1	0	0	2	2	2	5	1	1	2	0	4	3	4	4	1	**33**
14.45	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	1	0	0	1	0	0	0	**5**
15.45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Sum	**57**	**117**	**120**	**120**	**115**	**127**	**119**	**88**	**176**	**109**	**111**	**143**	**119**	**127**	**132**	**106**	**135**	**135**	**109**	**115**	**121**	**124**	**120**	**131**	**2876**

ML=Mid-length

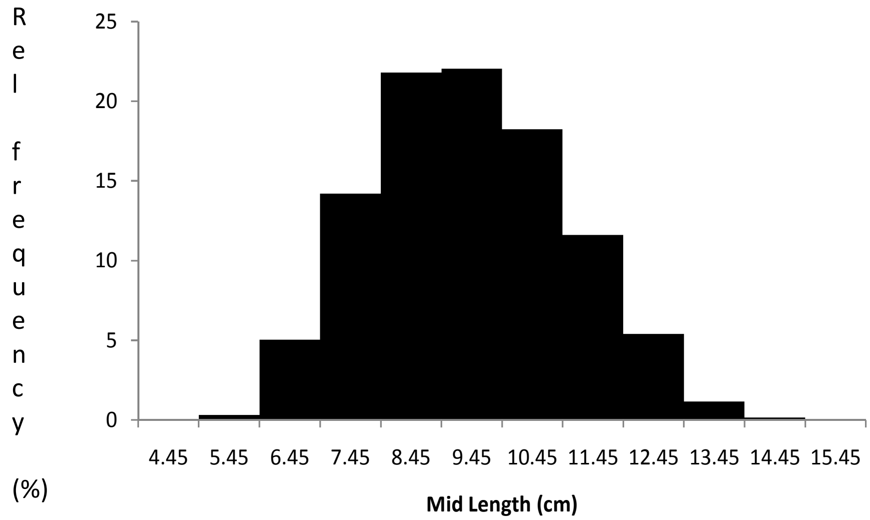

Fig. 2. The overall length-frequency distribution of P. barbarus from artisanal fisheries of the mangrove swamp of Iko River estuary (n = 2,876)

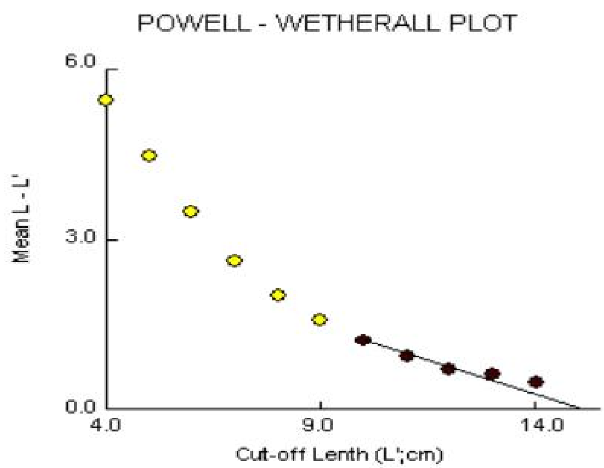

Fig. 3. Powell-Wetherall plot for the length frequency data of *P. barbarus* from mangrove swamp. Black dots were used as input in the Powell-Wetherall plot whose regression equation is Y =3.59 + (-0.239)* X, n = 6, r = - 0.893. Estimated parameters were L∞ = 15.03 cmTL and Z/K = 3.184

and mortality parameters of *P. barbarus* are presented in Table 1. The data indicate variations in the size (length, cm and weight, g). Total length ranged between 4.6 and 14.5 cm with a mean total length of 9.1841 ± 1.6346 corresponding to a total weight that ranged between 1.16 and 50.6 g with a mean of 9.96262 ± 5.4796. The length-frequency distribution (Fig. 2) showed that the 8 - 9 cm TL size groups were numerically dominant and depicts the only mode and constituted 21.88% of the population while the least value of 0.03% was observed at the length class 4 – 5 cm TL.

Analysis of the length-frequency data by the Powell-Wetherall method gave L∞ = 15.03 and Z/K = 3.184 (Fig. 3). 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 Asymptotic length: L∞ = 16.22 cm, Growth Coefficient (K) = $1.2yr^{-1}$, Amplitude of growth oscillation, C = 0.6, Winter point (WP) (period when growth is slowest) = 0.6; Goodness-of-fit (Rn) which signifies fitness of the curve = 3.127 (Table 2). Parameters of von Bertalanffy equation of *P. barbarus* from mangrove swamp of Iko River estuary, Nigeria estimated from length frequency distribution compared to other water bodies in southeast, Nigeria is shown in Table 3.

The seasonalized growth curves were super imposed on length frequency histogram (Fig. 4). The theoretical age, t_o was 0.071. From these parameters, von Bertalanffy length (Lt) growth function for the species was established as:

$$L_t = 16.22[1\text{-exp } -1.2\{t\text{-}(0.071)\}] \quad (14)$$

where L_t is the mean length 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, granted it grows throughout life in its natural habitat irrespective of the ecological peculiarities of the environment and K parameter indicates the speed at which the species grows in size in its years. The growth performance index φ' was also estimated [46] φ'= 2.499 (Table 2).

The effect of fishing on *P. barbarus* stock in the mangrove swamp of Iko River estuary was estimated [43] as Total instantaneous mortality, Z = 4.79 yr^{-1}, natural mortality coefficient, M = 2.39 yr^{-1} while fishing mortality coefficient F, was estimated as (Z-M) = 2.40 yr^{-1}, (Fig. 5); the current exploitation rate E_{cur} was computed as 0.50, while the ratio of exploitation, μ was 2.0 $year^{-1}$ [55]. The estimated population parameters of *P. barbarus* in the mangrove swamp in Iko 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 Lc was 7.33 cm TL (Fig. 6) and Lc/L∞ ratio was 0.45 while L_{opt} was 9.748 cm TL and longevity (t_{max}) was 2.5 years. The analysis of relative yield-per-recruit (Fig. 7) with the assumptions of knife-edge selection (KS),

Table 2. VBGF and some other population dynamics parameters for *P. barbarus* from mangrove swamp of Iko River estuary, Southeastern Nigeria

Population parameters	Mangrove swamp	
L∞ = Asymptotic length. CmTL	16.22cm	
K = Von Bertalanffy growth function yr^{-1}	$1.2yr^{-1}$	
C = Amplitude of growth oscillation	0.6	
WP = Winter Point	0.6	
R_n = Goodness of fit index	0.3127	
t_0 yr = Age of fish at zero length	0.071	
φ'= Growth performance index	2.449	
t_{max} = longevity. ($^3/_k$)	2.5	
$t_{r\,=}$ Age at recruitment		
L_{opt} = Optimum length	9.748	
Population parameters		
Z = Total Mortality	4.79	
M = Natural Mortality	2.39	
F = Fishing Mortality	2.40	
E_{cur} = Exploitation rate	0.50	
μ = Ratio of exploitation	1.99 (2.0)	
Lc = Length at first capture	7.33	
$y/_R$ = yield per recruit	KS	OS
a E-max	0.711	0.668
b E-10	0.607	0.552
c E- 50	0.349	0.34
m/k	1.99	
z/k	3.184	
Lm/L∞	M= 0.678, F=0.635	
Lc/L∞	0.450	
Functional equation	Y= 3.59+(-0.239)*x	
Length at 50% maturity or length at first maturity	M = 11.0	
	F = 10.3	

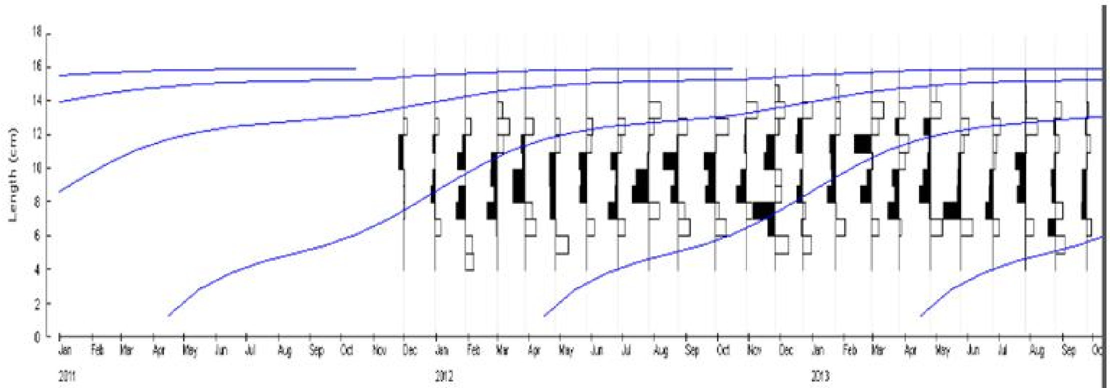

Fig. 4. Seasonalized von Bertalanffy growth curves of *P. barbarus* from mangrove swamp as superimposed over the restructured length-frequency histograms. The blank and white bars are positive (peaks) and negative (troughs) deviation from the weighted moving average of three length classes and they represent pseudo-cohorts. The VBGF parameters were: L∞ =16.22 cm, K=1.2yr^{-1},C= 0.6, Winter point (WP) = 0.6; the estimated goodness of fit index (Rn) = 0.3127

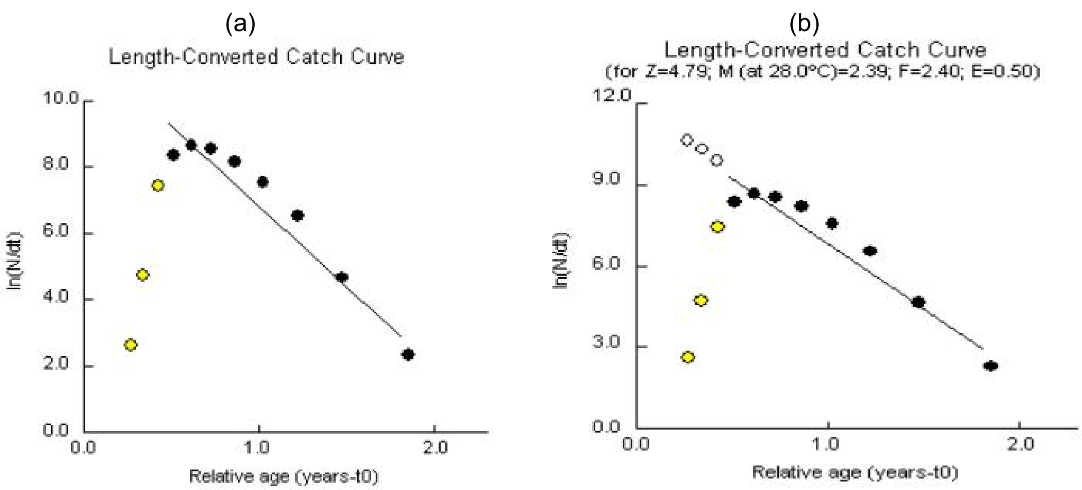

Fig. 5. Length-converted catch curves for *P. barbarus* from mangrove swamp(a) Seasonalized length-converted catch curve- the slope of the right descending arm (black dots) of the curve with sign changed gave an estimate of seasonalized Z. (b) Estimated Z = 4.79 yr^{-1}, M = 2.39 yr^{-1} , F =2.40 yr^{-1} and E = 0.50 from seasonalized length-converted catch curve

that only fish of lengths ≥ Lc were recruited by the gear, gave the summary statistics as follows: E_{max} = 0.711, $E_{0.1}$ = 0.607 and $E_{0.5}$ = 0.349 (Fig. 8a); whereas the ogive selection (OS) option gave E_{max} = 0.668, $E_{0.1}$ = 0.552 and $E_{0.5}$ = 0.340 (Fig. 8b).

The length at age growth analysis gave a t_o as 0.071 (t_o is length at age zero). And Lc/L∞ ratio was 0.45 (Fig. 9) while L_{opt} was 9.748 and longevity (t_{max}) was 2.5 The length at which 50% (L_m) of samples matured was 11.0cm for males and 10.3 cm for females and Lm/ L∞ was 0.68 for male and 0.64 for females.

4. DISCUSSION

The catch data presents *P. barbarus* of wide variations in sizes with the b value estimator of length-weight relationship with a b value of 3.099 indicating isometry (Table 2). This is close to other reports from Southeast Nigeria [26,62] but differ from the result gotten by [63,4]. The value falls within the valid limit reported for fish; 2.0 –

3.5 [64], 2.5 – 4.0 [44]; and 2.56 – 3.50 for eleven species of mudskippers caught in the coastal areas of Selangor, Malaysia [65]. In 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 [44], indicating a tendency towards slightly positive – allometric growth (increase in relative body thickness or plumpness) in most fishes. In this study, the b value tends toward positive – allometric growth. However, growth of fish is isometric at the early age (t_o) and allometric at later age (t_{max}) [66].

Table 3. Parameters of von Bertalanffy equation of *P. barbarus* from mangrove swamp of Iko River estuary, Nigeria estimated from length frequency distribution compared to other water bodies in Southeast, Nigeria

Location/Reference	L∞ cm TL	K, yr^{-1}	t_o, yr	φ'	t_{max}	tr	L_{opt}	C	WP
Powel – Wetheral Mangrove swamp (This study)	15.03								
Mangrove swamp (This study)	16.22	1.2	0.071	2.449	2.5		9.748	0.6	0.6
Imo River estuary (Udoh *et al*., 2013)	19.9	1.00	-0.75	2.59	3			0.9	0.6
Imo River estuary (Etim *et al*.,2002)	21.6	0.55	-0.49	2.28	5.5				
New Calabar (Chukwu and Deekae (2010)	10.73	3.57	-1.25	2.181	0.8				
Cross River (Etim *et al*., 1996)	19.6	0.51	-0.44	2.28	5.9				
Cross River (King, 1996)	17.8	0.36	-0.28	2.06	8.3				
Qeshm Island, Iran (Sarafraz, Abdoli, Kiabi, Kamrani and Akbarian, 2011)	14.15	0.46	0.79	1.96	6.5				
Bandar-Abbas, Iran (Sarafraz et al, 2011)	16.68	0.42	0.62	2.07	7.1				

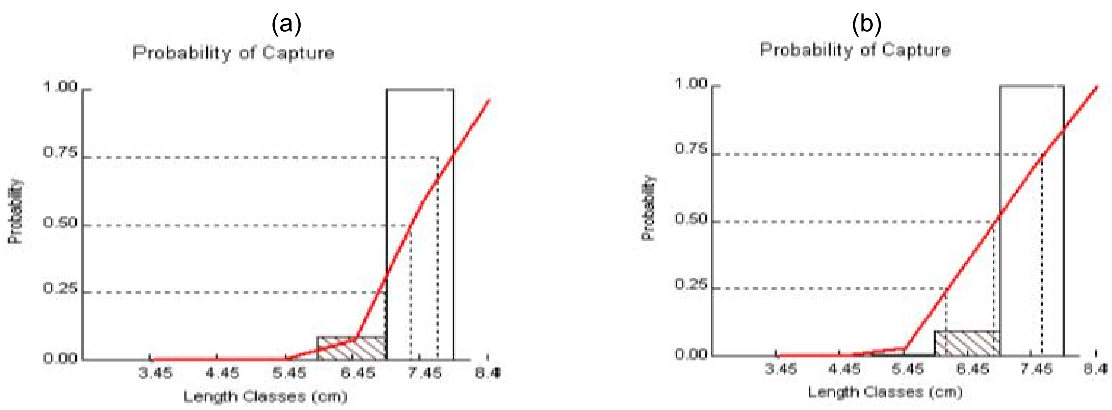

Fig. 6. Probability of capture by length class of *P. barbarus* from mangrove swamp estimated from the ascending arm of the catch curve. The length at first capture (L-50) = 7.33 cm, (L-25) = 6.94 cm, (L-75) = 7.72 cm by (a) logit transformation (b) Running average The estimated length at first capture (dotted line at the middle) is one of the inputs in computing the relative yield-per-recruit, relative biomass-per-recruit and plotting of the yield isopleths

Table 4. Comparison of the estimated population parameters of *P. barbarus* from mangrove swamp of Iko River estuary, Nigeria to other water bodies in Southeast, Nigeria

Location/References. Population Parameter	**(This study) Mangrove swamp**		**Imo River (Udoh *et al.*, 2013)**		**Imo River (Etim *et al.*, 2002)**	**Cross River Etim *et al.*, (1996)**	**Cross River (King, 1996)**	**New Calabar Chukwu and Deekae, 2010**
Total Mortality (Z)	4.79yr^{-1}		9.57yr^{-1}		4.21yr^{-1}	2.208yr^{-1}	0.836yr^{-1}	2.03yr^{-1}
Natural Mortality (M)	2.39yr^{-1}		2.04yr^{-1}		1.35yr^{-1}	1.34yr^{-1}	0.72yr^{-1}	1.68yr^{-1}
Fishing Mortality (F)	2.40yr^{-1}		7.53yr^{-1}		2.86yr^{-1}	0.868yr^{-1}	0.116yr^{-1}	0.35 yr^{-1}
Exploitation Rate (E)	0.50		0.79		0.68	0.393	0.139	0.17
Ratio of Exploitation (μ)	2.0yr^{-1}		0.787yr^{-1}		_			2.58
	KS	**OS**	**KS**	**OS**				
Emax	0.711	0.668	0.306	0.644	0.151			0.421
E0.1	0.607	0.552	0.252	0.516	0.465			0.355
E0.5	0.349	0.340	0.236	0.333	0.296			0.278
Lc	7.33		7.76 ch		7.69			0.764
Lopt.	9.748		11.85cm TL					
M/K	1.99		2.04		2.45	2.63	2	0.47
Z/k	3.184		2.396		7.65	4.33	2.32	0.57
Lc/L∞	0.450		0.38995		0.356			0.05
Lm	M = 11.0							
	F = 10..3							
Lm/L∞	M = 0.678							
	F = 0.635							

KS=Knife-edge selection; OS=Ogiv selection

The *P. barbarus* in the present study follows exponential growth pattern and the von Bertalanffy growth parameters (L∞=16.22, K=1.2 $year^{-1}$) are within range and compares (though K is higher) to studies reported for Imo and Cross River species [3,27,62,4], but lower than that of New Calabar River [68] for the same species (Table 3). The L∞ (16.22) was lower than those for Imo and Cross River [62,27,3,4] but higher than that of the same species from New Calabar River [67]. 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 4 m in long-lived fishes like whale sharks [4]. 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 [44,4].

The growth performance index in this study (φ'= 2.499), was higher than in other studies for the same species in Imo River, Cross River and New Calabar River [62,27,3,68], but lower than that of the same species in Imo River [4] (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' [69,4,70].

The longevity of this species (Table 3) in the present study was 2.5years (t_{max} = 2.5years) and contradicts higher values obtained [62,27,3,4]. The amplitude of growth oscillation (C= 0.6) and Winter Point in this study (WP = 0.6) was lower than that obtained for the same species in Imo River [4]. Winter Point (WP = 0.6) obtained for this research is in tandem with the one obtained for the same species in Imo River [4]. The amplitude of growth oscillation and Winter Point obtained in this study indicated 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. However, in the tropics, the environmental water temperature is high all year, except for slight variation. Therefore, temperature change may not be a major factor for growth retardation in this environment. The poorest growth of the fish in 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.

Mortality in an exploited fish population could be classified into natural mortality (M), fishing mortality (F) and total mortality (Z). Natural mortality is caused by disease, starvation, spawning stress and senescence. Other factors include predation, climate change and pollution

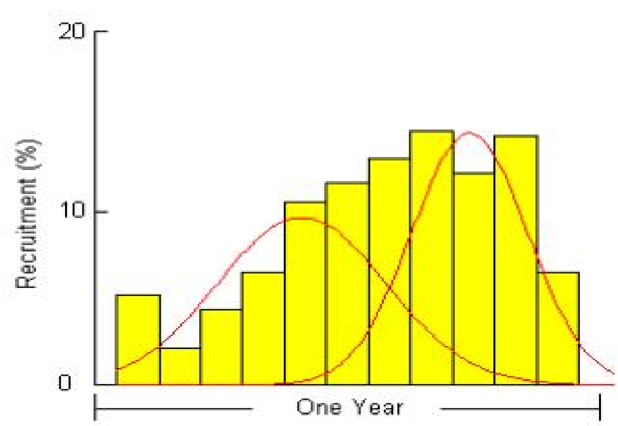

Fig. 7. Recruitment pattern of *P. barbarus* from mangrove swamp by backward projection along a trajectory defined by the VBGF, of the restructured length frequency data onto an arbitrary one-year time scale. The recruitment pattern was decomposed into pulses exhibiting two peaks of unequal pulse strength for *P. barbarus.* The pattern was decomposed using NORMSEP routine and fitted with two Guassian distributions

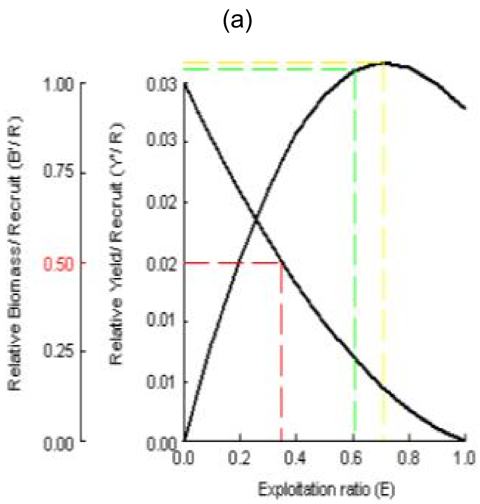

Fig. 8. (a) Relative yield per recruit and relative biomass per recruit for *P. barbarus* from mangrove swamp using the Knife- edge selection procedure, summary Statistics: E_{max} = 0.711, $E_{0.1}$ = 0.607 and $E_{0.5}$ = 0.349. This procedure is based on the unrealistic assumption that only fishes greater or equal Lc are retained by the gear.(b). Relative yield-per-recruit and relative biomass-per-recruit for *P. barbarus* using the ogive selection procedure, summary Statistics: E_{max} = 0.668, $E_{0.1}$ = 0.552, $E_{0.5}$ = 0.340. E_{max} = the value of exploitation rate (E) giving the maximum relative yield per-recruit. E0.1 = the value of E at which marginal increase in y/r is 10%. E0.5 = the value of E at 50% of the unexploited relative biomass –per recruit

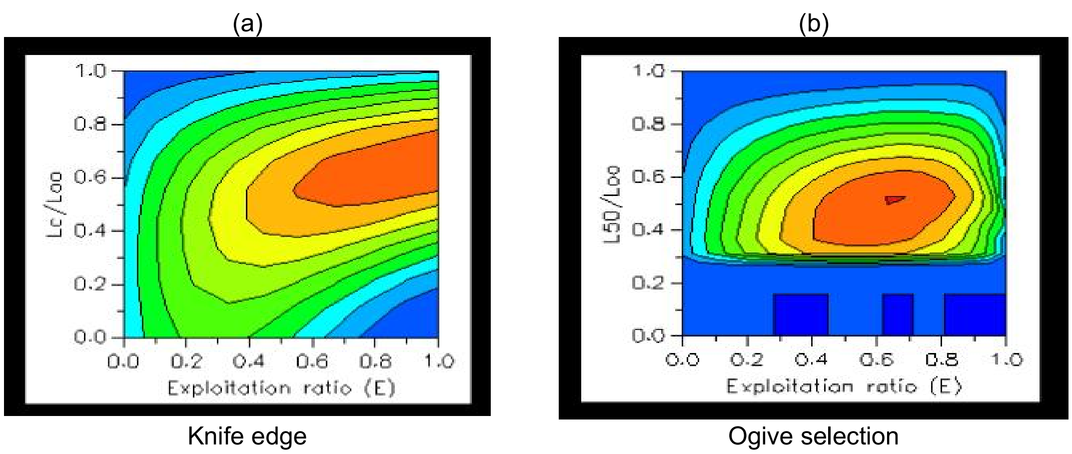

Fig. 9. Yield isopleths for *P. barbarus* from mangrove swamp. (a) The computed E = 0.50 and Critical ratio Lc/ L∞. = 0.450 and M/K = 1.99 for Knife–edge selection procedure (b) The computed E = 0.50 and Critical ratio Lc/ L∞. = 0.450 and M/K = 1.99 for Ogive selection procedure

[4]. Fishing mortality is caused by the activity of the fishers while Z is the sum of M and F [3.4]. The effect of fishing on *P. barbarus* was predicted from mortality values: Z = 4.79year^{-1}, M = 2.39 year^{-1} and F = 2.40 year^{-1} (Fig. 3). Z was higher than those reported in Imo River, Cross River, New Calabar River [62,27,3,68] but lower than the one reported for the same species in Imo River [4]. M was higher than those reported in Cross River, Imo River and New Calabar River for the same species [62,3,27,68,4]. This observation could be due to the fact that mudskippers in the mangrove swamp of Iko River estuary are more susceptible to natural conditions than those in other water bodies aforementioned. Further, it shows that environmental conditions in the mangrove swamp are less favourable than those of the

other water bodies. Fishing mortality (F) is mostly reported to cause changes in population parameters such as size ratio, growth rate, size composition, and size at first maturity. The estimated F was lower than those reported in Imo River [3,4] but higher than those reported in Cross River and New Calabar River [62,27,68] (Table 4).

The current exploitation rate, E_{cur} = 0.50, indicates that about 50% of the total mortality of the available stock was caused by exploitation; this was lower than those obtained for the same species in Imo River (Etim et al., 2002 and Udoh et al., 2013), but higher than those observed in Cross River and New Calabar River [62,27,68]. This result indicates that the stock was optimally exploited. The optimum yield of a fishery is taken when the fishing mortality (F) is about equal to natural mortality (M) that is, F = M or E = F/Z = 0.5; that is, E_{cur} = 0.5, indicate optimal fishing [4]. This result is lower than those reported for the same species in Imo River [3,4] but higher than those reported in Cross River and New Calabar River [62,27,68]. Consequently, the species are under excessive and high fishing pressure in Imo River and optimal fishing in Mangeove swamp of Iko estuary. This is probably because the fish is a food fish sought after by the inhabitants around Iko Estuary and Imo River; unlike, in the Cross River Estuary where it is largely exploited as fish – food or bait. The results indicate that the fish stock was not overexploited [E = 0.50 < E_{max} = 0.711 (KS), 0.668 (OS)]. However, the exploitation of this stock could soon approach the maximum sustainable yield if the current level of exploitation is not checked accordingly with subsequent negative consequences on the stock biomass and food security for fishing households. Therefore, the present fishing mortality (in terms of the use of non-selective gears) should be of urgent concern for fisheries managers in Akwa Ibom in particular and Nigeria as a whole.

The interaction of the fish with gear indicated that current Lc = 7.33 cm TL (Fig 4) was lower than those obtained for the same species in Imo River, Cross River and New Calabar River [4,3,62,27]. However, the length at first capture is lower than the length at first maturation (Lc = 7.33 < Lm = 10.9 (male); 10.2 (female). This shows that the fish stock was harvested before they could reach the matured stage, a characteristic feature of growth overexploitation. Growth overexploitation is mostly characterized by small fish species within the harvested catch. The Lc/L_∞ ratio of 0.45 indicates the fish was yet to complete 55% of growth as at the time of capture at L_{50}. The value is better than earlier values obtained for the same species in Imo River [3,4] (Table 4). However, the recorded Lc/L_∞ ratio of 0.45 was less than 0.5 which indicated that majority of the catch constituted juvenile fish species [4]. This assertion affirmed the evidence of growth overexploitation. The abundance of small-sized fish in the catch could be explained by the use of non-selective fishing gear. For this reason, a selective gear such as gill net with large mesh size should be employed. King (25) showed that minimum mesh sizes in net are applied in many fisheries to allow small individuals to escape and grow to a more valuable market size. A further aim may be to allow individuals to reach a size at which they can reproduce at least once before capture. Satoshi, Syed and Mansor [71] also stated that living resources are self-reproducible. If many matured fish were caught by the fishery during and/or before spawning season, the stock of the next generation would be decreased immediately.

The relative yield per recruit (Y`/R) is a function of different values of exploitation rate (E) and length at first capture Lc. The Y`/R based on the assumption of the knife edge selection assumes that specimens < Lc are not retained by the trap, while the selection ogive procedure assumes that the probability of capturing any specimen is a function of its lengths. Therefore, the selection ogive is much realistic. In this study, computed current exploitation rate (E_{cur} = 0.50) is less than the predicted values (E_{max} = 0.668) which suggests optimal 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 = 3.184 in this study and shows optimal level of exploitation (compared to others) and is higher than those obtained in Imo River, Cross River and New Calabar River [4,27,68] but lower than those reported in Imo and Cross River in other studies [62,3] (Table 4).

The ratio of natural mortality (M) to intrinsic growth rate (K), for mudskipper fishery in the southeast Nigeria (M/K = 1.99) falls within the range of 1.0 to 2.5 (for fish) indicating a good environmental state [72]. The M/K obtained in this work is lower than those obtained for the same species in Imo River and Cross River [62,3,4], higher than that obtained for New Calabar River [67] but agrees with that obtained in Cross River [27] (Table 4). 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 [73].

5. CONCLUSION

The study has revealed that *P. barbarus* population residing in the mangrove swamp of Iko River Estuary is experiencing exploitation rate close to the maximum sustainable yield amidst the presence of heavy fishing pressure. Moreover, the mudskipper fishery in this ecosystem is currently exhibiting growth overexploitation signs which could lead to severe implications on the population size and food security within vulnerable fishing households in the future. Therefore, urgent management interventions in the form of monitoring fishing efforts, return of captured juveniles back to the water body from the non-selective fishing gear and use of selective gear with large mesh size (to increase length at first capture) are needed to safeguard this important fish species from possible collapse in the future.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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