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Population Dynamics of the Exploited Penaeid Shrimp, *Penaeus* (*Farfantepenaeus notialis)* in the Cross River Estuary, Nigeria

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Abstract: The Southern Pink Shrimp, *Farfantepenaeus notialis* Perez-Farfante 1967 (Decapoda: Penaeidae) is Nigeria's foreign exchange earner in the fisheries industry. Fished by both artisanal and industrial fleets, this stock deserves effective management in order to maximize its contributions to national food protein and economy. For assessment of the population biology of this stock, length-frequency data were collected from commercial shrimp landings for two consecutive seasons, 2007 and 2008. Each year was analyzed for population parameters using the FAO-ICLARM Stock Assessment Tool (FiSAT II). Asymptotic length ($L\infty$) and growth rate (K) were 133.93 and 131 mm; 1.65 and 1.55 year^{-1} for 2007 and 2008, respectively. Mortality coefficients were; total mortality Z = 6.86 year^{-1} (r = 0.9912) and 9.37 year^{-1} (r = 0.9987); natural mortality (M) = 1.60 and 1.54 year^{-1}; fishing mortality (F) = 5.26 and 6.44 year^{-1}. The resultant exploitation ratios were 0.77 and 0.69, respectively. The exploitation ratios indicate that this fishery is being over-exploited. Although, information from the trawl catches is lacking in this study, a holistic management approach that would regulate both fisheries is recommended. Of concern should be the incidence of non-native *Penaeus monodon* in this ecosystem. A stock enhancement program would be desirable for the native *Penaeus notialis.* Both artisanal and trawl shrimpers should be monitored in order to ensure that a closed period management regulation was respected.

Key words: Penaeid shrimp, population biology, exploitation, estuary, Nigeria

INTRODUCTION

Shrimp fishery is one of the most important components of world annual fishery production. Its value has accentuated over the years, due to high demand, especially in developed countries. Shrimps are regarded as the most consumed fishery products in most developed countries. The demand and high foreign exchange earnings have driven exploitation of most shrimp stocks to unhealthy levels. The recent world catch of shrimp is about 3.4 million tons year^{-1} (Gillet, 2008). The attendant bycatch of finfish juveniles, turtles and mammals associated with shrimp fishery is a global issue for fisheries managers, conservationists and economists. Even with the introduction of Bycatch Reduction Devices (BDRs) and Turtle Excluder Devices (TEDs), this problem has only been marginally reduced (Ambrose *et al*., 2005; GFMC, 2006; Kelleher, 2005; Lae *et al*., 2004; Roberts, 2005). From 1970-2000, Penaeidae on average comprised 42.2% of the world catch of shrimps (FAO, 2000a). The species *Penaeus* (*Farfantepenaeus*) *notialis* Perez-Farfante, 1967 is distributed along the West African coast from Mauritania to Angola (East Atlantic) and in the Greater Antillers from Cuba to the Virgin Islands and on the Atlantic coast of Middle and South America from S. Mexico (Quintana Roo) to Brazil (S. to Rio de Janeiro) (Western Atlantic) (Holthuis, 1980; Powell, 1982). With preference for muddy or sand mud bottom habitats, it is usually available in depths of 3-100 m. In almost of its distribution range, *P. notialis* sustains rich fisheries with strong foreign exchange earnings for those countries, in addition to employment, food-protein and local income. For instance, the wild capture shrimp industry in Nigeria generates about US$57 million annually in foreign exchange (USAID, 2002) and as Fennessy *et al.* (2004) shown that of the 12,000 tons of landed shrimps, 8000 tons went to the export market. Penaeid shrimps are fast growing and short lived, commonly with a life cycle of about one year (Gulland and Rothschild, 1984). The reproductive biology of *Penaeus notialis* has been well documented by Garcia and Reste (1981) and Garcia (1985). According to Dall *et al.* (1990), *P. notialis* falls within Type II life history pattern i.e., the post-larvae migrate to estuarine nursery grounds. As the juveniles mature, they migrate from the estuaries. However, there is no information in literature on month of the year when post-larvae of this species arrives the Cross River Estuary. But it is the experience of local fishers that sub-adults become available to the fishery around January each year and sustains a fishery until about May-June.

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A recent development in the capture shrimp fishery is the occurrence of *Penaeus monodon* in trawl catches in Atlantic waters. This non-native giant prawn has become prominent in catches within Nigeria and neighbouring Cameroon. For instance, one Nigerian trawling company with 10 trawlers shown 2 tons catches of this species during fishing trips in 1999 (FAO, 2000b). As much as 10% of the species is shown in trawler catches around Calabar/Delta areas within the four years of its first occurrence in landings (USAID, 2002). Although, the source of *P. monodon* is presently speculative (as escapees from Gambian, Senegalese or Cameroonian shrimp farms), natural sources are ruled out. The implication of this introduction to the ecology of the native species *P. notialis* has yet to be ascertained.

Nigeria's capture shrimp fishery which subsists on the genus *Penaeus*, plays an important role in the national economy. Regular updating of the state of the stocks will ensure proper management of the resources and sustainability of their benefits.

The present study report focuses on the rate of exploitation of this stock using length-frequency analysis methods. Attention is being drawn to the potential ecological threat by the alien and thriving species *P. monodon* within the maritime area.

MATERIALS AND METHODS

The study area is the Cross River Estuary, located within the Gulf of Guinea Large Marine Ecosystem (LME) Latitudes 4° and 8°N and Longitudes 7°30 and 10°E (Fig. 1). It is the acclaimed biggest estuary in this LME with an estimated area of 100 km^2, shared between Nigeria and Cameroon. The sediment morphology is that of muddy to sandy mud, which makes it an ideal habitat for shrimps and prawns. The muddy sediments is sustained by regular tropical run-off and river discharge.

Population parameters for this study were estimated using FAO-ICLARM Stock Assessment Tool (FiSAT version II). FiSAT could be described as composite software incorporating several routines for tropical fish stock assessment. An array of Fisheries Scientists contributed to its development but the different programs were later assembled into single software with many routines by Gayanilo and Pauly (1997). The curvilinear von Bertalanffy growth equation was used to describe the growth of *P. notialis*:

$$L_t = L\infty(1 - \exp^{-K(t-t_0)}) \qquad (1)$$

Where:

- L_t = The length at time t
- $L\infty$ = The asymptotic length
- K = The growth coefficient which describes the rate at which asymptotic length is approached

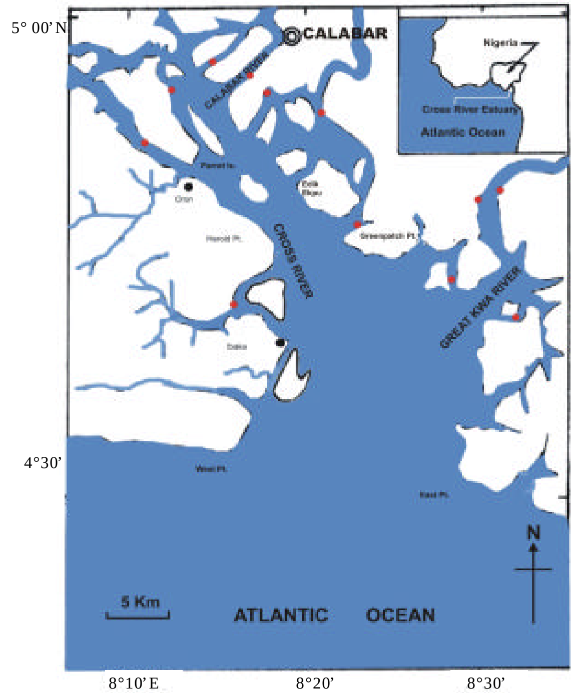

Fig. 1: Map of Cross River Estuary showing Calabar the sampling station

- t_0 = The hypothetical age when the size is zero assuming that the animal has always grown according to the von Bertalanffy growth equation (Dall *et al*., 1990)

The instantaneous rate of total mortality (Z) was estimated from length-converted catch curve analysis incorporated in FiSAT Package with the option accounting for oscillation in growth (Gayanilo and Pauly, 1997). Natural mortality (M) was derived from Pauly (1980a)'s empirical formula which is incorporated in FiSAT.

This formula requires an input of ambient temperature 26.7°C which was for this estuary. Fishing mortality (F) was calculated from Z-M. Longevity (t_{max}) was calculated using Pauly (1980b):

$$t_{max} \approx 3/K \qquad (2)$$

Probability of capture was estimated from the length-converted catch curve procedure. The method consists of backward extrapolation of the right descending side of the catch curve to include shrimps that ought to have been caught has it not been for the effect of incomplete selection and recruitment. An important output of this routine is the length or size at first capture (L_{50} or L_c).

RESULTS AND DISCUSSION

The monthly length-frequency data for this investigation are shown in Table 1 and 2. Figure 2 and 3 are ELEFAN I output of the length-frequency data for 2007 and 2008, respectively. Estimated growth parameters for the study years were L_∞ = 133.93 and 131 mm and K = 1.65 and 1.55 $year^{-1}$ for 2007 and 2008, respectively.

Total mortality coefficients (Z) estimated from length-converted catch curve routine (Fig. 4 and 5) were 6.86 (r = 0.9912) and 9.37 $year^{-1}$ (r = 0.9987) while natural mortality (M) = 1.60 and 1.54 $year^{-1}$ and fishing mortality (F) = 5.26 and 6.44 $year^{-1}$.

Table 1: Length-frequency data for *Penaeus notialis* from the Cross River Estuary, Nigeria

	Year (2007)				
Midlength (mm)	January	February	March	April	May
32	11	-	-	-	-
37	30	-	10	-	-
42	105	-	41	10	-
47	73	27	33	10	-
52	35	38	40	40	-
57	29	156	40	23	-
62	-	80	45	35	-
67	-	91	30	32	-
72	-	91	37	11	-
77	-	91	16	37	26
82	-	83	128	43	73
87	-	35	32	31	31
92	-	58	13	175	12
97	-	40	70	25	-
102	-	40	25	36	-
107	-	13	11	11	-
112	-	12	2	12	-
117	-	2	0	5	-
122	-	-	1	-	-
Total	283	857	574	536	142

Table 2: Length-frequency data for *Penaeus notialis* from the Cross River Estuary, Nigeria

	Year (2008)					
Midlength (mm)	January	February	March	April	May	June
32	12	-	-	10	10	-
37	51	40	70	121	10	10
42	143	55	322	224	43	10
47	30	189	350	240	55	10
52	20	120	384	315	90	84
57	10	50	349	147	104	25
62	12	44	485	218	40	16
67	2	65	240	150	90	10
72	2	42	203	45	246	10
77	-	20	203	124	120	-
82	-	40	110	124	73	-
87	-	23	120	70	56	-
92	-	11	64	19	21	-
97	-	11	13	19	10	-
102	-	-	14	15	-	-
107	-	-	0	15	-	-
112	-	-	2	3	-	-
117	-	-	-	1	-	-
Total	282	710	2929	1860	968	175

The resultant exploitation ratios were 0.77 and 0.69. Probabilities of capture (Fig. 6 and 7) estimated length at first capture (L_{50}) at 84.73 and 63.51 mm; L_{25} at 75.88 and 43.17 mm and L_{75} at 91.16 and 69.63 mm, for 2007 and 2008, respectively. Figure 8 and 9 depicted the regular pattern

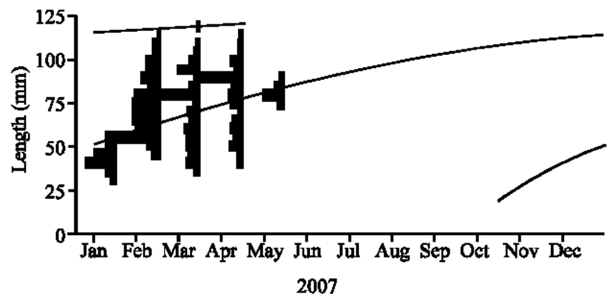

Fig. 2: *Penaeus notialis* growth curve superimposed over the length-frequency histograms for 2007 (L_∞ = 133.93 mm (total length), K = 1.65 $year^{-1}$, C = 0.25, WP = 0.15, Rn = 0.259

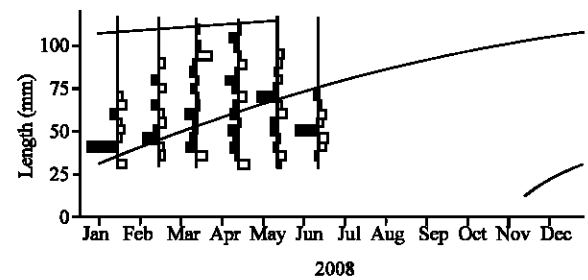

Fig. 3: *Penaeus notialis* growth curve superimposed over the length-frequency histograms for 2008 (L_∞ = 131.00 mm (total length), K = 1.55 $year^{-1}$, C = 0.25, WP = 0.15, Rn = 0.261

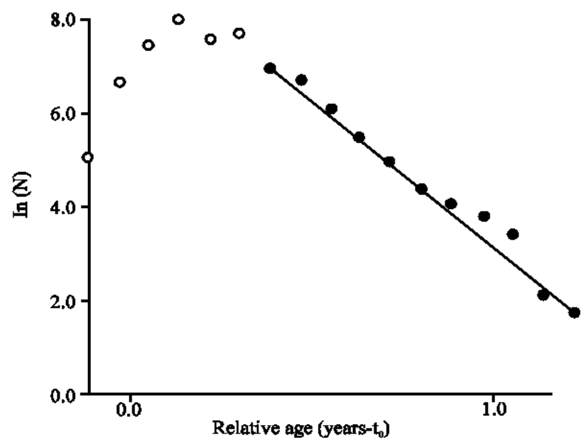

Fig. 4: Length-converted catch curve of *Penaeus notialis* of the Cross River Estuary, Nigeria. Estimated from 2007 data: Z = 6.86 $year^{-1}$, r = -0.991

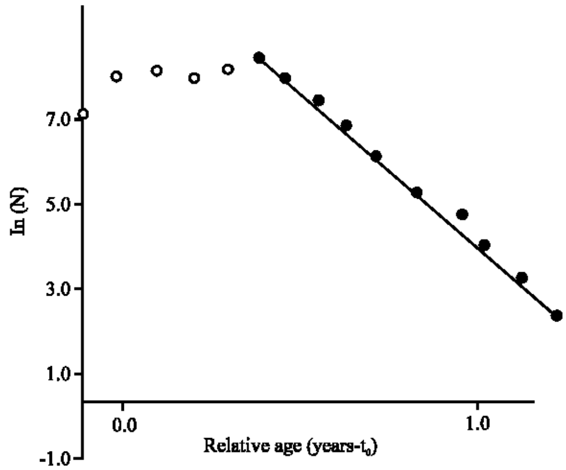

Fig. 5: Length-converted catch curve of *Penaeus notialis* of the Cross River Estuary, Nigeria. Estimated from 2008 data: $Z = 9.37$ year^{-1}, $r = -0.999$

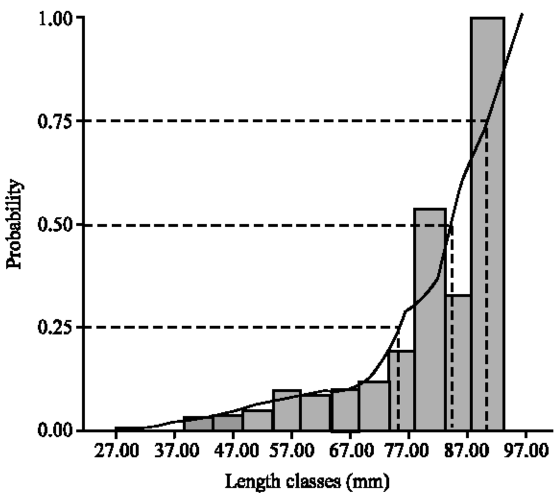

Fig. 6: Probability of capture of *Penaeus notialis* (2007 data) estimated from the ascending arm of the catch curve. The length at first capture (L_{50}) 84.73 mm, $L_{25} = 75.88$ mm, $L_{75} = 91.16$ mm

of population degradation of the exponential decay model using FiSAT length-based Virtual Population Analysis. Longevity, the approximate length of time the oldest individual in a population is expected to live (t_{max}) is 22 months (2007) and 23 months (2008).

Field observations of the maximum size (total length) have been recorded as 113 and 135 mm (Powell, 1982); 175 and 192 mm (Holthuis, 1980) for male and female, respectively. Maximum size recorded in this study was 124 mm (sex undifferentiated). This falls within the range of male-female maxima (113-135) recorded by Powell (1982) in the Niger Delta on the same coast of Nigeria. The

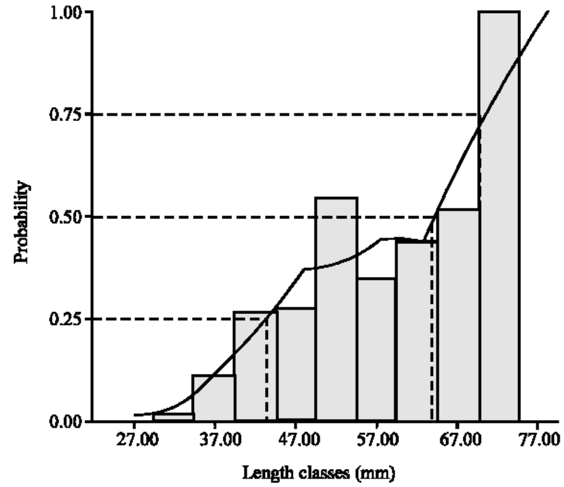

Fig. 7: Probability of capture of *Penaeus notialis* (2008 data) estimated from the ascending arm of the catch curve. The length at first capture (L_{50}) 63.51 mm, $L_{25} = 43.17$ mm, $L_{75} = 69.63$ mm

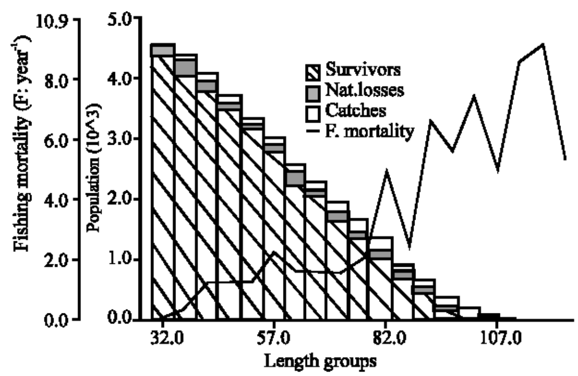

Fig. 8: Length-structured Virtual Population Analysis (VPA) for *Penaeus notialis* using 2007 data

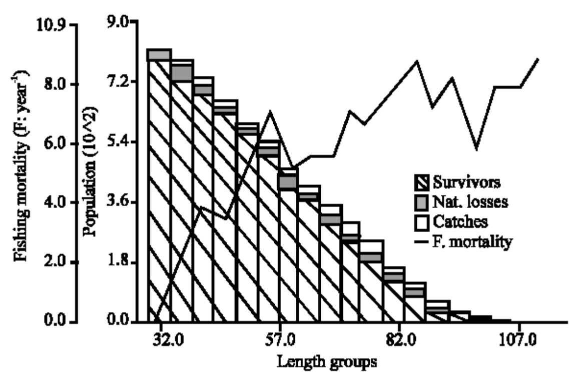

Fig. 9: Length-structured Virtual Population Analysis (VPA) for *Penaeus notialis* using 2008 data

maximum length (L_{max}) (124 mm) observed in samples in the study area suggests that the asymptotic lengths ($L\infty$) of

133.93 mm (2007) and 131.00 mm (2008) are within expected range. According to Taylor (1962), Beverton (1963) and Pauly (1984), the oldest fish of a stock grow approximately to 95% of their asymptotic length ($L_\infty \approx L_{max}/0.95$). By this formula, the L_{max} of 124 mm yields L_∞ of 130.53 mm. The annual growth curvature parameter (K-rate at which L_∞ is approached) of 1.65 (2007) and 1.55 (2008) indicates fast growth rate and agree with Gulland and Rothschild (1984) that penaeids are fast growing and short-lived species. This is confirmed by the longevity (t_{max}) of approximately 22 months (2007) and 23 months (2008) with no option a second estuarine life cycle. In the Persian Gulf, Niamaimandi (2006) shown annual K of 1.6 and 2.2 and longevity of 15 and 20 months, respectively, for male and female *Penaeus semisulcatus*.

Predation on the species in this estuary is regarded as the main cause of natural mortality as is the case of most aquatic life within the lower trophic levels. This situation might change to senescence further up the trophic pyramid. The relatively high natural mortality (M) recorded in this study (M = 1.6 and 1.54 for 2007 and 2008, respectively) indicates rate of predation on the species. Figure 8 and 9 confirm that specimens of higher length groups had less predation but were more susceptible to fishing. Caveriviere and Andriamirado (1997) studying the diet of potential fish predators of this shrimp species (*Penaeus notialis*) in Senegal's commercial pink shrimp fishery, found low predation on this shrimp in the open sea. These researchers concluded that the low predation on *P. notialis* in open sea was due to the large size in marine phases and predicted an opposite predator-prey relationship in the estuaries where juveniles of this species predominate. The researchers further shown that the genus *Pseudotolithus* was the only predator of *P. notialis* in their study. In the present study area, *Pseudotolithus elongatus* contributed 63.2% by weight in the artisanal gill net fisheries (Holzlohner *et al.*, 2007). The high natural mortality of *P. notialis* in this estuary is probably consistent with trophic interactions within such ecosystem. Some penaeid species however, suffer more predation with higher M. For instance, Abdulqader (2002) estimated M at 2.6 and 3.2 $year^{-1}$ for males and females *P. semisulcatus* in Bahrain waters. But Zimmerman *et al.* (1984) noted that prey density increases predation was recorded in the brown shrimp during their study.

Exploitation ratio (E = F/Z) is the management basis for computation of growth parameters. Gulland (1971) had established that E = 0.5 indicates an overfished stock. For the present study, E was 0.77 (2007) and 0.69 (2008). As shown in Fig. 6-9, there was higher intensity of exploitation on specimens and length groups >60 mm (TL>60 mm). Management regulatory measures are needed for this fishery. However, this study has not been able to establish if the observed over-fishing is as a result of exploitation alone or competition from the newly introduced *P. monodon*. Unfortunately, previous studies of this nature (population biology) for *P. notialis* from the area (artisanal or industrial) that could have allowed for direct comparison are scanty in the literature.

Concentrating management efforts on the estuarine (artisanal) fisheries alone will not likely produce desirable management results. Mesh-size requirement for shrimp fisheries in Nigeria is 44 mm cod-end but this is obviously violated. Enforcement of recommended mesh size for shrimp trawlers, coupled with the periodic closures will be necessary to ensure recovery and sustainability of this fishery in both the inshore and offshore fishery sectors. The ecological requirements of the non-native *Penaeus monodon* should be investigated. It is not unlikely that it could out-compete the native *Penaeus notialis*, a common trait of invasive species.

CONCLUSION

A closed period will be ideal for the artisanal fisheries. This would translate to a late start to and shorter shrimping season within the estuary. For the trawl fisheries, a mesh size regulation would be more effective to restoring the stock. Already, Nigeria shown a promising result, experimenting with a codend mesh size of 60 mm compared to the presently approved 44 mm (FAO, 2000b). Although, the aim of the suggested new mesh size was to reduce bycatch of juvenile fishes by shrimp trawlers, it is expected to facilitate stock recovery for the target shrimp species.

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