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Original Research Paper

Biological aspects and yield of the shrimp *Parapenaeus longirostris*, West Africa

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This study within 12 months (January-December) examined the growth, mortality rates and recruitment pattern of exploited deep-water rose shrimp *Parapenaeus longirostris* (Lucas, 1846) in Ivorian marine waters. Length-frequency samples and FISAT software (which incorporates both the ELEFAN and LSFA programs) was used for the data analysis.A fit of the seasonalized von Bertalanffy growth equation to the Length-frequency data gave the following results: $L\infty$ = 17.61 cm; total length, K=0.784 year^{-1} and an R_n value of 0.376. The study also estimated the total mortality coefficient Z=4.837year^{-1} through the seasonalized length-converted catch curve procedure. The instantaneous natural mortality coefficient M was 1.097 year^{-1} while the instantaneous fishing mortality (F) coefficient was 3.740 year^{-1}. An exploitation rate E of 0.773 implies that the stock is over exploited. The results of the yield-per-recruit analysis lend further credence to this assertion. The distribution of juveniles and ovigerous females in the samples show that there were two reproduction peaks (February and August) and two recruitment peaks (March and September). The results of back-projected length-frequency data set on to an arbitrary one-year scale also show that there were two recruitments in a year.

Key words: *Parapenaeus longirostris*, deepwater rose shrimps, mortality rates, recruitment, Côte d'Ivoire

INTRODUCTION

Three species of penaeid shrimps dominate the West Africa marine waters, namely: the prawn *Farfantepenaeus notialis*, the shrimp *Melicertus kerathurus* and the deep shrimp or prawn *Parapenaeus longirostris.* The first two species are found in coastal waters at depths of 0 to 100 m and regularly enter into brackish waters. The third species is found on the continental shelf in the muddy- sandy bottoms at depths of 100 to 300 m. Fischer et al. (1981) report that this species can be found from Morocco to Angola and that it is a significant part in the catches of West Africa. With regard to *F. notialis and P. longisrostris*, many studies have been carried out in West Africa for the first species including the work of Galois (1975); Garcia (1976), and in the Mediterranean for the second species (Chaouachi and Hassine, 1998; Abelló et al., 2002; Abdel et al., 2006; García-Rodríguez et al., 2009).

Unfortunately, there is no information in West Africa on the deep rose shrimp *P. longirostris*, particularly on biological and dynamic parameters.

According to Fischer et al. (1981), the deep water rose shrimp lives in water temperatures between 8°C and 15°C. Its depth distribution is in relation to the size of individuals - larger individuals living further. It performs daily and monthly vertical migration and reproduction occurs between November and April. Finally, it is a diurnal benthophagous shrimp that attacks bivalves, mysids and crangonids.

Since, the biology parameters of *P. longirostris* in West Africa (Côte d'Ivoire) have never been studied; the present work will fill this gap in knowledge. Thus, this study analyze the growth, mortality rates and recruitment pattern of deep rose shrimp *P. longirostris* in Ivorian marine waters.

MATERIALS AND METHODS

Data collection and processing

From January to December 2009, the captures of *Parapenaeus longirostris* by an industrial ship owner using trawlers in Ivorian waters were studied. This work was conducted on an experimental basis with the Oceanological Research Centre (CRO,Abidjan) because the Government has closed the shrimp fishing since 2001 due to drastic 'collapse' of the stock of these crustaceans. The volume of the captured *P. longirostris* was recorded and *a* sample of 2 kg of the total catch was used monthly. Samples from August to December were too small for computation but enough for reproduction analysis- such as number of ovigerous females. The total length in cm of each shrimp caught was measured from the base of the eye stalk to the tip of the telson with a pair of sliding callipers.

Data analysis

Justification of the tools/software used

The most common techniques used in studying biological parameters include graphic analysis, grouping polymodal size distributions, the application of annual growth data analysis, integration of increase in moulting and annual probability of moulting, the method of von Bertalanffy and the method of Wetherall in (Thiam 1990a, b and c). In addition to these graphical methods, we have the tools of software like MIX by MacDonald and Pitcher (1979), ELEFAN by Pauly and David (1981), PROJMAT by Rosenberg et al. (1986), LFSA by Sparre (1987), CASA by Sullivan et al*.* (1990), MULTIFAN by Fournier et al*.* (1990), and FISAT by Gayanilo et al. (1996). Finally, many computer-assisted methods also exist today for the analysis of length-frequency data of fish, shellfish, crab, crayfish and shrimp (e.g. PROJMAT by Rosenberg et al. (1986), CASA by Sullivan et al. (1990), MULTIFAN by Fournier et al. (1990)).Using the above computer-assisted methods is a reliable way of obtaining analysis of length-frequency data of shrimp population and fisheries parameters. Comparisons of some of these methods have been carried out (Isaac, 1990; Tomalin, 1995). Each method has its own advantages and disadvantages. The ELEFAN procedure was used by this study, since it is the most widely used, and the requirements of many other methods exclude those who are not "statistically sophisticated users" (Tomalin, 1995). Also, ELEFAN is presented in a user-friendly format. Its use demands little processing power, it does not require normality in the distribution of the data set used, and the theory behind it is easy to understand. Additionally, the software is neither copy-protected nor copyrighted, and its distribution is often supported by free training courses. Pauly et al. (1981) first demonstrated the applicability of ELEFAN in analyzing length-frequency data of shrimp. To obtain a reliable estimate of growth and population parameters, the suitability of length-frequency data must be ascertained. The raw length-frequency data should exhibit peaks with apparent shift in modal length over time (Wolf, 1989).

The number of monthly samples and the total number of specimens must be adequate. Pauly (1987) provides a rough scale of 0-5 on which the adequacy of samples could be judged. Generally, a total sample size of 1500 or more, gathered over a period of six months is excellent. Our length-frequency data set meets all these criteria. It displayed clear modes that could be followed through time, and has a total sample size of 7343 specimens, which were taken over a period of seven consecutive months (in Table 1).

Data analysis

FISAT software was used for the analysis of study's length-frequency data. The seasonalized von Bertalanffy growth equation developed by Pauly and Gaschütz (1979) and later modified by Somers (1988) was also used and takes the form:

$$L_t = L_\infty \left(1 - \exp\left(-K(t - t_0) - (CK/2\pi)\sin 2\pi(t - t_s) + (CK/2\pi)\sin 2\pi(t_0 - t_s)\right)\right) \quad (1)$$

Where L_∞ is the asymptotic length, K the Von Bertalanffy growth coefficient, L_1 the length at age t; $\boldsymbol{C}$ the amplitude of growth oscillations; t_0 the age of the shrimp at zero length and t_s is the time between birth and onset of the first growth oscillations. This equation reverts to the original von Bertalanffy growth function (vBGF) if C=0, i.e. if the effect of changing season on growth is ignored. In this computation, WP (winter point is the time when growth is slowest) is substituted for t_s, such that $WP=t_s+0.5$.

In this method the Beverton and Holt (1956) length-based Z equation is rearranged to a linear regression model of the following form:

$$\bar{L} - L' = a + bL' \quad (2)$$

Where L' is the smallest length of fully recruited shrimp and $\bar{L} = [L\infty + L'] / [I + (Z/K)]$ is the mean length of all shrimps ≥ L' cm. We computed L_∞ and Z/K from Eq. (2) thus: $L_\infty=a/b$, and $Z/K=-(1+b)/b$. With this initial estimate of L_∞ as the seeded value, we then used ELEFAN procedure to fit the seasonalized VBGF to our length-frequency data. We calculated the index of goodness-of-fit R_n as $10^{(ESP/ASP)} / 10$. Here ASP (available sums of peaks) is the sum of all values of available peaks while ESP (expected sums of peaks) is the sum of all peaks and troughs which the growth curve passes through.

The seasonalized length-converted catch curve (Pauly, 1990; Pauly et al., 1995) was used to obtain the instantaneous mortality coefficient Z of the single negative exponential mortality model:

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

Table 1. Length-frequency data of *P. longirostris* taken from January to July off Côte d'Ivoire (ML = Mid length of class interval, size class = 1 cm, N = 7343.502).

				Year : 2009			
Ml	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**
4.75						0.95	
5.25	0.95				0.95	2.85	
5.75	4.75				1.90	5.70	0.95
6.25	13.30	0.95		2.85	4.75	3.80	4.75
6.75	17.10	3.80		7.60	20.90	20.90	7.60
7.25	35.15	16.15	2.85	19.95	35.15	35.15	16.15
7.75	60.80	36.10	8.55	19.00	79.80	56.05	84.55
8.25	106.40	76.95	18.05	19.95	151.05	97.85	113.05
8.75	71.25	154.85	74.10	60.80	202.35	163.40	168.15
9.25	50.35	143.45	99.75	136.80	255.55	267.90	176.70
9.75	39.90	128.25	101.65	200.45	215.65	279.30	213.75
10.25	24.70	102.60	55.10	262.20	168.15	207.10	247.00
10.75	15.20	76.00	26.60	247.00	101.65	115.90	182.40
11.25	17.10	60.80	7.60	133.00	81.70	58.90	95.00
11.75	9.50	27.55	2.85	84.55	66.50	45.60	57.00
12.25	3.80	11.40	0.95	43.70	54.15	26.60	31.35
12.75	1.90	8.55	0.95	12.35	35.15	24.70	17.10
13.25	5.70	2.85	0.95	5.70	11.40	4.75	7.60
13.75	1.90	3.80		1.90	2?85	3.80	2.85
14.25	0.95	2.85		2.85		1.90	0.00
14.75	0.95	0.95		0.95			0.00
15.25	0.95			0.95			0.95
15.75	0.95						
SUM	483.55	857.85	399.95	1262.55	1489.60	1423.10	1426.90

Here, N_0 is the initial number and *N*, is the number at time t, Z with seasonality was then computed from the regression equation:

$I_n(N) = a + bt'$ (4)

Where *N* is the number of shrimps in pseudo-cohorts sliced by the growth curves, *t'* is the relative age of shrimps in that pseudo-cohort, and *b (*with the sign changed) gives the value of Z. We also computed Z-without seasonality from the equation:

$I_n(N_i/ \Delta t_i) = a + bt_i$ (5)

Here N_i is the number of shrimp in length class *i,*

$\Delta t_i = (1/K)\ I_n[(L_\infty - Lt)/(L_\infty - L_2)]$ the time needed for the shrimp to grow through length class *i.* $t_i = -1/K\ I_n[(l-(L_1/L_\infty)]$ the relative age (computed with $t_0=0$) corresponding to the mid length of length class *iI.* L_1 and L_2 the lower and upper limits of length class *i* and *b* with sign changed gives an estimate of Z (without seasonality).

We also estimated Z from the mean length of shrimp in the catch (Beverton and Holt, 1956) from the following equation:

$Z = [K(L\infty - \bar{L})] / (\bar{L} - L')$. (6)

Here $\bar{L}$ and L' are as defined for Eq. (2).

We computed the instantaneous natural mortality coefficient *M* using the empirical model of Pauly (1980)

$\log M = -0.006 - 0.27 \log L\infty + 0.654 \log K + 0.463 \log T$ (7)

T is the mean ambient water temperature in degree centigrade (29°C). We calculated the index of overall growth performance ϕ' (Pauly and Munro, 1984):

$\phi' = 2 \text{ Log } L_\infty + \text{Log } K$ (8)

and estimated the longevity t_{max} of the shrimp from the relationship (Pauly. 1980):

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

The study analyzed the probability of capture *P* of each size class i using the ascending left arm of the length converted catch curve (Pauly, 1987). This involves dividing the numbers actually sampled by the expected numbers (obtained by backward extrapolation of the straight portion, i.e. 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 of class interval, we obtained a resultant curve from which the length at first capture L_c was taken as corresponding to the cumulative probability at 50%.

The seasonal recruitment pattern of the shrimp was reconstructed using an entirely restructured length-frequency data set. This entails back-projecting along a trajectory defined by the vBGF all the length frequency onto one-year time scale (Paul, 1987). We predicted the relative yield-per-recruit *(Y'/R)* using the Beverton and Holt (1966), and length-based method as modified by Pauly and Soriano (1986):

$Y'/R= EU^{MIK}\{I-(3U)/(1 + m) + (3U^2)/(1 + 2m)- (U^3)/(1 +$

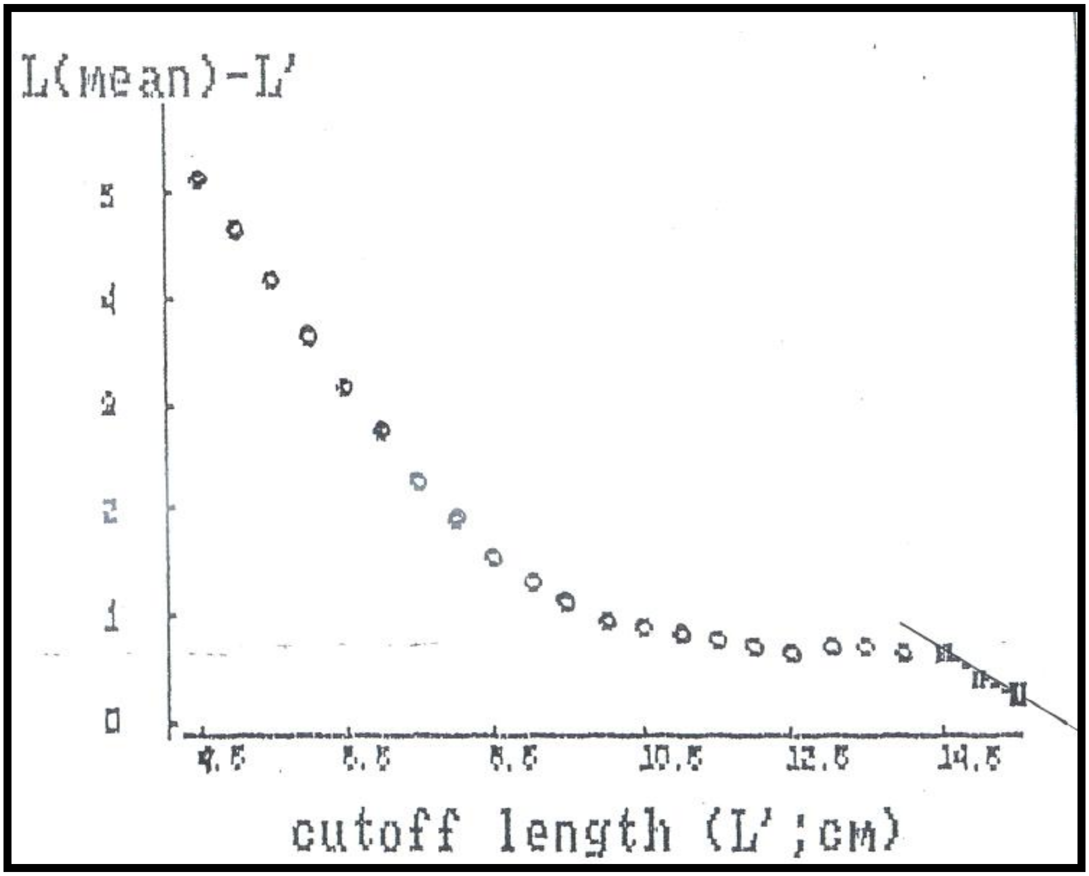


Figure 1: Powell-Wetherall plot for *P. longirostris*. The original length-frequency data from table 1 are pooled and the frequency plotted against midlength of class interval then the right branch is used as input in the Powell-Wetherall plot whose regression equation is Y = 6.41+(-0.399)X; r = - .995; estimated L∞ = 16.060 cm and Z/K = 1.506

3m)}. (10)

Where *U= 1-(L_c / L_∞)* is the fraction of growth to be completed by the shrimp after entry into the exploitation phase, m= *(1-E)/CM/K) = (KIZ), a*nd *E=F/Z* the exploitation rate, i.e. the fraction of mortality of the shrimp caused by the fishermen. *F* the instantaneous fishing mortality coefficient and *L"* is the length at first capture.The relative biomass-per-recruit *(B'/R)* was estimated from the relationship:

B'/R = (Y'/R)/ F. (11)

Then E_{max} (the value of exploitation rate *E* giving the maximum relative yield-per-recruit) was computed. $E_{0.1}$ (the value of *E* at which marginal increase in Y/*R* is 10% of its value at E=0) and $E_{0.5}$ (the value of *E* at 50% of the unexploited relative biomass-per-recruit) through the first derivative of the Beverton and Holt (1966) function.

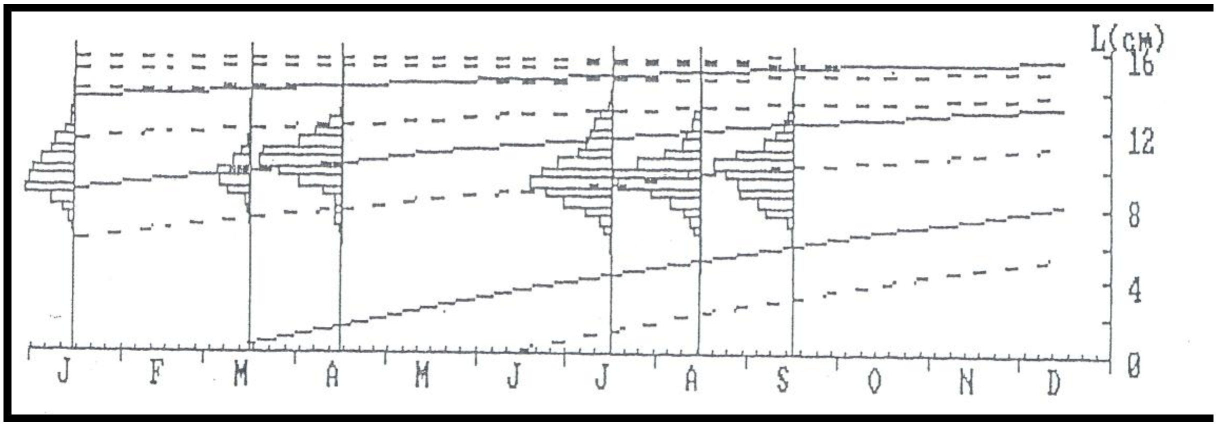
RESULTS

The monthly length-frequency data of the deep rose shrimp collected during this investigation are given in Table 1. The analysis of these data by the Powell- Wetherall procedure (Figure 1) gave an initial estimated L∞ = 16.06 cm and Z/K = 1.51. This initial L∞ value was seeded into ELEFAN 1 to produce the optimized seasonalized growth curve, which was superimposed on both the normal Length-frequency and the restructured length-frequency histograms (Figure 2). The parameters of the seasonalized von Bertalanffy growth curve are: L∞ = 17.61cm; K = 0.784 year^{-1} and R_n = 0.376.

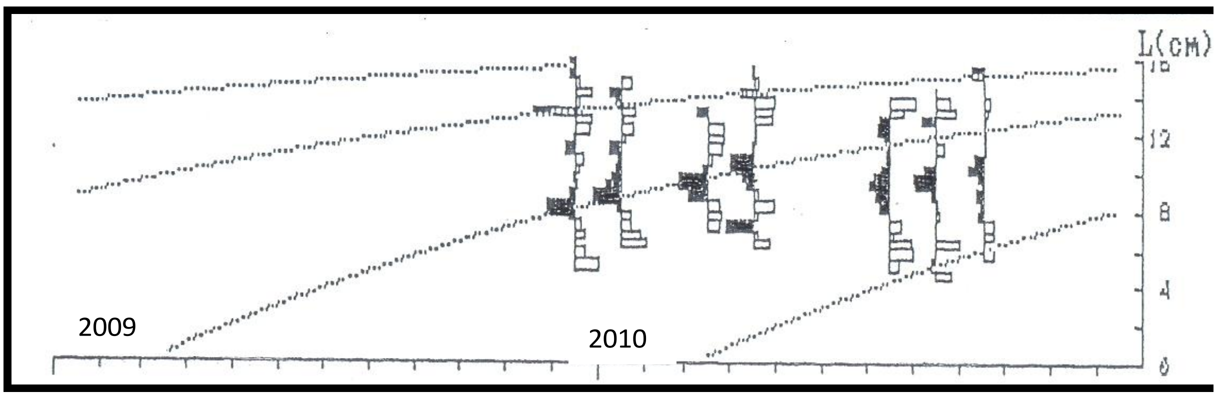
The value of t_0 was not determined because the ELEFAN does not extract t_0 from length-frequency data. ±T_0 is only a location parameter (i.e. it is useful in locating the starting point of the growth curve) and its absence here does not compromise the accuracy of other computed vBGF coefficients.

Equation (1) was used to estimate length-growth parameters of *P. longirostris*. The initial estimate of L∞ was calculated with the Powel-Wetherall plot (Powell, 1979; Wetherall, 1986) modified by Pauly (1986) (Figure 1).

From the seasonalized length-converted catch curve (Figure 3), the study obtained the cut-off length (L') = 10 cm, the mean length(from L') = 10.970 cm, *Z* from mean



(A)



(B)

Figure 2: Seasonalized von Bertalanffy growth curve (L∞ = 17.61cm; K = 0.784 year^{-1}; and R_n = 0.376 of *P. longirostris* as surimposed over (A) the normal length frequency histogram and (B) the restructured length-frequency histograms. The black and white bar in B are positive and negative deviations from the "weighted" moving average of three length classes and they represent pseudo-cohorts. R_n is an index of goodness-of-fit analogous, but not equivalent to r in linear regression (see section 2 for computational details).

length = *5.365* cm year^{-1}. The non-seasonalized catch curve yielded a Z value of 6.34 cm year^{-1}, the natural mortality (M) = 1.097; the fishing mortality (F) = 3.746; the total mortality (Z) = 4.837 and the exploitation rate (E) = 0.773.

The analysis of probability of capture using L_∞ = 17.610 cm and K = 0.784 showed that L_{25} = 8.096 cm; L_{50} = 8.725 cm and L_{75} = 9.237 cm (Figure. 4).

The recruitment pattern of the deep rose shrimp is shown in Figure 5. Analysis of the monthly prevalence of ovigerous females in the samples shows that there were no egg-bearing females in the samples during the whole study, except in January-February (30 egg-bearing females) and July - September (21 egg-bearing females).

DISCUSSION

Asymptotic length is the largest theoretical size a species could attain (granted it grows throughout life) in its habitat given the ecological peculiarities of that environment. This study's computed value of 17 cm for an asymptotic length of *P. longirostris* is similar to those found for rose shrimp *P. notialis*. Galois (1975) and Garcia (1976) working on the rose shrimp *P. notialis* found between 15 cm and 18 cm for the asymptotic length and attributed the difference to environment and food. Direct inter or intra-specific and simultaneous comparisons of L∞ and K have been carried out using Hotelling T^2-*te*st (Bernard, 1981) and likelihood a ratio test (Kimura, 1980; Cerraio, 1990). Univariate comparisons based on either t-student or chi-squared test have also been carried out (Gallucci and Quin Il, 1979; Misra, 1980, 1986). The results showed that in general, the growth pattern of shrimps or any fish is not linear, so such a direct comparison of growth parameters is not biologically plausible. Hence, a comparison of growth curves is inherently a multivariate problem (Moreau, 1987), which must take both *L∞ and K* into consideration. Pauly and Munro (1984) ϕ' meets this criterion and

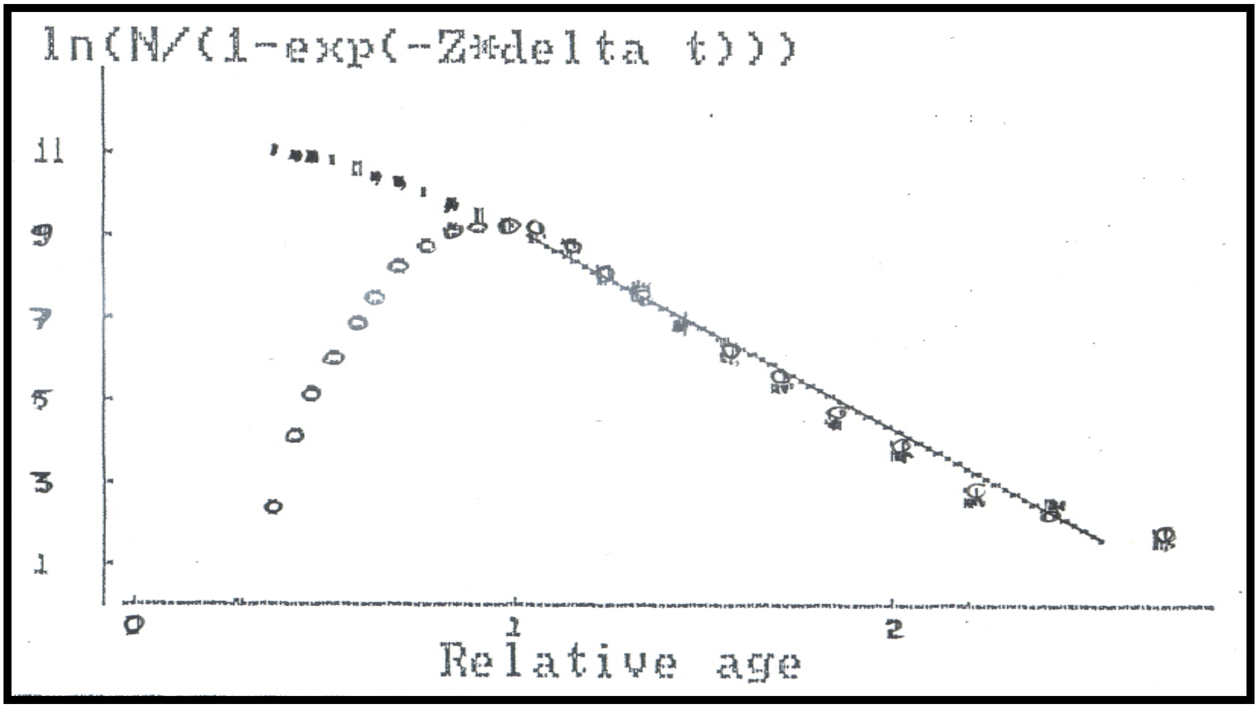


Figure 3: Non seasonalized length-converted catch curve (open dots = numbers actually sampled, open squares = expected numbers). Growth parameters : L∞ = 17.610 cm; K = 8.781, Cutoff L' = 10.000; Mean length : from L' = 10.970; 2 from mean length = 5.365 ; Mean temperature (°C) : 10.0; Natural mortality (M) = 1.097 ; Fishing mortality (F) = 3.740, Total mortality (Z) = 4.837, Exploitation rate (E) = 0.773

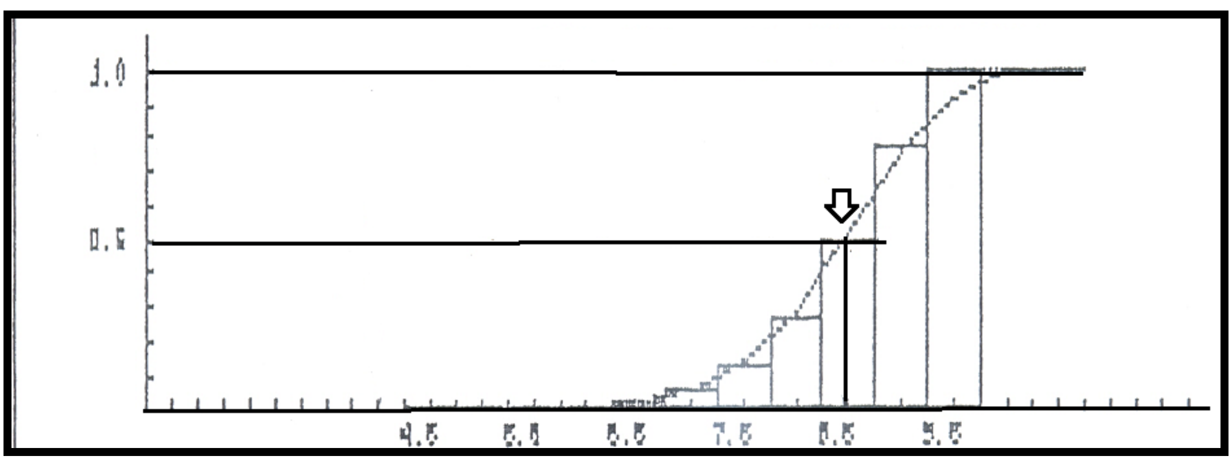


Figure 4: Probability of capture of each size class of *P. longirostris* as derived from the ascending left arm of the catch curve (Fig 3). The estimated length at L_{25} = 8.096 cm; L_{50} = 8.725 cm and L_{75} = 9.237 cm is one of the inputs in computing the relative yield-per recruit.

provide an easy procedure for comparing fish and shrimp growth performances. Moreau et al. (1986) using this index and other indices and working with 100 different tilapia populations, concluded that ϕ' is one the best approach because it exhibited minimum variance. In this study, the overall growth performance index ϕ' for *P. longirostris* was 2.48, which is similar to that found for M. vollenhovenii in Fahe reservoir (Etim and Sankare, 1998).

In West Africa, growth variation is usually linked to the seasonal pattern of rainfall. The study used Eq. (1) to quantify growth seasonality because it has some advantages. It is widely used and has been incorporated into many fisheries computer software (e.g. ELEFAN, MULTIFAN, LFSA etc.). It deals with length-growth oscillations, thus avoiding the problem of shrinkage which could occur in weight-growths. It contains an empirical

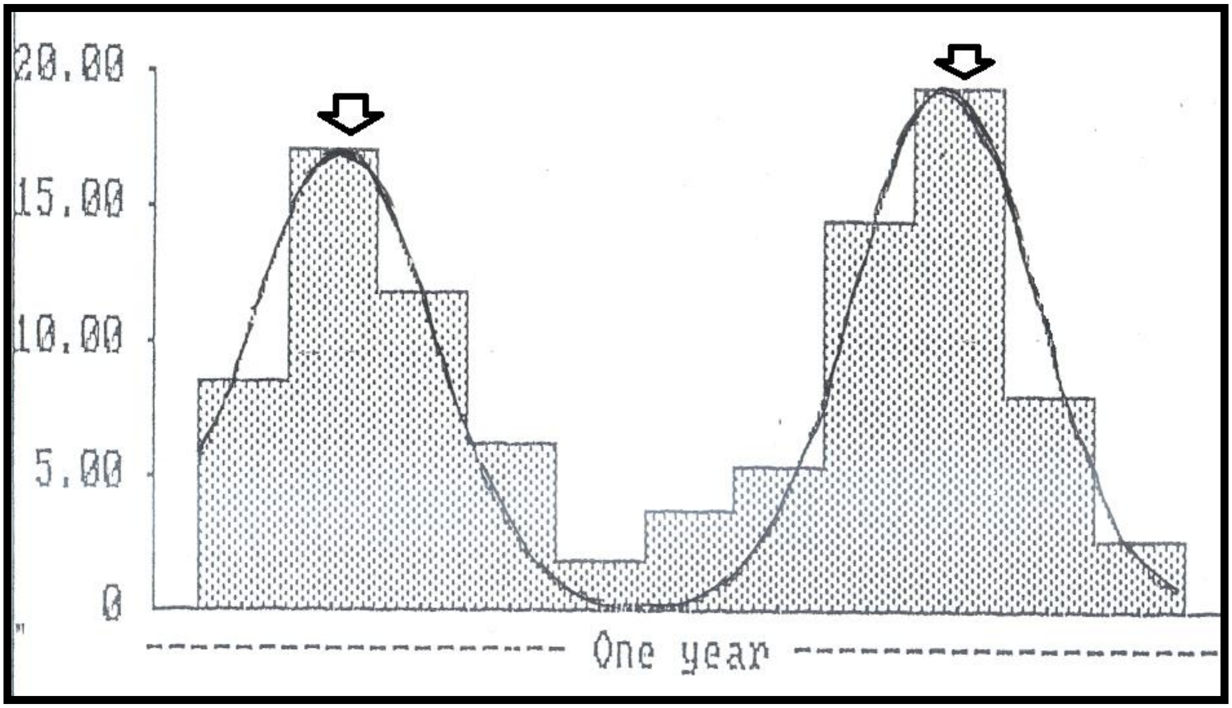


Figure 5. Recruitment pattern of *P. longirostris* obtained by backward-projection, through the trajectory defined by the vBGF of the restructured length-frequency data onto an arbitrary one-year timescale. The months on the x-axis cannot be located exactly (hence the abscissa is an arbitrary year) because of the absence of the location parameter (t_0) of the vBGF. The species exhibits two pulsed recruitment peaks. From table 1, those recruitments peaks seem to occur in February and in September.

constant C, which indicates the amplitude of growth oscillations and another WP which shows the time of the year when growth is slowest. In this study the amplitude of growth oscillations (C=0) and (WP=0) were not significant for *P. longirostris*. Those observations were linked to the stability of the environment condition such as the temperature, the salinity and the abundance of food.

Generally, tropical species should have continuous reproduction because of the relative stability of water temperatures and salinities which allow year-round breeding compared to European and American species that face four seasons (Garcia et al., 2009). In this study the amplitude of growth oscillations *were not significant* for *P. longirostris*. But in reality, most of the tropic animal species reproduce seasonally in relation to rainfall (temperature, salinity and food) and that directly influences growth-though, extended reproductive seasons and year-long reproductions with decreasing latitude seem to be the norm. From this study, *P. Longirostris* respects the norm, since, ovigerous females were more abundant during February (dry season) and September (rainy season), when the maximum reproductive activity occurred. The abundance of ovigerous females is an indicator of reproductive activity while the preponderance of the juveniles in the length-frequency sample is an indicator of juvenile recruitment intensity and pattern into the fishery. Here, peak reproduction is in February and August,and is characterized by high temperature/salinity (during these periods we assisted to gonad development) while peak recruitment is in March and September during decrease in temperature/salinity and enrichment of the environment by important food due/linked to upwelling processes and rivers flowing into the sea. From the study's results, the general trend is that in West Africa *P. longirostris* reproduction and peak recruitment activity occurs in the dry and rainy seasons. The timing of these activities is such that juveniles stand to profit from the abundance of food during the ensuing dry (December to May) and rainy seasons. However, according to Sastry (1983), there are many exceptions to this. For example, the breeding period of *P. notialis* covers the rainy months of May to July (Garcia, 1976). At sea, *P. notialis* exhibits one recruitment with one pulse (May to July) (Garcia, 1976). Besides, breeding and juvenile recruitment of palaemonid, shrimp *M. intermedium* occur year-round, gravid females are most abundant in summer/autumn and juveniles recruited predominantly in late summer/autumn and spring according to Abdel Razek et al*.* (2006).

Z from the classical (non-seasonalized) length-converted catch curve may be overestimated by as much as 536*.* On the other hand, seasonalized length-converted catch curves produce Z = 4.837 values equal or similar to age-structured catch curves. Age-structured catch curves are unbiased because 'growth in age' has no seasonality within these contexts. This study's value of Z must be accurate and reliable since generally, shrimps are not long-lived crustaceans and Z value obtained elsewhere (Garcia, 1976a and 1976b) for *P. notialis* was between 3 to 5; thus confirming this study's results.

Etim and Sankare (1998) study of the exploitation of the brackish-water shrimp *Macrobrachium* vollenhovenii in West Africa concluded that the stock in Cross River in Nigeria with (E=0.68) was the most heavily exploited, followed by the stock of Fahe reservoir in Côte d'Ivoire with *(E=0.47)* and that of the Lobe River in Ghana, which was lightly exploited with *(E=0.07).* Considering the study's relative yield-per-recruit and computed current exploitation rate with *E (*= 0.773), it is concluded that deep rose shrimp *P. longirostris* of Côte d'Ivoire was also heavily exploited.

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