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Population Parameters and Stock Assessment of the Cassava Croaker *Pseudotolithus senegalensis* (Valenciennes, 1833) in the Coastal Waters of Côte d'Ivoire

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ABSTRACT

The state of the stock of the Cassava croaker *Pseudotolithus senegalensis* off Côte d'Ivoire with data collected from January 2013 to December 2014 was examined by applying Beverton & Holt, virtual population analysis and Thompson & Bell models. The growth parameters of 2062 specimens *Pseudotolithus senegalensis* were $L\infty$ = 47.90 cm, K = 0.41 year^{-1}, t_0 = -0.35 year^{-1}, and $W\infty$ = 112.31 g. The growth performance index (φ') was 2.97. The slope *b* of the length-weight relationship was found to be 3.029. The mortality estimates were Z = 1.17, M = 0.85 and F = 0.32 year^{-1}. The recruitment pattern was continuous throughout the year with one major peak. The current fishing mortality (0.32 year^{-1}) was lower than both F_{max} (1.84 year^{-1}) and $F_{0.1}$ (0.71 year^{-1}). In addition, the current exploitation level (0.28) was lower than the maximum allowable limit of exploitation (E_{max}) estimated as 0.61. The current yield was estimated to be 136.20 tons and the maximum sustainable yield of 182.57 tons was obtained at F-factor = 3.565 with a mean biomass of 202.52 tons, indicated that by increasing the present level of fishing effort by 260%, the yield will increase by about 34.04%. These results show that the stock of *P. senegalensis* is not overexploited.

INTRODUCTION

Population dynamics of fishes are studied with the major objective of rational management and conservation of the resource (Nasser, 1999). Knowledge of various population parameters such as asymptotic length ($L\infty$) and growth coefficient (K), mortalities (natural and fishing) rate and exploitation level (E) are necessary for planning and management fish resources. There are many tools for assessing the exploitation level and stock status. Of these, FiSAT (FAO-ICLARM Stock Assessment Tools) has been most frequently used for estimating population parameters of fish (Al-Barwani, 2007), primarily because it requires only length frequency data. The reproductive biology gives some information for the success of fisheries management and recruitment in natural water bodies (Adebiyi, 2012), Biological and fisheries management studies on Sciaenids is very scarce, thus Sylla *et al.* (2016) conducted some biological on *Pseudotolithus senegalensis* from the Ivorian continental shelf.

The Sciaenids constitute a large and varied family of fishes that are closely related to snappers but differ in that the spinous dorsal fin is short, and the adipose tissue is much longer than the anal fin, which has only one or two spines (Edwards *et al*., 2001). This family comprises croakers, drums, meagres, and weakfishes. The croakers are found along the West African coast from Senegal to Gabon (Fisher *et al.*, 1981) where they are exploited by both the artisanal fishery (Uwe-Bassey, 1988) and the industrial fishery (Löwenberg and Künzel, 1991). The majority of these species are also caught as by-catch in the shrimp fishery in the region, and over the last 20 years, the juvenile mortality of these species has been increasing as a result of an increase in the by-catch rate in the shrimp fishery. In addition, this situation is aggravated by the indiscriminate use of destructive fishing methods and illegal fishing mesh in spawning and nursery areas by artisanal and industrial fisheries (Seisay and Sarr, 2009). The dominant species are *Pseudotolithus elongatus*, *P. typus*, and *P. senegalensis* but *P. senegalensis* is economically the most important species in West African trawl fishery (Troadec, 1971). In Côte d'Ivoire, *P. senegalensis* represents 9-10% of the forty species landed by the demersal trawlers (FAO, 2008). Due to the high demand and the limited biological information for this species, it was necessary to examine some biological and fisheries aspects in coastal waters of Côte d'Ivoire, in order to suggest some of the management strategies to sustain the exploited fishery.

MATERIALS AND METHODS

Sampling

The Ivorian oceanic zone (Fig. 1) is bordered to the north by the Gulf of Guinea shoreline stretching from the Cape Palmas (7°30W) and the Cape Three Points (2°W). The shoreline is 550 km long with a narrow continental shelf of 10,200 km² and is characterized by a series of sandy beaches forming a wide arch opened to the Atlantic Ocean (Le Loeuff and Marchal, 1993). The waves from the open sea are very energetic and the swell originating from the South Atlantic Ocean produces permanent surf parallel to the coastline. According to Colin (1988), the coastal upwelling occurs seasonally along the shoreline from July to October (the major event) and from January to February (the minor event).

The specimens of Cassava croaker come from the industrial bottom trawlers catches, caught along the coast of Côte d'Ivoire. The specimens were sampled monthly from January 2013 to December 2014 at the fishing harbor of Abidjan. The total length of 2062 individuals was measured to the nearest 0.1 cm and weighed in terms of total body mass to the nearest 0.1 g using a Sartorius electronic balance. The length measurements were then grouped into 1 cm class intervals for the construction of monthly length distribution.

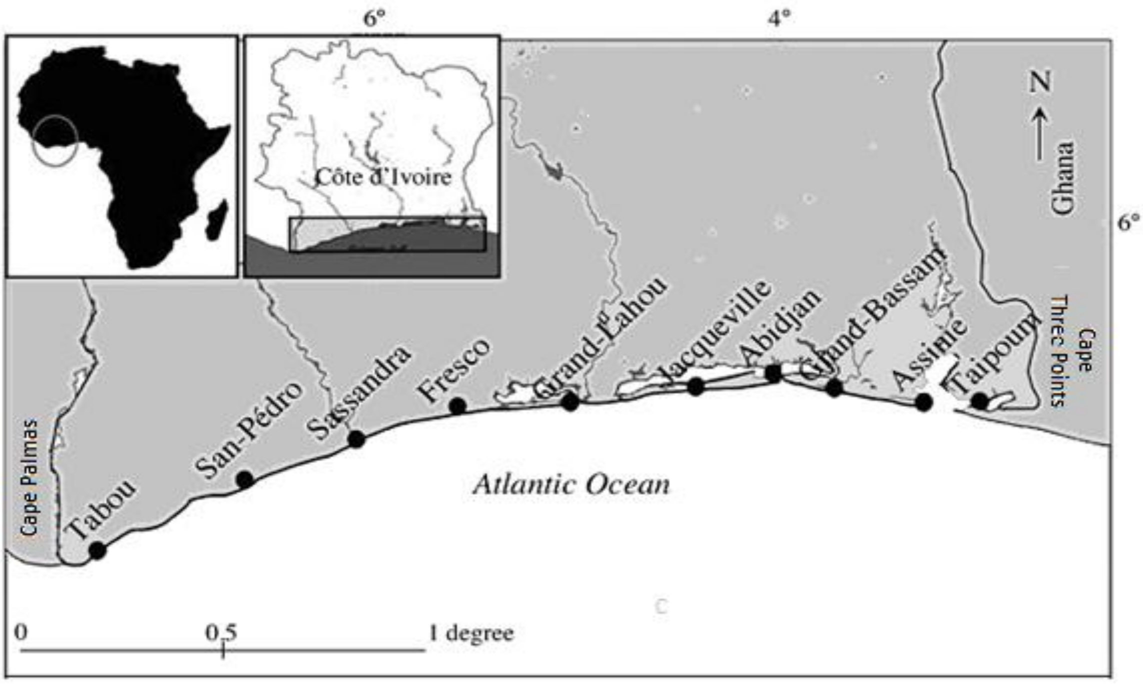

Fig. 1: Coastal zone of Côte d'Ivoire, showing the sampling locality of *Pseudotolithus senegalensis*

Data analysis

Length-weight relationship

The length-weight relationship was computed according to Le Cren (1951) as follow:

$$W = a L^{b}$$

Where, W is the weight (g), L is the total length (cm), *a* is the intercept and *b* is the slope.

The parameters *a* and *b* were estimated by least squares linear regression analysis. In order to check if the *b* value was significantly different from 3, the t-test was used at p = 0.05.

Growth parameters

The data analysis was done using ELEFAN I routine of FAO ICLARM Stock Assessment Tools II (FiSAT II) (Gayanilo et al. 1996). The growth parameters were obtained using the Von Bertalanffy Growth Formula (Sparre and Venema 1998), expressed as:

$$L_t = L\infty \left(1 - e^{-K(t - t_0)}\right)$$

Where, Lt is the predicted length at age t, L∞, the asymptotic length, K the growth coefficient, and t_0 the theoretical age at length zero.

The empirical equation of Pauly (1979) was used to obtain the t_0:

$$\log_{10}(-t_0) = -0.392 - 0.275 \log_{10} L\infty - 1.038 \log_{10} K$$

The reliability of growth parameters was tested applying the growth performance index (φ') according to the method of Pauly and Munro (1984), as follows:

$$\varphi' = \log_{10} K + 2 \log_{10} L\infty$$

Mortality parameters and exploitation rate

The total mortality (Z) was estimated using the length-converted catch curve method (Sparre and Venema, 1998). The natural mortality (M) was estimated using the empirical equation of Pauly (Pauly, 1980) as follows:

$\log_{10} M = -0.0066 - 0.279 \log_{10} L\infty + 0.6543 \log_{10} K + 0.4634 \log_{10} T$, where, T is the mean annual temperature of surface water (being 26°C in this case).

The fishing mortality rate (F) was estimated using the relationship of the mortality parameter (Z = F + M). The exploitation level (E) was estimated using the Beverton and Holt's equation (E = F/Z).

Estimation of relative yield and biomass per recruit

The relative yield per recruit (Y'/R) and biomass per recruit (B'/R) were estimated according to Beverton and Holt (1957) using the Knife-edge selection. From the analysis, the maximum allowable limit of exploitation (E_{max}) giving maximum relative yield-per-recruit was estimated. The exploitation rate ($E_{0.1}$) at which the marginal increase in relative yield-per-recruit is 10% as well as the exploitation rate corresponding ($E_{0.5}$) to 50% of the unexploited relative biomass per-recruit were estimated.

Estimation of the biological reference points

The yield (Y/R) and biomass (B/R) per recruit were estimated using the model of Beverton and Holt (1957) as follows:

$$Y/R = F \, x \exp\left(-M \, x \, (Tc - Tr)\right) x \, W\infty \, x \left[\frac{1}{Z} - \frac{3U}{Z+K} + \frac{3U^2}{Z+2K} - \frac{U^3}{Z+3K}\right]$$

$$B/R = e\,xp\left(-M \, x \, (Tc - Tr)\right) x \, W\infty \, x \left[\frac{1}{Z} - \frac{3U}{Z+K} + \frac{3U^2}{Z+2K} - \frac{U^3}{Z+3K}\right]$$

Where, Lc is the length at first capture, Lr is the length at recruitment, W∞ is the asymptotic weight and A can be estimated under this from:

$$A = \left[\frac{L\infty - Lc}{L\infty - Lr}\right]^{M/K}$$

The extreme values of the fishing level such as the limit reference point (F_{max}) and the target reference point ($F_{0.1}$) were defined as biological reference points and were estimated according to Cadima (2003).

Predictive model of Thompson and Bell

For a length-weight relationship, the Jones' cohort analysis model and the Thompson and Bell model were adopted. The length-based virtual population analysis (VPA) by Jones (1984) was used to estimate the number of recruits, the total mortality (Z), fishing mortality (F) and stock sizes with the terminal exploitation rate (F/Z) chosen as 0.5 on the assumption that the stock is under reasonably good exploitation. The Thompson and Bell (1934) length converted analysis was used to assess the current state of the stock and forecast of the yield and stock biomass. The number of survivors, the growth, and mortality parameters was then used as inputs for calculating the yield (Y), the biomass (B) and the value (V). The biomass and yield estimates were made by keeping M fixed and gradually varying the value of F and, in so doing, varying the values of Z or F/Z. A brief outline of the biomass (B) and the yield (Y) estimates is summarized below.

The average body weight was obtained using

$W_i = a\left[\frac{L_i + L_{i+1}}{2}\right]^b$, where *a* is the intercept and *b* is the slope of the length-weight relationship; Li and Li+1 are respectively the lower and upper limits of the size class.

The Calculate Catch (C_i), value (V_i) and average population size (N_i) for each size class were given by:

$$C_i = [N(L_i) - N(L_{i+1})] \text{ x } F_i / Z_i$$

$V_i = Y_i \; v_i$, with vi is the average price per kg of fish between size class

$$N_i = \frac{N(L_i) - N(L_{i+1})}{Z_i \; \Delta t_i}, \text{ where } \Delta t_i = \frac{1}{K} \text{ x} \ln \frac{L_\infty - L_i}{L_\infty - L_{i+1}}$$

The total yield and the average biomass combing all the cohorts were calculated as:

$$Y = \sum Y_i, \text{ where } Y_i = C_i \; W_i$$

$$B = \frac{\sum B_i \; \Delta t}{\sum \Delta t}, \text{ where } B_i = N_i \; W_i \; \Delta t_i$$

The total yield, average biomass, and total value were then plotted against different values of F-factor x (0.0-4.0) to estimate the MSY and the MSE levels.

RESULTS

Length-weight relationship

The graphic representation of the estimated length weight relationships provided a good fit for *P. senegalensis* data as, $W = 0.0075 \times LT^{3.029}$, ($r = 0.957$, $n = 2062$). The *b* value was not statistically different from 3 (t-test = 1.2385, $p > 0.05$).

Growth parameters

The response surface technique of ELEFAN 1 was used to estimate the growth parameters ($L\infty$ = 47.90 cm and K = 0.41 year^{-1}). The age at zero length was estimated as -0.35 year^{-1}, which gave the von Bertalanffy growth equation for this species as: $Lt = 47.90 \times (1-\exp(-0.41(t+0.35))$. The asymptotic weight ($W\infty$) was 112.31 g while the growth performance index was 2.97.

Mortality and exploitation rate

The total mortality (Z), the mortality (M) and the fishing mortality (F) were respectively 1.17 year^{-1}, 0.85 year^{-1} and 0.32 year^{-1} (Figure 2). The exploitation rate was 0.28.

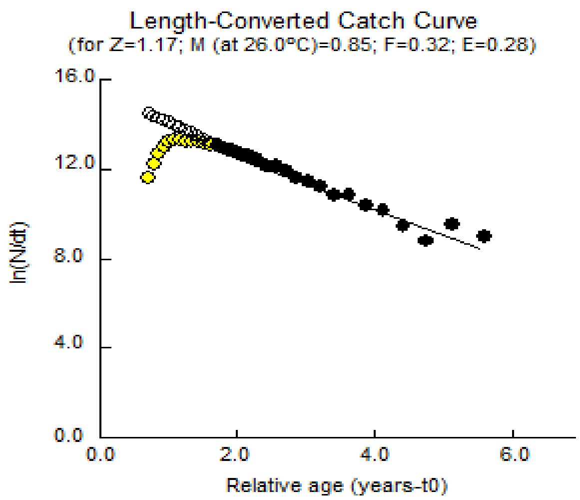

Fig. 2: Estimation of Z from Length converted catch curve method

Recruitment pattern

The recruitment pattern showed that *P. senegalensis* was recruited in the fishery continuously throughout the year with the peaks from January to May (Fig. 3). The percent recruitment varied from 2.71 to 16.25%. The highest recruitment was observed in the month of April (13.4%) whereas the lowest recruitment was observed between June and September. The mid-point of the lower length class (12.5 cm) in the sampled data was used as a length at recruitment. The length at first capture (Lc) was 17.61 cm whereas the lengths at which 25% and 75% of fish are captured were respectively 14.92 cm and 20.31 cm.

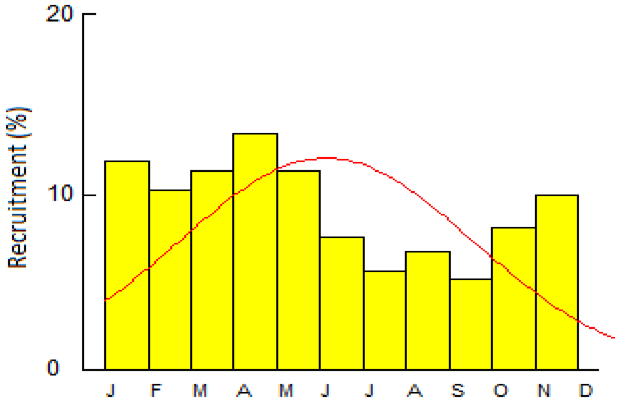

Fig. 3: Recruitment pattern of *Pseudotolithus senegalensis* sampled in Ivorian coast waters

Virtual population analysis

Population estimates from VPA computed by FiSAT program indicated that the main loss in the stock up to 13.0 cm size was due to natural causes (Fig. 4). Fish became more vulnerable to the gear after this size and mortality due to fishing increased and eventually outnumbered the natural losses from 23.0 cm onwards. The maximum fishing mortality of 0.66 yr^{-1} was recorded at the size of 42.0 cm.

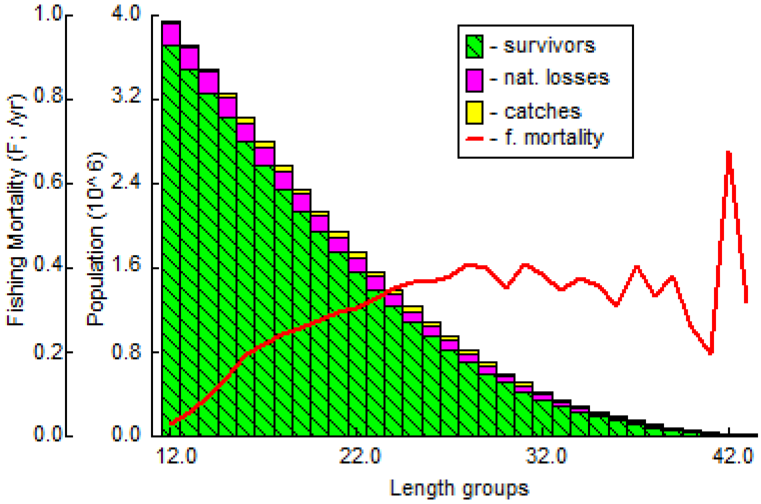

Fig. 4: Length based virtual population analysis of *Pseudotolithus senegalensis* in the coastal water of Côte d'Ivoire.

Yield and biomass per recruit and biological reference points

The yield and biomass per recruit as a function of fishing mortality was presented in Fig. 5. The current fishing mortality (0.32 $year^{-1}$) in estimated population was lower than both F_{ox} (1.84 $year^{-1}$) and $F_{0.1}$ (0.71 $year^{-1}$). The maximum sustainable yield per recruit (Y/R_{max}) was 6.12 grams per recruit. The corresponding biomass per recruit (B/R_{max}) was 3.32 grams per recruit and represented 15.91% of the virgin biomass per recruit (Bv/R). The relative Y'/R and B'/R analysis were estimated using Lc/L∞ = 0.36 and M/K = 2.07 as input for knife-edge selection procedure (Fig. 6). The maximum allowable limit of exploitation level (E_{max}) that gives the maximum relative Y'/R was 0.61. The exploitation level ($E_{0.1}$) at which the marginal increase in relative yield per recruit is 10% of its value at E = 0 was 0.51 whereas the exploitation level ($E_{0.5}$) which corresponds to 50% of the relative B'/R of an unexploited stock was 0.32.

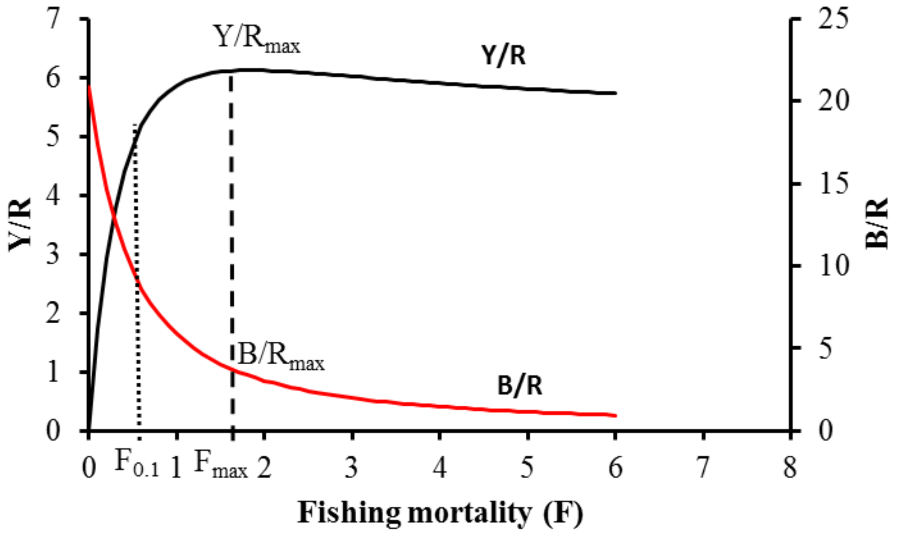

Fig. 5: Yield and biomass per recruit (Y/R, B/R) for *Pseudotolithus senegalensis* in function of the fishing mortality rate (F). F_{max} = value of F which gives the maximum possible yield per recruit from a cohort during its life for a given exploitation pattern

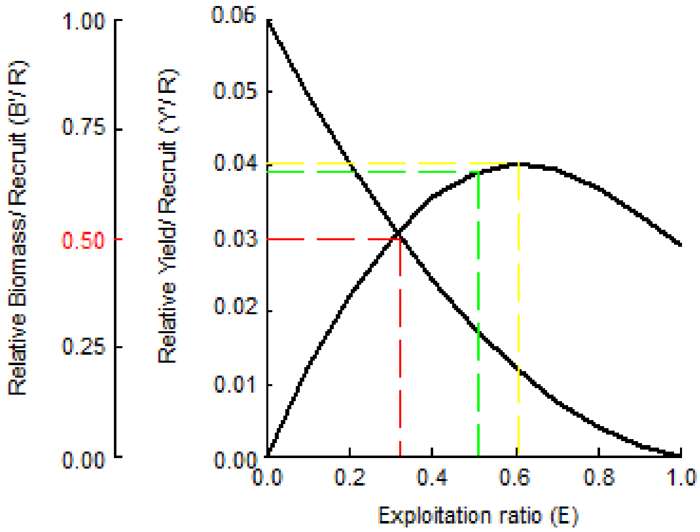

Fig 6: Relative yield per recruit (Y'/R) and biomass per recruit (B'/R) of *Pseudotolithus senegalensis* in the Ivorian coast waters

Thomson and Bell prediction analysis

The yield (Y), the biomass (B) and the value of *P. senegalensis* at different fishing levels predicted were presented in Table 1 and Fig. 7. The maximum sustainable yield (MSY) would be obtained at a fishing level of 3.580 whereas the maximum economic yield (MEY) would be obtained at a fishing level of 2.192. The estimated MSY was 182.57 tons and the corresponding B_{MSY} was 201.82 tons whilst the MSE and the corresponding B_{MSE} were 395.26 million dollars and 294.83 tons respectively.

Table 1: Length based Thompson and Bell analysis for estimation of MSY and MSE of *Pseudotolithus senegalensis*

F-factor X	Yield (tons)	Biomass (tons)	Value (x 10^6 $)
0.0	0.000	792.469	0.000
0.2	46.189	696.546	128.260
0.4	79.202	620.326	214.220
0.6	103.593	557.936	273.357
0.8	122.033	505.787	314.613
1.0	136.198	461.521	343.499
1.2	147.195	423.501	363.587
1.4	155.790	390.536	377.281
1.6	162.526	361.733	386.255
1.8	167.808	336.401	391.702
2.0	171.925	313.996	394.490
2.2	175.115	294.079	395.263
2.4	177.553	276.296	394.504
2.6	179.380	260.351	392.582
2.8	180.707	246.000	389.780
3.0	181.622	233.039	386.315
3.2	182.200	221.294	382.359

3.4	182.498	210.616	378.045
3.6	182.566	200.881	373.477
3.8	182.443	191.979	368.739
4.0	182.164	183.817	363.895

MSY = 182.57 tons B_{MSY} = 201.82 tons F-factor = 3.580

MSE = 395.26 million $ B_{MSE} = 294.83 tons F-factor = 2.192

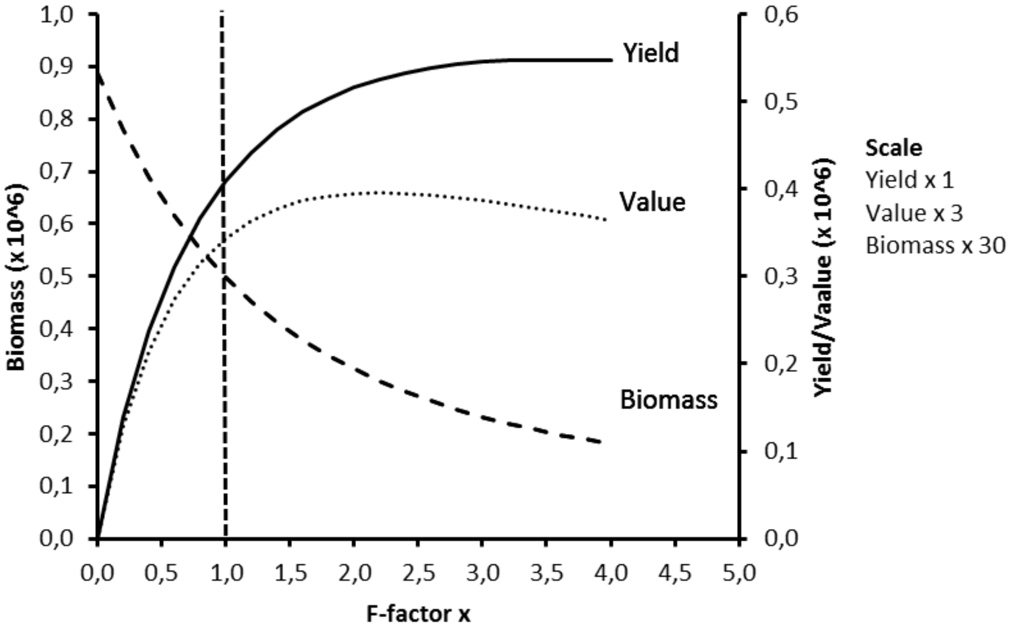

Figure 8: Thompson and Bell analysis of *Pseudotolithus senegalensis* in coastal waters of Côte d'Ivoire

RESULTS AND DISCUSSION

The growth coefficient *b* of length-weight relationship generally lies between 2.5 and 3.5 and the relation is said to be isometric when it is equal to 3 reported for most aquatic organisms (Le Cren, 1951; Carlander, 1977). The previously published values of the growth coefficient b in various areas were 3.22 (Djama and Pitcher, 1989), 3.21 (N'jock, 1990) and 3.02 (Sidibé, 2003) for the same species. In the present study, the estimated *b* was 3.03 which is not significantly different from the isometric value (3). The reasons for the variation of *b* in the different regions are said to be due to seasonal fluctuations in environmental parameters, physiological conditions of the fish at the time of collection, sex, gonadal development and nutritive conditions in the environment of fish (Biswas, 1993).

The L∞ obtained in this study (47.90 cm) was lower than 61.4 cm, 60.8 cm and 51.4 cm recorded respectively in Cameroon waters (N'jock, 1990), Guinean waters (Sidibé, 2003) and Benin waters (Sossoukpe, 2013), suggesting that the stock is relatively exploited at small size since larger specimens of 100 cm (TL) have been reported by Sidibé (2003). However, the K value in this study (0.41 $year^{-1}$) was higher than 0.20 $year^{-1}$, 0.24 $year^{-1}$ and 0.35 $year^{-1}$ reported respectively by N'jock (1990), Sossoukpe (2013) and Sidibé (2003). According to Hernandez (1986), the differences among various geographic localities for the same species are due to variations in environmental conditions as well as sampling techniques and computations. The growth parameters estimated are biologically reasonable because the growth performance index (φ') of *P. senegalensis* was in the range of 2.75-3.11 reported by these authors. In general, the correlated parametric values adjust themselves to provide a similar growth pattern represented by φ' (Sparre and Venema, 1998). Baijot and Moreau (1997) reported that the φ' mean values for some important fishes in Africa range of 2.65-3.32 and considered these as low. In this study, the φ' estimated for *P. senegalensis* was 2.97, so this species also might be regarded as showing low growth. This low growth rate might be induced by changes in physical and chemical characteristics of the waters (Ofori *et al*., 2002).

The total and natural mortality (1.07 $year^{-1}$ and 0.85 $year^{-1}$ respectively) estimated in the present study was higher than those of Sossoukpe (2013) which were 0.91 $year^{-1}$ and 0.49 year-1 respectively but these estimates were close to those of Sidibé (2003) estimated as 1.20 $year^{-1}$ and 0.97 $year^{-1}$ respectively. However, the total mortality (1.07 $year^{-1}$) in the present study was lower than those of Sossoukpe (2013) and Sidibé (2003) respectively in Benin (0.42 $year^{-1}$) and Guinean (0.51 $year^{-1}$) waters. The variation in natural mortality can be explained as a natural phenomenon which is controlled by density-dependent (predation, availability of food etc.) as well as density independent factors (disease, natural calamities etc.) and varies within same species in the different location.

Generally, the yield per recruit (Y/R) model has been used to assess growth overfishing. The model estimates the Y/R for various fisheries activities (fishing mortality and fish size), describes the current usage of the stock and suggests policies to enhance the yield. The Y/R depends on the exploitation pattern or fishing regime and natural mortality. It increases with the fishing mortality up to a point where the maximum sustainable yield is obtained.

According to Cadima (2003), beyond this point overfishing occurs and the population collapses. The Y/R and B/R analysis of *P. senegalensis* indicated that maximum Y/R is obtained at F_{max} = 1.84 whereas B/R decreased by 15.91 % compared to unexploited biomass. The current fishing mortality was lower than both the target reference point ($F_{0.1}$) and the limit reference point (F_{max}), indicated that the fishing pressure on the stock is not excessive. This assertion is supported by both the obtained VPA and relative yield and biomass per recruit values. The results obtained from VPA analysis indicate that the fish which die by natural mortality are higher than those which die by fishing mortality. The current exploitation rate (E) was estimated as 0.28, which was lower than the optimum level of exploitation estimated by the Beverton and Holt's method, confirmed the previous conclusion. According to Gulland (1971) the optimum exploitation ratio Eopt = 0.5, this indicates that the stock of this species from coastal waters of Côte d'Ivoire is under-exploited. The maximum relative yield per recruit was obtained at E = 0.61. The current level of E = 0.28 was relatively lower than that which gave the maximum Y'/R. So raising the exploitation rate to this value will increase in the E value from 0.28 to 0.61 (56.26%) and would lead to an increase in Y'/R by about 93.64%. The current exploitation rate was lower than both the exploitation rate ($E_{0.1}$) at which the marginal increase in relative yield-per-recruit is 10% (0.51) and the exploitation rate corresponding ($E_{0.5}$) to 50% of the unexploited relative biomass per-recruit (0.32). This also reveals that the fishery is being under-exploited in terms of relative yield-per-recruit.

The result obtained by the Thompson and Bell's model illustrates the important conflict between the desire to maximize the total yield from the fishery, by weight or by value. Beyond the maximum sustainable yield, the catch decreases steadily as the effort increases and may in practice become too small to make the fishery profitable, even at effort levels smaller than those corresponding to the maximum on the curve for the total value of the yield. The result showed that the fishing effort can be increased to realize higher production. It is seen that the current level of fishing effort gave a yield of 136.20 tons and a mean biomass of 461.52 tons. The maximum sustainable yield of 182.57 tons was obtained at F-factor =3.565 with a mean biomass of 202.52 tons. This means that by increasing the present level of fishing effort by 260%, the yield will increase by about 34.04%, which indicates that the catch per unit of fishing effort will be reduced drastically. At the same time, the mean biomass will be 56.47% (260.64 tons) lower than the mean biomass available at current F and 74.65% (591.59 tons) lower than the virgin biomass, thus rendering considerable loss in the strength of biomass and potential breeders. Similarly, the increase of the present level of fishing effort by 120% will realize only a 15.07% (51.76 million dollars) increase in the value and a 38.28% (167.44 tons) decrease in the mean biomass. However, the value depends greatly on the price of *P. senegalensis* which vary according to their abundance and the season; the smoked fish is sold at a higher price than fresh fish.

CONCLUSION

The natural mortality coefficient estimated using Pauly's empirical formula for *P. senegalensis* was relatively higher than the fishing mortality. The exploitation ratio, as well as the results of the Beverton and Holt relative yield per recruit analysis and Thompson and Bell analysis, indicated that there was scope for increasing the exploitation rate along the coast of Côte d'Ivoire. Although the results of Thompson and Bell analysis show the need for a high increase in effort level to realize maximum sustainable yield, such an advice can never be implemented in the multispecies-multiyear context as in the present case. However, the exploitation of the small and juveniles by trawlers operated relatively close to shore can affect the recruitment of commercial sizes not only along the coastal waters of Côte d'Ivoire but also in the Committee for the Eastern Central Atlantic (CECAF) Sub-region.

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