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Original Research Article

Stock assessment of the bigeye grunt *Brachydeuterus auritus* (Valenciennes, 1832) in the coastal water of Ivory Coast

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The stock assessment of *Brachydeuterus auritus* was carried out in the coastal water of Ivory Coast from January to December 2009. Monthly length frequency data were analyzed using FiSAT software and Jones' Cohort Analysis Model for the estimation of population parameters, total biomass and Maximum Sustainable Yield (MSY). The asymptotic length ($L\infty$) was 25.20 cm, the growth coefficient (K) was 0.58 year^{-1}, and the calculated growth performance index (φ') was 2.57. The total mortality (Z), the fishing mortality (F) and the natural mortality (M) were 2.01, 0.74 and 1.27 year^{-1}, respectively. The exploitation level (E) was 0.37 while the maximum allowable limit of exploitation (E_{max}) was 0.85. The biomass was 2507 tons, which provided the MSY of 2079 tons. The recruitment pattern was continuous with two major peaks per year. The exploitation level (E = 0.37) and the fishing mortality approximated the precautionary target reference point (0.64 year^{-1}) and was within the precautionary limit reference point (0.84 year^{-1}), suggesting that the big eye grunt stock is exploited at a low rate.

Key words: stock assessment, growth parameters, MSY, bigeye grunt, Ivory Coast.

INTRODUCTION

Determining the status of fish stocks means estimating one or more biological characteristics of the stock, such as abundance (numbers of fish) or biomass (weight), and comparing estimated to reference values that define desirable conditions. An essential characteristic of a fish stock is that its population parameters remain constant throughout its area of distribution and stock assessment should be carried out separately (Wang and Liu 2006). In tropical and subtropical waters, it is not possible to determine age by counting rings in hard parts of the fish body, such as otoliths or scales. The lack of strong seasonality makes the distinction of seasonal rings and year-rings problematic for tropical species. However, with the development of the length based stock assessment methodologies, it is possible to investigate population dynamics of fish stocks in tropical waters (Pauly 1984, Pauly and Morgan 1987).

The big eye grunt, *Brachydeuterus auritus* (Valenciennes, 1831) belonging to the Family of Haemulidae is a semi-pelagic species inhabiting the coastal waters off the African coast from Morocco to Angola (Salzen 1957). The big eye grunt is considered as one of the most important fishery resources off the Ivorian coast because of its abundance in the landings. The biology and stock details of the species is less known, despite its economic importance and widespread occurrence in the Ivorian waters since the work of Barro (1968). The length at first maturity reported for this species is 13.8 cm (Baro 1968) and fish recruit into the fishery at length of 4 cm (Bannerman 2002). Due to long term exploitation of the fishery resources along coastal waters of Ivory Coast, the growth parameters and mortality of *B. auritus* could have changed. The present study is to

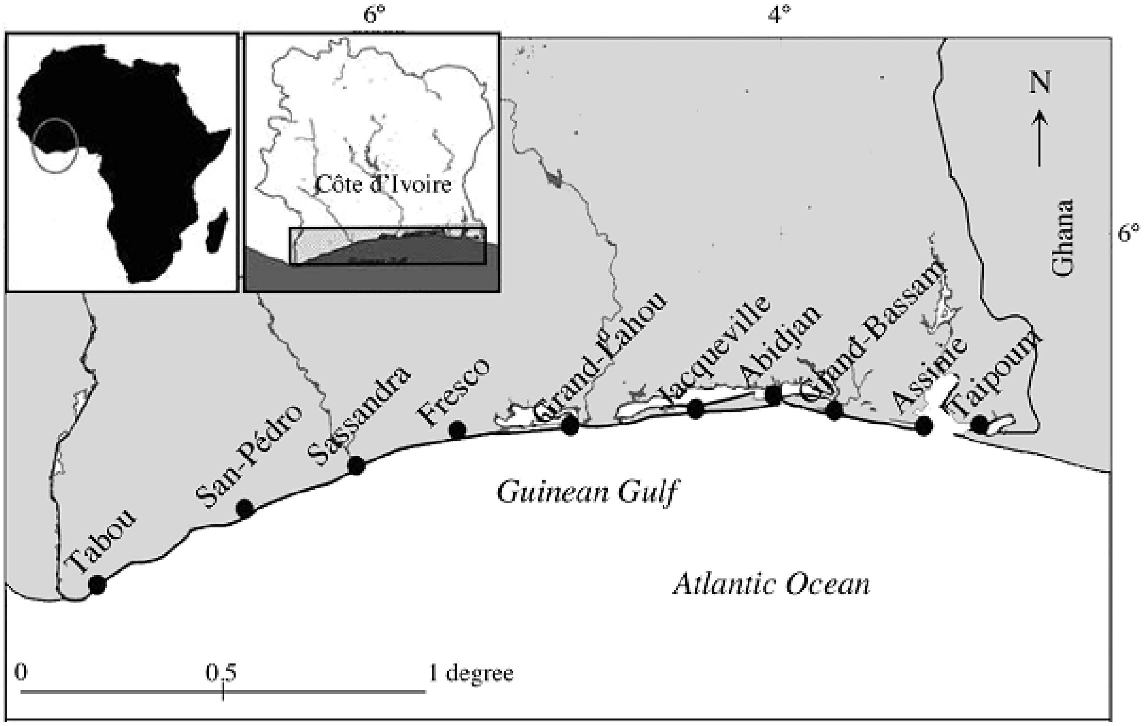

Figure 1: Map of Ivorian waters, showing the sampling locality of *Bracydeuterus auritus*

estimate population parameters, yield per recruit, biomass and MSY of *B. auritus* in order to formulate management and conservation policies.

MATERIALS AND METHODS

Brachydeuterus auritus fishery in Ivory Coast

Brachydeuterus auritus is caught by artisanal and industrial fisheries operated along the coast. The artisanal fleet exploits this species in the coastal zone, whereas the trawlers exploit it at depths of 30 to 70 m (Bannerman 2002). In the industrial fishery, *B. auritus* is mostly landed by the industrial bottom trawlers at the harbour of Abidjan. The fleets are equipped with radar, sounder and ice hold. Most of bottom trawlers are 15-20 m long and have stretch mesh size from 45 to 67 mm with engine horse power ranging from 200 to 600 HP and an average crew size of 15 persons. In 2007, the fleet composed of 18 foreign and 05 national trawlers. Forty fish species are usually recorded at the landing site, 10 species belonging to 9 families represent more than 80% of the total capture and the contribution of *B. auritus* is 22.95% (FAO 2008).

Description of study area

The specimens were caught along the coast of Ivory Coast, comprising 550 km coastline and narrow continental shelf of 10,200 km^2 (Figure 1). Except for some rocky cliffs in the West, the sea bed is characterized by low and sandy bottoms. According to Arfi et al. (1993), the hydro-climatic season influences oceanographic conditions and the availability of fishery resources due to salinity of more than 35 ppt and sea surface temperature (SST) ranging from 23 to 30°C. The SST is characterized by four distinct climatic periods; two dry seasons (December-March and August-September) and two rainy seasons (April-July and October-November). The coastal area is greatly affected by the seasonal upwelling which takes place in the Gulf of Guinea. Thus, the period from July to October corresponds to the major upwelling whilst a minor upwelling is usually observed between January and February (Colin 1988).

Collection of data

The specimens of big eye grunt were collected from commercial catches at the fishing harbour of Abidjan from the industrial bottom trawlers. The specimens were sampled monthly from January to December 2009. The total length of each individual was measured to the nearest 0.1 cm. The length measurements were then grouped into 1 cm class intervals for the construction of monthly length distribution.

Analysis of data

The data in length and weight of individuals were used to

Table 1: Catch at length of the big eye grunt caught by the coastal waters of Ivory Coast from January to December 2009

Size	J	F	M	A	M	J	J	A	S	O	N	D
6	0	0	0	0	0	0	5080	0	0	0	0	0
7	0	0	0	0	5080	5080	5080	0	0	0	0	0
8	5080	24304	0	53688	0	5080	10161	5080	0	0	0	10161
9	74009	68929	39545	72911	44625	63848	64946	20321	29384	83072	10161	20321
10	157081	167242	177402	118634	54786	113554	162161	34464	34464	77992	20321	45723
11	215849	240153	298921	158179	59866	128795	148018	63848	39545	107376	30482	55884
12	240153	264457	328305	182483	84170	153099	153099	108473	68929	112456	35562	60964
13	240153	264457	352609	182483	84170	153099	177402	157081	103393	112456	40643	60964
14	215849	254296	250314	177402	84170	153099	177402	157081	127697	88152	40643	55884
15	210769	254296	288760	172322	108474	94330	172322	157081	127697	88152	40643	45723
16	162161	219832	229992	142938	103393	89250	167242	152001	122617	88152	40643	50803
17	200608	249216	167242	113554	103393	64946	162161	127697	112456	88152	25402	45723
18	141840	141840	171224	108474	79089	54786	113554	74009	102295	88152	20321	35562
19	107376	79089	88152	58768	88152	15241	98313	88152	107376	77992	5080	20321
20	5080	5080	72911	53688	53688	0	5080	53688	77992	53688	5080	15241
21	24304	5080	0	0	48608	0	5080	24304	24304	0	0	0
22	0	0	0	0	24304	0	0	24304	24304	0	0	5080
23	0	0	0	0	24304	0	0	0	0	0	0	0
24	0	0	0	0	24304	0	0	0	0	0	0	0

estimate the length-weight relationship using the formula (Le Cren, 1951).

$$W = a L^{b} \quad (1)$$

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.

The data analysis (Table 1) 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:

$$L_t = L\infty\left(1 - e^{-K(t - t_0)}\right) \quad (2)$$

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

$$\varphi' = \log_{10} K + 2\log_{10} L\infty \quad (3)$$

The life span (t_{max}) that fish of a given population would reach was calculated:

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

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 incorporated in FiSAT II (Pauly 1980) as follows:

$$\log_{10} M = -0.0066 - 0.279\log_{10} L\infty + 0.6543\log_{10} K + 0.4634\log_{10} T \quad (5)$$

Where, T is the mean annual temperature of surface water (being 26°C in this case).

The fishing mortality coefficient (F) and exploitation ratio (E) were estimated using the relationships Z-M and E = F/Z respectively. 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. The length-based virtual population analysis (VPA) by Jones (1984) was applied to estimate the biomass (tons), the yield (tons), total and fishing mortality and exploitation ratios of *B. auritus* using the following equations (Jones 1984):

$$N_{L1} = (N_{L2} \times X_{L1,L2} + C_{L1,L2}) \times X_{L1,L2} \quad (6)$$

Where, N_{L1} and N_{L2} are the number of animals for the beginning (L_1) and the ending (L_2) length interval, $C_{L1,\,L2}$ is the catch for the length interval, and $X_{L1,\,L2}$ the natural mortality factor for the length interval.

$$X_{L1,L2} = \left(\frac{L\infty - L_1}{L\infty - L_2}\right)^{M/2K} \quad (7)$$

The exploitation rate (E) and the fishing mortality (F) for each length interval are given by

$$E = \frac{C_{L1,\,L2}}{N_{L1} - N_{L2}} \quad (8)$$

$$F = \left(\frac{F/Z_{L1,L2}}{1 - F/Z_{L1,L2}}\right) \quad (9)$$

The total mortality (Z) for each length interval was obtained using

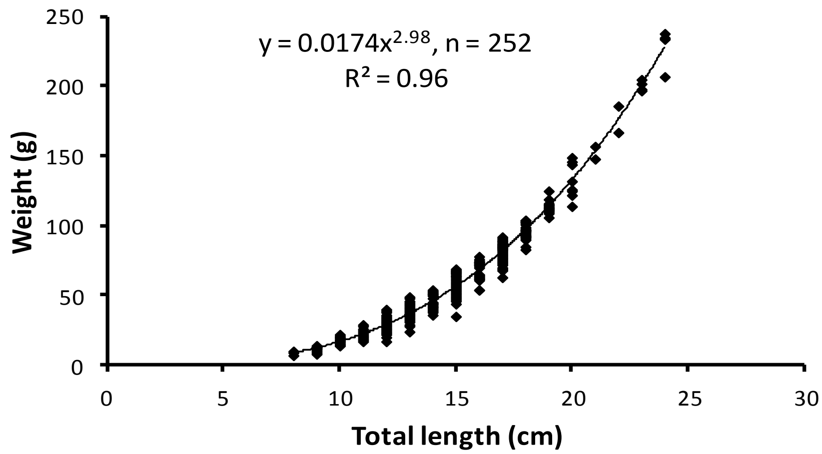

Figure 2: Length-weight relationship of *Brachydeuterus auritus* sampled in the Ivorian coast waters

$$Z = \frac{M_{L1,L2}}{\left(1 - \frac{F_{L1,L2}}{Z_{L1,L2}}\right)} \quad (10)$$

The total biomass (B) was calculated as

$$B = \sum \frac{N_{L1} - N_{L2}}{Z_{L1,L2}} \text{ x mean body weight} \quad (11)$$

The body weight for each length interval was calculated as:

$$\text{Body weight} = a \text{ x} \left[(L_1 + L_2)/2\right]^b \quad (12)$$

Where, *a* is the intercept and *b* is the slope of the length-weight relationship.

The maximum sustainable yield (MSY) for *B. auritus* was estimated using Cadima's formula for exploited stocks (Sparre and Venema 1998):

$$MSY = 0.5 \text{ x} (Y + MB) \quad (13)$$

Where, B is the average biomass calculated from cohort analysis in the same year, and M the natural mortality and the Y the annual yield which is given by the formula,

$$Y = \sum W_{L1,L2} \text{ x } C_{L1,L2} \quad (14)$$

The resource status was evaluated using estimates of exploitation rate (E) associated with a maximum sustainable yield (E_{max}) and by comparing estimates of the fishing mortality rate with target (F_{opt}) and limit (F_{limit}) biological reference points which were defined as F_{opt} = 0.5M and F_{limit} = 2/3M following Patterson (1992).

RESULTS

A total of 3645 specimens with total length ranging from 6 to 24 cm were collected, of which 252 specimens were weighed to obtain length weight relationship (Figure 2). The length-weight equation calculated in exponential form was W = 0.0174 x $LT^{2.98}$ with a regression coefficient R^2 of 0.96. The slope *b* of this relationship was 2.98, which was not significantly different from 3 (t-test = 0.534, p> 0.05).

The restructured form of the length-frequency data is presented as output of ELEFAN I in Figure 3. The asymptotic length ($L\infty$) and the growth coefficient (K) for *B. auritus* were respectively 25.20 cm and 0.58 year^{-1}. The asymptotic weight obtained was 261.05 g. The growth performance index (φ') was 2.57 and the longevity (t_{max}) was 5.17 years.

The instantaneous rate of total mortality (Z) from the length-converted catch curves estimated was 2.01 year^{-1} (Figure 4). The natural mortality (M) and the fishing mortality were 1.27 year^{-1} and 0.74 year^{-1} respectively, whereas the exploitation level (E) was 0.37. The fishing mortality rate was above the precautionary target reference point (F_{opt} = 0.64 year^{-1}) but under the precautionary limit reference point (F_{limit} = 0.84 year^{-1}).

The recruitment pattern showed two major peaks of recruitment for *B. auritus* in Ivorian waters (Figure 5). The major recruitment occurred from February to April peaking in March (18.24%) and the minor one was observed in September-October. The mid-point of the lower length class (6.5 cm) in the sampled data was used as a length at recruitment. The length at first capture (Lc) was 12.89 cm whereas the lengths at which 25% and 75% of fish are captured were respectively 11.77cm and 14.01 cm.

The total catch for 2009 was approximately 16.35 million specimens. The total biomass and the yield values of *B. auritus* estimated using Jones' method were 2507 tons and 972 tons respectively, which provided the Maximum Sustainable Yield (MSY) of 2079 tons (Table 2). The relative yield per-recruit (Y'/R) and biomass per-recruit (B'/R)

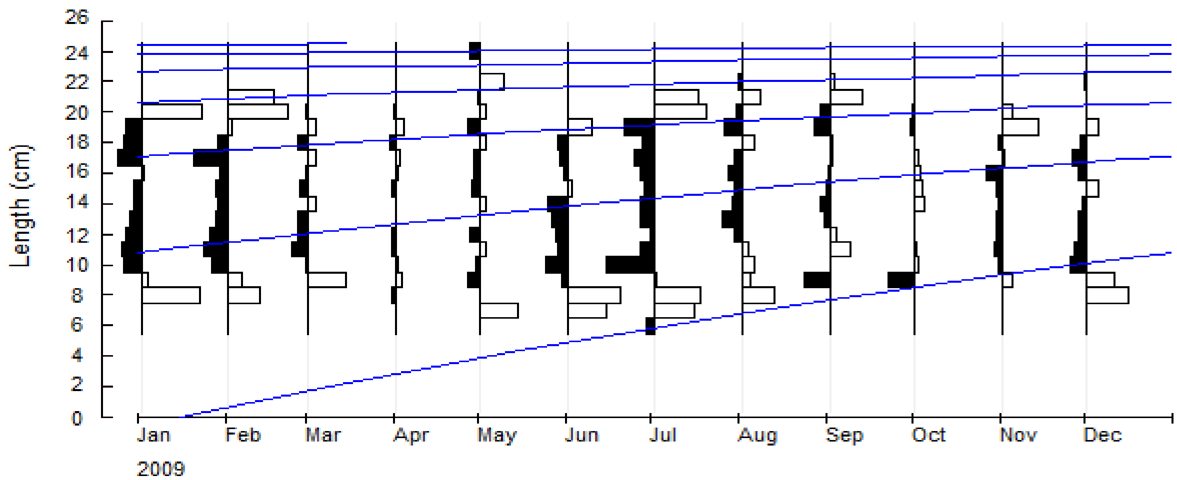

Figure 3: Growth curve superimposed over the restructured length-frequency histograms for *Brachydeuterus auritus*. Rn = 0.236

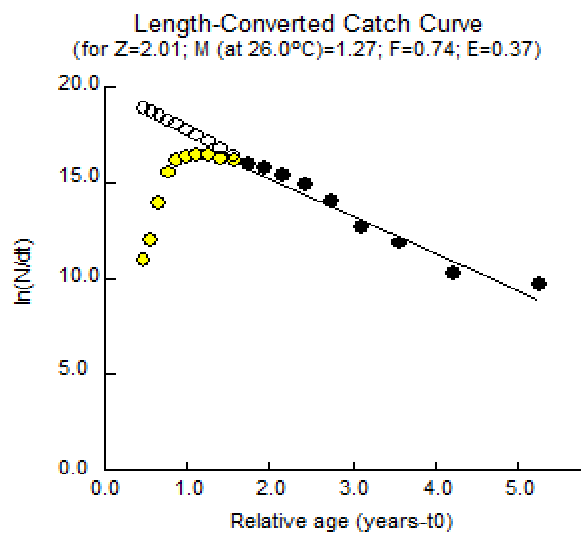

Figure 4: Length-converted catch curve of *Brachydeuterus auritus* sampled in Ivorian coast waters. Solid dots = points used in calculating through least square linear regression. Open dots = point either not fully recruited or nearing L∞

were determined as a function of Lc/L∞ and M/K (Figure 7). The optimum exploitation rate (E_{max}) which produces maximum and economic sustainable yield was 0.85 whereas the exploitation level ($E_{0.1}$) at which the marginal increase in relative yield per recruit is 10% was 0.72. The exploitation level ($E_{0.5}$) which corresponds to 50% of the relative biomass per recruit of the unexploited stock was 0.37.

DISCUSSION

According to Carlander (1977), the slope *b* generally lies between 2.5 and 3.5 and growth is assumed to be isometric when it is equal to 3 (Quinn and Deriso 1999). The *b* value estimated for *B. auritus* in this study was 2.98 and it was not significantly different from 3, indicating isometric growth for this species. This implies that small specimens in the samples under consideration have the same form and condition as large specimens (Nandikeswari et al., 2014). According to Neilson and Johnson (1980), the isometric growth (b= 3) exists when fish shapes do not change as fish grow.

Galucci et al. (1996) highlighted the weakness of ELEFAN-I methods to estimate growth parameters, particularly when length distribution did not indicate any

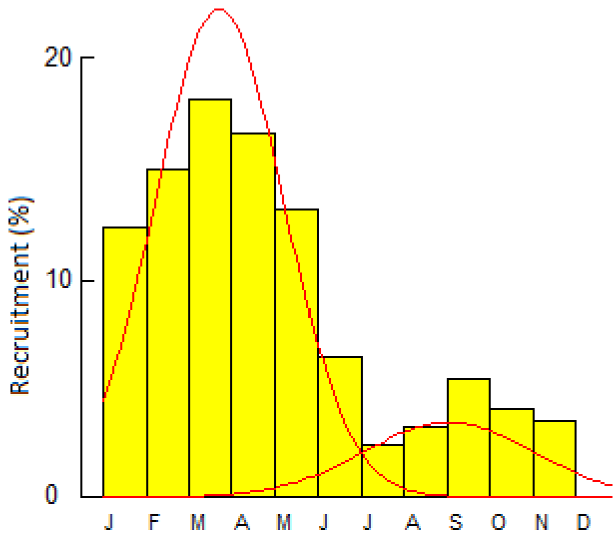

Figure 5: Recruitment pattern of *Brachydeuterus auritus* sampled in Ivorian coast waters

Table 2. Estimates of the total biomass (tons), the yield (tons) and the MSY (tons) from the length frequency data of *Brachydeuterus auritus* using the Jones's Cohort Analysis Model. $X_{L1, L2}$ = Natural mortality factor, F = Fishing mortality, E = Exploitation rate, Z = Total mortality, MSY= Maximum Sustainable Yield

Mid-point	Catch	$X_{L1, L2}$	Survivors	F	E	(Z)	Biomass (kg)	Body weight (kg)	Yield (kg)
6.5	5080	1.06	120293254	0.001	0.001	1.27	48185	0.005	23
7.5	15240	1.06	106993276	0.002	0.001	1.27	69132	0.007	107
8.5	113554	1.07	94525742	0.012	0.01	1.28	93608	0.010	1163
9.5	592075	1.07	82800357	0.070	0.052	1.34	120632	0.014	8444
10.5	1163827	1.08	71465864	0.151	0.106	1.42	148448	0.019	22366
11.5	1546918	1.08	60491677	0.223	0.149	1.49	175023	0.025	38985
12.5	1792150	1.09	50124712	0.292	0.187	1.56	198285	0.032	57905
13.5	1928911	1.10	40538689	0.363	0.222	1.63	216014	0.041	78389
14.5	1781992	1.11	31859183	0.395	0.237	1.67	226723	0.050	89605
15.5	1760571	1.12	24350898	0.472	0.271	1.74	228765	0.061	107992
16.5	1569026	1.13	17853854	0.526	0.293	1.8	220586	0.074	115953
17.5	1460552	1.15	12494037	0.639	0.335	1.91	201257	0.088	128623
18.5	1131148	1.178	8131124	0.684	0.35	1.95	171809	0.104	117555
19.5	834013	1.21	4900412	0.746	0.37	2.02	135966	0.122	101397
20.5	401215	1.26	2646097	0.563	0.307	1.83	100530	0.141	56618
21.5	131680	1.35	1340141	0.295	0.188	1.56	72660	0.163	21416
22.5	77992	1.51	641072	0.298	0.19	1.57	48773	0.186	14525
23.5	24304	1.94	230474	0.196	0.134	1.47	26301	0.212	5152
24.5	24304		48608	1.270	0.500	2.54	4707	0.229	5978
							Total 2507 tons		**Total** 972 tons
MSY: 2079 tons									

separation of age groups. Considering the suitability of length-frequency data used for the estimation of growth parameters for this species, a number of criteria exist for judging this. The presence of modal groups should be discernible from the raw data (Wolff 1989), with apparent shifts in the modal length overtime. These features were observed in the length data used in the present analysis. Furthermore, Pauly (1984) developed a system for assessing length data for growth studies, based on the need to obtain a sufficient number of measurements, well distributed over time. So, a total sample size of 1500 and above accumulated over a period of six months and above, is regarded as excellent for such analysis. The sample used in the present analysis is far in excess of this criterion. The

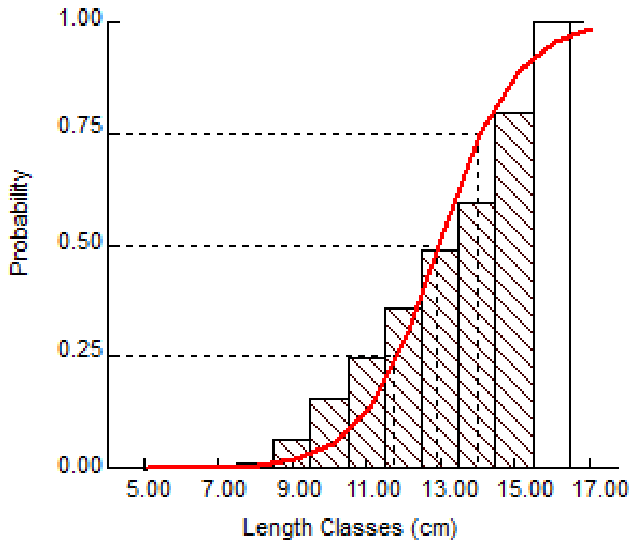

Figure 6: The probability capture curve showing the L_{25}, L_{50} and L_{75} of *Brachydeuterus auritus* in Ivorian coast waters

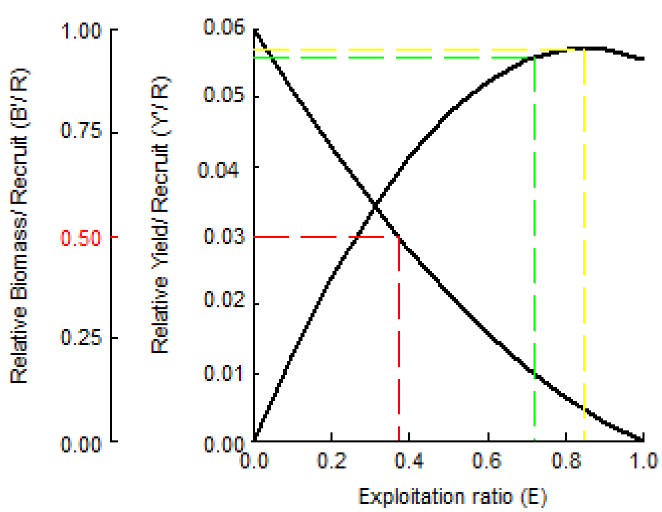

Figure 7: Relative yield per recruit (Y'/R) and biomass per recruit (B'/R) of *Brachydeuterus auritus* in the Ivorian coast waters using the Knife-edge option

estimated asymptotic length (25.20 cm) and growth coefficient (0.58 year^{-1}) for *B. auritus* were compared with other studies. These values were not significantly different from those obtained in other areas in Africa. However, the L∞ was slightly higher than those observed by Beck (1974) and Bannerman (2001) in Togolese (23.1 cm) and Ghanaian (23.1 cm) waters, respectively. On the other hand, the K value was higher in Ghanaian waters (0.73 year^{-1}), followed by Ivorian waters (present study) and Togolese waters (0.29). The growth performance index φ' (2.57) estimated in this study was higher than that of Bannerman (2002) in Ghanaian waters (2.41) and Beck (1974) in Togo waters (2.19). It is assumed that Ivory Coast shares the same stock of big eye grunt with Ghana, Benin and Togo in the Committee for the Eastern Central Atlantic (CECAF) Sub-region. Over the past two decades, the growth constant K and the growth performance have greatly increased, with an increase in fishing effort on demersal species, especially on juveniles (Bannerman 2002). In fact, the trawlers often operate relatively close to shore where juveniles are aggregated around the nursery ground in the shallow waters. This greatly causes changes in mean body size of the big eye grunt, because of the removing of species with a high longevity and a large body size (Genner et al., 2010). The high growth obtained in this study could be an adaptation of *B. auritus* in response to the fishing pressure and ecosystem perturbations. According to Duponchelle and Panfili (1998), some fish species have remarkable adaptations affecting the growth or reproduction (i.e. early sexual maturity, dwarfism and variation of growth) in response to ecosystems perturbations.

The total and fishing mortality found in this study (2.01 year^{-1} and 0.74 year^{-1}, respectively) were lower than those presented by Bannerman (2002), who estimated Z = 2.58 year^{-1} and F = 1.43 year^{-1} using the same method. However, the natural mortality was not significantly different (1.27 year^{-1} and 1.24 year^{-1} respectively). Based on the fishing mortality, the fishing pressure seems to be higher in Ghanaian waters. The higher natural mortality compared to fishing mortality for *B. auritus* indicates the unbalanced position in the stock. Jarre-Teichmann and Christensen (1998) found that natural mortality of small pelagic fish is much higher than fishing mortality in the four major eastern boundary current ecosystems. This high natural mortality can be the fact of some predators such as *Pseudotolithus senegalensis*, *Pseudotolithus typus and Sphyraena guachancho* which target considerably this species (Anyanwu et al., 1990, Akadjé et al., 2013). Barro (1979) reported that this species spawned once a year, from January to June. So, the critical period of its early life history falls within the upwelling periods (January-February and July-October) where several predators are found for feeding. According to Curry et al. (2000), upwelling ecosystems support a wide diversity of predators and almost 55% of all small pelagic fish in the Benguela Current region are eaten by top predators. However, the effect of the other factors on the natural mortality namely, diseases, competitive interactions, density-dependent factors and other vagaries of nature are unknown.

Based on the assumption that a stock is optimally exploited when F=M or E=0.5 (Gulland, 1971), the estimated exploitation level was below the 0.50 optimum level of exploitation, indicating that the stock is not overexploited. This assertion is supported with the obtained relative yield-per-recruit (Y'/R) and relative biomass-per-recruit (B'/R) values established for *B. auritus* in the present study. Both estimates indicated that the present level of exploitation rate (E = 0.37) was lower than the maximum allowable limit based on the yield-per-recruit calculation (E_{max} = 0.85). The specified precautionary target reference point (F_{opt}) and limit reference point (F_{limit}) values were also used to evaluate the status of the stock. These biological reference points are considered more appropriate in light of the constraints of the yield per recruit model. The fishing mortality was above the F_{opt} (0.64 $year^{-1}$) but under the F_{limit} (0.84 $year^{-1}$), suggesting that the stock is exploited at a low rate. However, given that the upper 95% confidence interval of F (1.18 $year^{-1}$) exceeded the limit reference point, further expansion of the fishery could be a threat for the stock. On the other hand, the annual yield obtained in 2009 was 2407 tons which was slightly above the MSY from Jones' Cohort Analysis method (2079 tons), attesting that precautions must be taken since the presence of several juveniles in the catches is a real threat for *B. auritus* stock.

Recruitment has been described as a year-round phenomenon for tropical fish and shrimps species (Weber 1976). In this population, there were one major and one minor recruitment peaks in the year, and they overlapped in time to give a continuous year-round pattern. It is in confirmation with Pauly (1982) suggesting of double recruitment pulses per year for tropical fish species and for short-lived species.

Conclusion

It is recognized that the first and last steps of VPA sometimes introduce errors into the population estimates and the assumption on terminal F leads to a systematic overestimation of the stock size when the stock is declining. Despite these weaknesses, VPA is a suitable method which provides estimates helpful for management actions (limiting fishing effort, quota, TAC, etc.). Data of one year can provide some information to study the dynamics of population of the species which recruit into the fishery at a length of 4 cm.

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