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Study of the population parameters of the bigeye grunt, *Brachydeuterus auritus* (Valenciennes, 1831) in Ghanaian coastal waters and its implications for management

Samuel KK Amponsah, Patrick K Ofori Danson and Francis KE Nunoo

Abstract
Some vital population parameters of the bigeye grunt, *Brachydeuterus auritus* (Valenciennes, 1831), within Ghana's coastal waters were evaluated based on monthly pooled length-frequency data from June 2014 to January 2015 using the FiSAT Tool II. The estimated growth parameters from 1675 samples were: asymptotic length ($L\infty$) = 16.28 cm standard length, growth rate (K) = 0.78 per year, growth performance index (ϕ) = 2.315, longevity (t_{max}) = 4 years, theoretical age (t_o) = -0.24 years and the ratio of Z/K = 1.26. The length at first capture (Lc_{50}), length at first maturity (Lm_{50}) and length at first recruitment (Lr) were estimated at 3.95 cm, 10.9 cm, and 3.5 cm respectively. The observed recruitment pattern portrayed an absence of recruitment overfishing while the ratio of $Lc_{50}/L\infty$ (0.24) showed the presence of growth overfishing. Total mortality rate (Z), natural mortality rate (M) and fishing mortality rate (F) were estimated at 3.21 per year, 1.73 per year and 1.48 per year, respectively. The current exploitation rate ($E_{current}$) was 0.46 whereas the maximum exploitation level (E_{max}) was 0.48. The yield isopleth indicated that small sized *Brachydeuterus auritus* are harvested at low fishing effort level – characteristic feature of a fishery at the developing stage. Results from the study indicated that *Brachydeuterus auritus* stock is vulnerable to collapse in the absence of urgent management interventions such as mesh size regulations and monitoring of fishing efforts.

Keywords: Ghana, growth overfishing, mortality, *Brachydeuterus auritus,* recruitment, population dynamics

1. Introduction

Brachydeuterus auritus which used to be referred to as *Otoperca aurita* (Valenciennes, 1831) belongs to the family Pomadasyidae and is widely distributed in Ghanaian coastal waters. Its distribution spans from Mauritania to Angola at depths between 30-80 m (Fischer *et al*., 1981) [10]. *Brachydeuterus auritus* is mostly abundant during the daytime and it is reported to feed on fingerlings including its own kind and larvae (Blay *et al.,* 2006; Kwei & Ofori Adu, 2005) [8, 18]. It is commercially exploited and encountered in catches of artisanal fishermen engaged in Ghanaian coastal fishing operations. *Brachydeuterus auritus* is harvested with bottom trawls, gill nets, set nets, beach seine and purse seine fishing gears, hence *Brachydeuterus auritus* is the most exploited species of the Pomadasyidae family along the coastline of Ghana (Aggrey-Fynn & Sackey-Mensah, 2012) [1]. Though *Brachydeuterus auritus* accounts for more than 5% of the total marine fish catch in Ghana, it dominates demersal fish landings by small-scale fishing crafts including beach seiners (Bannerman & Cowx, 2002) [4]. However, its dominance as the most occurring demersal fish species was displaced by triggerfish, particularly *Balistes capriscus,* and *Balistes punctatus* for almost two decades from the early 1970s to the late 1980s (Koranteng, 2000) [19]. Locally, *Brachydeuterus auritus* is a good food fish and, they are marketed either in fresh, dried or salted form. Harvested *Brachydeuterus auritus* are sometimes reduced to fishmeal while discarded in some countries like Senegal (Kwei & Ofori-Adu, 2005) [18]. Regarding food security, *Brachydeuterus auritus* forms part of the main animal protein source for many fishing households within coastal communities in Ghana as a result of its low purchasing price. However, despite its crucial contribution to food security within most coastal communities, there appears to be limited information on its population parameters and stock status dovetailed with a consistent decline in yearly catches in Ghana. It is against this backdrop that the present study sought to estimate some vital population parameters of *Brachydeuterus auritus* within Ghana's coastal waters and their implications for management.

2. Materials and Methods

2.1 Study area

The study focused on four fish landing sites along the eastern coastline of Ghana. In selecting these study sites, a two-stage stratified sampling method was applied. For the first stage, stratification was based on geographical isolation, where two study areas were selected from the two coastal regions along the eastern coast of Ghana. For the second stage, stratification was based on the fishing methods used. In that regards, the fishing methods practiced within the selected four fishing landing sampling sites encompassed the various fishing methods deployed in the Ghanaian coastal fishing industry, namely beach seining, purse seining and gill netting. The four fish landing sampling sites involved Tema & Jamestown (Greater Accra region) and Vodzah & Denu (Volta region) (Figure 1). In all the four fish landing sampling sites, fishing and its related activities served as the primary source of livelihoods for the majority of the indigenes with the minority of them engaged in alternative livelihoods such as trading, masonry, farming, and driving.

2.2 Data collection

Fish samples were purchased from local fishers at the selected fish landing sampling sites for eight months, spanning from June 2014 to January 2015, who operated with multifilament fishing gears (both beach seine and purse seine). Acquired fish samples were preserved on ice in an ice chest and transported to the laboratory at the Department of Marine and Fisheries Sciences, University of Ghana. At the laboratory, fish samples were weighed using the electronic scale to the nearest 0.01g while standard lengths were measured to the nearest 0.1cm using the 100-cm measuring board. Further, biological identification of the acquired fish samples was done to the species level using fish identification keys by Fischer *et al.* (1981) [10] and Kwei & Ofori-Adu (2005) [18]. In all, a total of 1675 specimen of *Brachydeuterus auritus* were sampled.

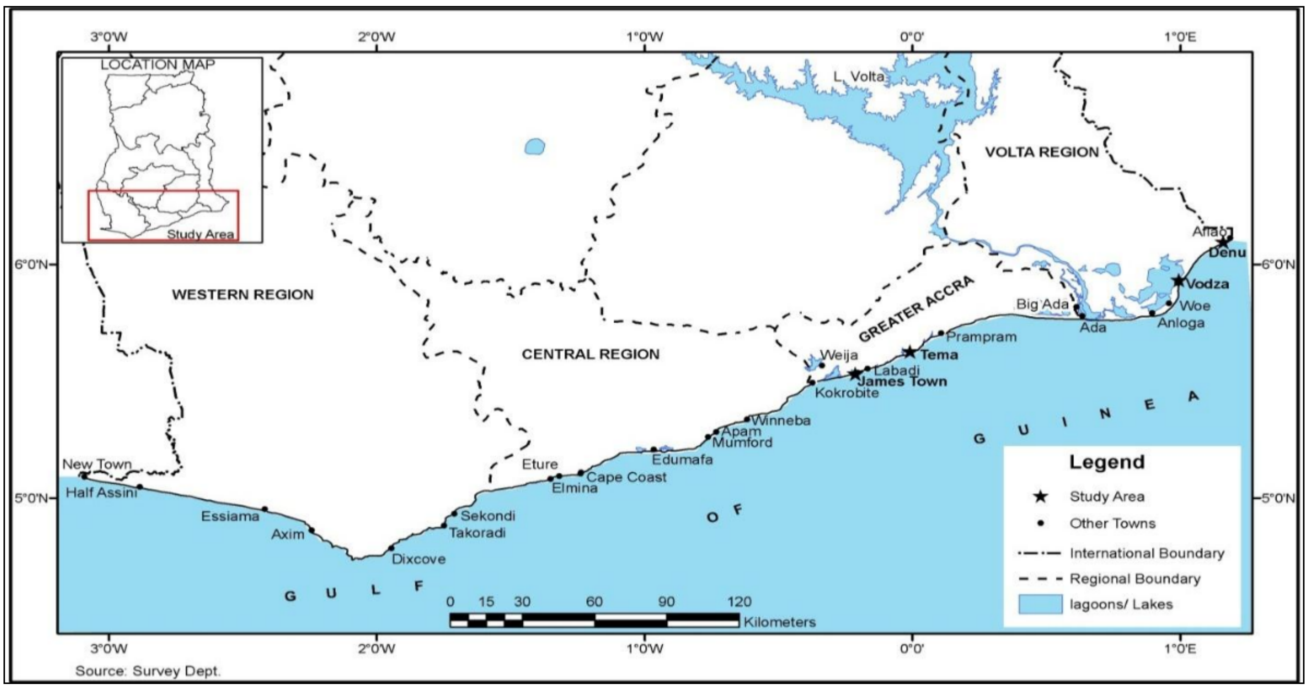

Fig 1: Map showing the sampling sites

2.3 Methods

2.3.1 Growth parameters

To obtain the growth parameters; growth rate (K), asymptotic length (L_∞) and the growth performance index (ϕ), the Von Bertanlaffy Growth Function (VBGF) fitted in FISAT II was used. The growth curve towards the asymptotic length at an instantaneous growth rate (K) was established using the VBGF by Sparre & Venema (1998) [28]: $Lt = L_\infty (1-e^{-k\ (t-t0)})$. The growth performance index was generated in order to compare with published growth rate of the fish species from other studies, following the expression by Munro & Pauly (1983) [20]: (ϕ) =2 * $\log_{10}L_\infty + \log_{10}K$. The theoretical age at birth (t_o) was calculated independently, using the empirical formula: $\log_{10}(-t_o) = -0.3922 - 0.275 * \log_{10}L\infty - 1.038 * \log_{10}K$ (Pauly, 1980) [23]. The longevity was estimated as $t_{max} = 3/K + t_o$, where t_o is the theoretical age at birth (Pauly, 1980) [23].

2.3.2 Mortality parameters

Total annual instantaneous mortality rate (Z) was estimated using the Jones and van Zalinge plot (Sparre & Venema, 1998) [28]. Natural mortality rate (M) was computed using the empirical formula; $Log_{10}M = - 0.0066 - 0.279 * \log_{10}L_\infty + 0.6543 * \log_{10}K + 0.4634 * \log_{10}T$ with a mean annual temperature of 25.7 °C (Pauly, 1980) [23]. Fishing mortality rate (F) was estimated following equation by Beverton & Holt (1957) [7]: F = Z−M. The current exploitation ratio ($E_{current}$) was calculated using the equation $E_{current}$ = F/Z (Gulland, 1971) [14]. The maximum fishing effort (F_{max}) was estimated using the expression: F_{max} = 0.67K/0.67–Lc (Hoggarth *et al*., 2006) [15], where $Lc = Lc_{50}/ L_\infty$. The precautionary limit reference point (F_{limit}) was computed as F_{limit} = (2/3) * M (Patterson, 1992) [25]. The optimum fishing rate (Fopt) which serves as a precautionary target reference point was calculated as Fopt = 0.4*M (Pauly, 1984) [22].

2.3.3 Probability of Capture
The probabilities of capture were estimated through the logistic transformation of the probabilities from the left hand-side of the length-converted catch curve fitted in FiSAT II Tool. Additionally, the lengths at which 25% and 75% of the stock are captured were taken as corresponding to the cumulative probability at 25% and 75% respectively. The length at first capture (Lc_{50}) was taken as corresponding to the cumulative probability at 50%.

2.3.4 Recruitment pattern
By projecting the length-frequency data backward onto the time axis down to zero length, using the von Bertalanffy growth equation and the estimated growth parameters, the recruitment pattern was established (Nurul *et al*., 2009) [21]. The midpoint of the smallest length interval in the catch was estimated as the length at first recruitment (Lr) (Gheshlaghi *et al*., 2012) [13].

2.3.5 Length first maturity (Lm_{50})
The length at first maturity (L_{m50}) is the maiden length at which the fish is capable of contributing to the stock size. The length at first maturity (L_{m50}) was calculated as:

$L_{m50} = (2^* L_\infty) / 3$ (Hoggarth *et al*., 2006) [15].

2.3.6 Relative Yield per Recruit (Y'/R) and Relative Biomass per Recruit (B'/R)
The maximum exploitation rate (E_{max}), which implies exploitation rate producing maximum yield, exploitation rate at which the stock is 10% of its virgin stock ($E_{0.1}$) and $E_{0.5}$ indicating exploitation rate with which the stock is reduced to half of its virgin biomass were computed using the Knife-edge option incorporated in the FiSAT II Tool.

2.3.7 Yield isopleth
Yield contours which characterize yield isopleth were plotted to identify the impact on yield based on changes in exploitation rate (E_{max}) and critical length at capture (Lc) which is the proportion of the length at first capture (Lc_{50}) to the asymptotic length ($L\infty$) ratio ($Lc_{50}/L\infty$) using the FiSAT II Tool.

2.4 Data Analysis
The monthly pooled length frequency data was grouped using 1cm length intervals. The resultant data was analyzed using the FiSAT II (FAO-ICLARM Stock Assessment Tools) software (Gayanilo *et al.,* 2005) [12]. The age at length plot was done using the Yield software (Branch *et al*., 2000) [9].

3. Results
3.1 Growth parameters
Figure 2 presents the restructured length frequency with superimposed growth curves. The growth parameters were calculated as $L\infty$ = 16.28 cm SL and K = 0.78 year $^{-1}$. The theoretical age at birth (t_o) as well as the longevity (t_{max}) were obtained at t_o = -0.24 and 4 years respectively (Figure 3B). Therefore, the growth curve for *Brachydeuterus auritus* based on Von Bertalanffy Growth Function (VBGF) was established as $Lt=16.28(1-e^{-0.78(t-(-0.24))})$. Growth performance index (ø) was estimated as 2.315. The Wetherall plot gave an estimate of the Z/K ratio to be 1.26 (Figure 3A).

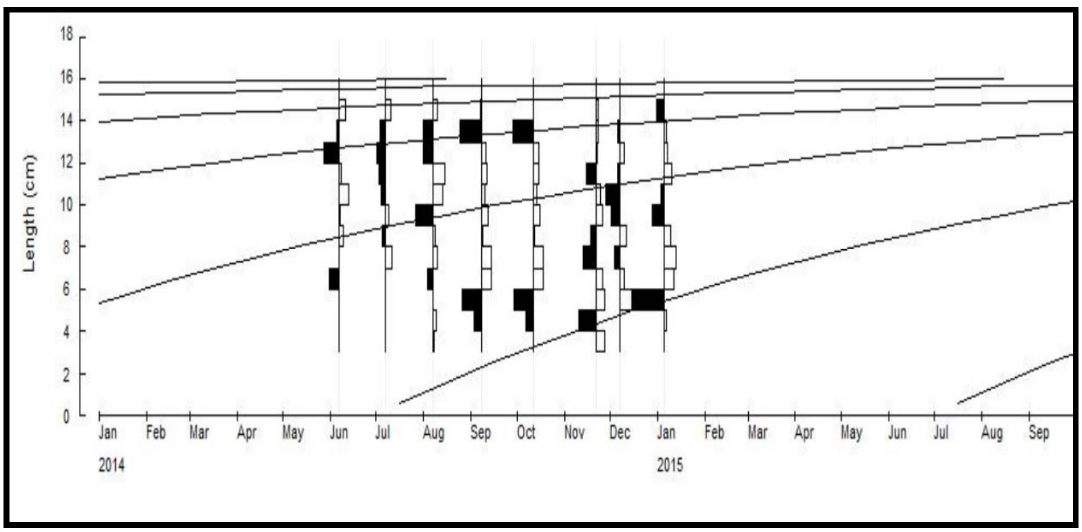

Fig 2: Reconstructed length frequency distribution superimposed with growth curve

3.2 Mortality Coefficients and Current Exploitation Rate
The mortality coefficients and current exploitation rate were estimated as Z = 3.21 year $^{-1}$ (Figure 3C), M = 1.73 year $^{-1}$, F = 1.48 year $^{-1}$ and $E_{current}$ = 0.46. The optimum fishing rate (F_{opt}), maximum fishing limit (F_{max}) and the precautionary fishing limit (F_{limit}) were 0.69 year $^{-1}$, 1.04 year $^{-1}$ and 1.15 years $^{-1}$ respectively.

3.3 Probability of capture and Length at first maturity (Lm_{50})
The length at first capture (Lc_{50}) was 3.95 cm whereas the lengths at which 25% (L_{c25}) and 75% (L_{c75}) of the stock was captured were 2.95 cm and 8.43 cm respectively (Figure 3D). The length at first maturity (Lm_{50}) was estimated as 10.9 cm.

3.4 Relative Yield per Recruit (Y'/R) and Relative Biomass per Recruit (B'/R)
Using the Knife-edge option in FISAT tool II, the maximum exploitation rate (E_{max}) was found to be 0.48. The exploitation rates responsible for 10% ($E_{0.1}$) and 50% ($E_{0.5}$) reduction in the virgin stock were estimated as 0.41 and 0.29 respectively (Figure 3E).

3.5 Recruitment pattern
Based on the size distribution of the catch, the recruitment pattern from the FISAT II tool (Figure 3F) outlined two recruitment peaks (major and minor). By macro inspection, the major recruitment peak occurred in September - October while the minor peak occurred in June - July. The length at first recruitment (Lr) was 3.5 cm.

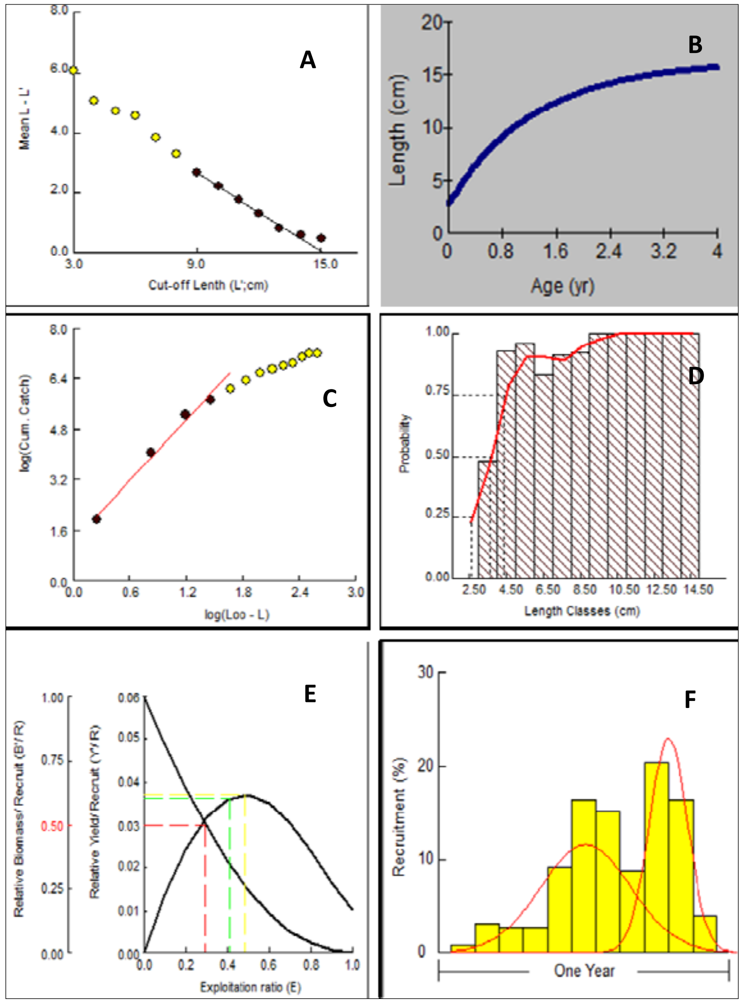

Fig 3: A) Powell-Wetherall plot for Z/K ratio; B) Length at age plot; C) Jones and van Zalinge plot; D); Probability of capture E) Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R). and F) Recruitment pattern

3.6 Yield isopleths
The yield contours predict the response of relative yield-per-recruit of the fish to changes in Lc = 0.24 and E_{max} = 0.48. From the yield isopleths, the status of *Brachydeuterus auritus* fishery in Ghana's coastal waters fell within Quadrant B (Fig. 4).

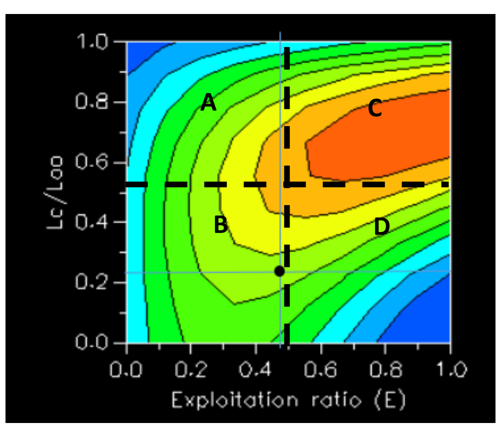

Fig 4: Yield isopleth

4. Discussion

The estimated values of the asymptotic length ($L\infty$) and growth rate (K) varied from other studies (Table 1). Variation in estimates may be attributed to factors like sampling methods, nature of data, computation methods used and the obtained length frequency. However, the relatively high growth rate (K = 0.78 per year) depicts the response by *Brachydeuterus auritus* stock to the intense fishing pressure in order to avert extinction of its species (Table 1). The calculated growth rate (K = 0.78 per year) was greater than 0.67 yr^{-1}, which indicated that *Brachydeuterus auritus* is a short-lived fish species (Kienzle, 2005) [16]. Further, the estimated growth performance index (ϕ = 2.315) was similar to values from other studies (Table 1). This implied that *Brachydeuterus auritus* from the respective study areas are of the same taxonomic fish family. However, the estimated growth performance index (2.315) was not within the range documented by Baijot *et al* (1997) [3] for African fishes with fast growth performance, thus depicting that *Brachydeuterus auritus* has a slow growth performance. Similarly, the estimated growth performance index from other studies (Table 1) was all not within the range as well, buttressing the assertion that *Brachydeuterus auritus* stock has a slow growth performance.

Table 1: Comparison with growth estimates from other studies

Authors	Location	L∞ (cm)	K/ year	ϕ/year
Raitt and Sagua (1972) [26]	Nigeria	20.6	0.40	2.23
Beck (1974, male) [6]	Togo	23.1	0.29	2.19
Beck (1974, female) [6]	Togo	22.1	0.32	2.20
Fontana & Bouchereau (1976) [11]	Congo	23.5	0.73	2.61
Barro (1979) [5]	Ivory Coast	23.1	0.40	2.33
Bannerman and Cowx (2002) [4]	Ghana	23.1	0.73	2.41
Samb (2003) [27]	Senegal	22.3	0.59	2.47
Konan *et al* (2015) [1 7]	Ivory Coast	25.2	0.58	2.57
This study	Ghana	16.3	0.78	2.32

Though the length at first capture (L_{c50}) was similar to estimate by Bannerman & Cowx (2002) [4], it was found to be lower than estimated by Konan *et al* (2015) [17] (Table 2), owing to the rampant use of fishing gears with smaller mesh size, less than 25 mm (diagonal stretch). Therefore, the bigger the mesh size, the higher the length at first capture (Lc_{50}). Consequently, the $Lc_{50}/L\infty$ ratio of 0.24 from the present study was also lower than 0.5, which showed that majority of the harvested fish were small in size (< 10cm): a feature of growth overfishing (Pauly & Soriano, 1986) [24]. Similar observation was documented by Bannerman and Cowx (2002) [4] who estimated the $Lc_{50}/L\infty$ ratio as 0.17. In contrast, Konan *et al* (2015) [17] documented a $Lc_{50}/L\infty$ ratio of 0.51, which indicated that greater portion of the harvested fish was of relatively large size (Table 2).

Compared to studies done in other coastal regions (Table 2), the calculated length at first maturity (Lm_{50}) from the present study was the lowest. Possible reasons include changes in genetic makeup, intense fishing pressure and environmental conditions (Sylla *et al*., 2016) [29]. Further, the length at first maturity (L_{m50} = 10.5 cm) was nearly thrice the length at first capture (L_{c50} = 3.95 cm); an indication that fish species get harvested before maturing (Table 2). This observation confirms the earlier assertion that growth overfishing is currently occurring within the *Brachydeuterus auritus* stock in Ghana's coastal waters. Nonetheless, in the presence of growth overfishing absent proper management measures, the stock size of *Brachydeuterus auritus* may approach zero.

Table 2: Comparison of derived population parameters for *Brachydeuterus auritus* with estimates from other studies

Authors	Location	Lc_{50} (cm)	$Lc_{50}/L\infty$	Lm_{50} (cm)
Barro (1979; male) [5]	Ivory Coast	-	-	13.8
Barro (1979; female) [5]	Ivory Coast	-	-	14.5
Asabere-Ameyaw (2001; male) [2]	Ghana	-	-	14.8
Asabere-Ameyaw (2001; female) [2]	Ghana	-	-	15.1
Bannerman and Cowx (2002) [4]	Ghana	3.92	0.17	-
Samb (2003; male) [27]	Senegal	-	-	14.4
Samb (2003; female) [27]	Senegal	-	-	14.8
Konan *et al* (2015) [17]	Ivory Coast	12.89	0.51	-
Sylla *et al* (2016; male) [29]	Ivory Coast	-	-	12.9
Sylla *et al* (2016; female) [29]	Ivory Coast	-	-	12.7
This study (Unsexed)	Ghana	3.95	0.24	10.9

The double recruitment peaks from the present study confirmed the assertion by Pauly (1984) [22] that the double recruitment pulses per year are a general feature of tropical fish species (Figure 3). The presence of all year-round recruitment showed that spawning occurs throughout the year and that recruitment is not dysfunctional. This observation was in line with findings by Asabere-Ameyaw (2001) [2] whose study documented that spawning of *Brachydeuterus auritus* in Ghana's marine waters is often throughout the year. However, to confirm the functionality of recruitment within a fish stock, the length at first recruitment should be lower than the length at first capture. From the present study, the calculated length at first recruitment (Lr=3.5cm) was lower than the length at first capture (Lc_{50}=3.95cm). Inferably, such observation shows that juveniles of *Brachydeuterus auritus* get recruited into the stock before becoming vulnerable to capture by any fishing gears. Meanwhile, the calculated length at first recruitment was lower than the estimate by Konan *et al* (2015) [17], chiefly due to variation in the mesh size of fishing gears.

The Z/K of 1.26 inferred that the *Brachydeuterus auritus* stock is currently mortality dominated. Comparatively, the obtained Z/K ratio was highly lower than the ratio calculated by Bannerman & Cowx (2002) [4] as shown in Table 3. This could be due to the estimated high growth rate (K) from the present study as well as the computation procedures. Furthermore, the calculated natural mortality rate (M=1.73 year $^{-1}$) was much higher than estimates from other studies (Table 3). Possible causes include the increased intensity of predators, an increase in temperature and diseases as well as an intense decline in food abundance. Also, the estimated fishing mortality rate (F = 1.48 year $^{-1}$) calculated from the study was higher than the fishing mortality rates calculated from other studies (Table 3). Potential reasons for the observed high fishing mortality rate include intense fishing pressure, the gear type and mesh size, sampling procedure and monthly fishing effort because data used in this study was fishery dependent. As a thumb rule, optimum fishing mortality should be approximately 40% of the natural mortality (M) or Fopt. = 0.4 M (Pauly, 1984) [22]. From the study, fishing mortality (F=1.48 per year) appeared to be relatively higher than the maximum fishing mortality (F_{max} = 1.04 per year), limiting fishing mortality (F_{limit} = 1.15 per year) and optimum fishing mortality (F_{opt} = 0.69 per year). These results confirm the existence of relatively intense fishing pressure on *Brachydeuterus auritus* stock. The current exploitation rate ($E_{current}$ = 0.46) revealed that exploitation of *Brachydeuterus auritus* stock in Ghana's marine waters has reached its optimum exploitation level based on the optimization category of E = 0.5 for sustainable exploitation of fish species (Pauly, 1984) [22]. This situation suggests that any further expansion in the current exploitation rate will fasten the rate of the already existing growth overfishing.

Table 3: Comparison of mortality parameters for *Brachydeuterus auritus* with estimates from other studies

Authors	Location	Z/K	M/ year	F/ year	Z/year	E
Bannerman & Cowx (2002) [4]	Ghana	3.82	1.24	1.43	2.67	0.54
Samb (2003) [27]	Senegal	-	1.12	0.42	1.54	0.27
Konan *et al* (2015) [17]	Ivory Coast	-	1.27	0.74	2.01	0.37
This study	Ghana	1.26	1.73	1.48	3.21	0.46

Comparatively, in Table 3, the current exploitation rate ($E_{current}$ = 0.46) from the present study was lower than the exploitation rate estimated by Bannerman & Cowx (2002) [4]. This could be due to the relatively high estimate of the total mortality (Z) rate from the present study, particularly the contribution from natural mortality (M) rate (Table 3). However, the current exploitation rate ($E_{current}$ = 0.46) was relatively close to the maximum exploitation rate (E_{max} = 0.48), revealing that the maximum sustainable yield (E_{max}) may be reached soon and gradually surpassed if fishing effort continues to expand. At such level of exploitation ($E_{current}$ > E_{max}), the *Brachydeuterus auritus* stock will experience recruitment overfishing, making it vulnerable to collapse eventually.

The quadrant B category from the yield isopleth in Figure 4 demonstrated that *Brachydeuterus auritus* fishery is at the eumetric or developing stage (Pauly & Soriano, 1986) [24]. Using the same quadrant rule as an assessment of a fishery, the fishing regime of *Brachydeuterus auritus* is characterized as 'catching small size fishes at low fishing effort level, hence requiring no management intervention. However, as a precautionary approach to averting the possible collapse of this important fishery, mesh sizes should be increased as fishing efforts continue to rise.

5. Conclusion

The study has revealed that *Brachydeuterus auritus* stock within Ghana's coastal waters is a short-lived species with slow growth performance. Furthermore, *Brachydeuterus auritus* stock is experiencing growth overfishing due to the heavy unsustainable fishing pressure within Ghana's coastal fishing operations. Consequent to the intense unsustainable fishing pressure, its exploitation rate will soon surpass the maximum sustainable yield, a proxy for recruitment dysfunctional. Despite being labeled as a fishery in the developing stage, *Brachydeuterus auritus* stock is vulnerable to collapse if mesh size of fishing gears and fishing effort are not well regulated.

6. Acknowledgment

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