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Aspects of population dynamics of Red Pandora, *Pagellus bellottii* (Steindachner, 1882) from the coastal waters of Ghana

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Abstract

Population parameters for Red Pandora, *Pagellus bellottii* (Steindachner, 1882) from the eastern coastline of Ghana, using length-frequency data from June 2014 to January 2015 were assessed. A total of 440 samples of *Pagellus bellottii* were measured for standard length and analyzed with FiSAT II. The asymptotic length (L_∞) and growth rate (K) were 19.43 cm and 0.42 per year. Theoretical age at birth (t_0) and growth performance index (ϕ) were -0.44 per year and 2.20. The age at first maturity (tm_{50}) and longevity (t_{max}) were 2.2 years and 7 years. The Bhattacharya's method revealed three modal lengths groups: 9.3 cm, 12.1 cm, and 14.6 cm. Total mortality rate (Z), natural mortality rate (M) and fishing mortality rate (F) were 2.58 per year, 1.10 per year, and 1.48 per year. Exploitation rate ($E_{current}$) and maximum exploitation rate (E_{max}) were estimated as 0.57 and 0.93 respectively. The recruitment pattern was continuous with two major recruitment pulses. VPA outcome showed that mid-lengths of 11.5 cm and 12.5 cm experienced the highest harvesting rate. The fishing regime of *Pagellus bellottii* fell in the developed stage based on the quadrant rule. Maximum Sustainable Yield (MSY) was 7864.18 tons. Results from the study indicated the existence of growth overfishing with the present state of exploitation as a forewarning to the collapse of the fishery in future. With resilience of Red pandora within the medium category, incidence of overfishing will produce economic consequences. The developed stage of fishing suggested that maximization of yield per recruits will lead to low stock biomass of Red pandora.

Keywords: Population dynamics, Ghana, Red Pandora, Mortality, Growth, Exploitation rate.

INTRODUCTION

Pagellus bellottii (Steindachner, 1882), commonly known as ' Wiriwawa' in Ghana, belongs to the Family, Sparidae. Reportedly, these fish species feed on arthropods, mollusks, echinoderms, cephalopods, ophiuroids as well as annelids throughout the whole year (Fehri-Bedou & Hassaine, 2009; Rijavec, 1973). Though *Pagellus bellottii* inhabits all grounds regardless of the nature of the bottom, they serve as indicators of shallow depth ranging from 15m to 70m (Rijavec, 1973). Catches of these fish species among artisanal coastal fishers are relatively high within this depth range. They are often eurythermic, meaning adaptable to a wide range of temperatures. Mean size of *Pagellus bellottii* increases with depth, where small sized specimen (7-8cm) are mostly found within shallow waters (Skornyakov, 1963). Red pandora possess a discontinuous breeding nature due to the presence of two distinct ova representing mature and immature stocks (Asabere-Ameyaw, 2000). Their spawning activity within Ghanaian coastal waters is mostly restricted to a depth range of 37m–55m with the main spawning season in June. Considering seasonal migration, these fish species are reported to penetrate inshore up to 10 fathoms depth during the upwelling months. However, in February, May and October, they become restricted to the depth of 25- 30 fathoms because of the presence of both hydrographic stability and sharp thermocline (Rijavec, 1973). In Ghana, Red pandora forms part of the dominant demersal fish species targeted by coastal fishing operators, particularly artisanal fishermen. As such, Red pandora are harvested along the entire coast of Ghana with the highest catch mostly found in the Central region of Ghana (Figure 1). In terms of gears, the targeted gears for harvesting Sparidae including *Pagellus bellottii* include hooks and lines, Ali/Poli/ Watsa (APW) and bottom set nets. Generally, major catches of Red pandora are observed during the minor upwelling season spanning from December to January (Asabere-Ameyaw, 2000). However, the presence of intense fishing and high consumer demand for Sparids including *Pagellus bellottii* has resulted in a drastic decline in catches. For instance, catches of Red pandora in Ghana dropped drastically from

7000 tons in 2005 to 1000 tons in 2009. In spite of the socio-economic gains accrued from *Pagellus bellottii* fishery both at the national and regional stage, there appears to be inadequate information on fish stock assessment pertaining to the population structure and dynamics, exploitation status and resilience of this important commercial fish species within Ghana's coastal waters. Globally, fish assessment techniques have relied heavily on age-based models which have proven to be an effective method of assessment. However, in tropical fisheries mostly in developing coastal states like Ghana, age-based methods for fish stock assessment appears to be difficult hence the increased interest in length based fish assessment methods (Koranteng & Pitcher, 1987). Many studies have indicated that length based methods using length frequency analysis are more reliable and less subjective, thus making length frequency analysis in fish stock assessment an attractive alternative (Macdonald, 1987; Petersen, 1982; Harding, 1949). In this study, length based analytical methods are applied to estimate the various population parameters, stock status, and resilience category of *Pagellus bellottii*. Information gained from this study will facilitate sustainable management of *Pagellus bellottii* within Ghana's coastal fishing operations.

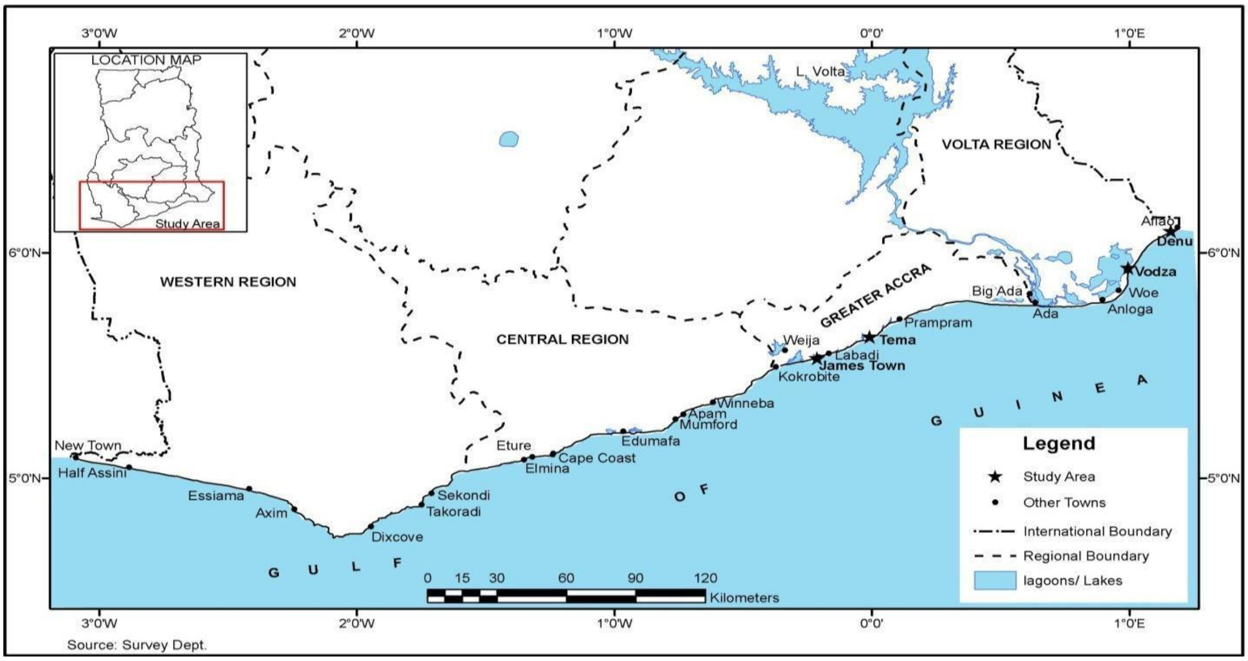

Figure 1: Map showing the sampling sites

MATERIALS AND METHODS

Study area

The coastline of Ghana measures 550 km from 3° 06' W to 1° 10' E and lies between latitudes 4° 30' and 6° 6' N (Koranteng & Mensah, 1992). This study focused on the eastern coastline of Ghana comprising of Volta and Greater Accra regions. For each coastal region, two fish landing sampling stations were selected, giving a total of four fish landing sampling stations. These fish landing sampling stations were Jamestown and Tema for Greater Accra Region and Vodzah and Denu for Volta Region (Figure 1). Denu, the capital of Ketu South Municipal, a district on the south-eastern corner of the Volta region is a coastal community located on coordinates 06 ° 06' 0" N, 01° 08' 52" E. Vodzah is located in Keta, Volta region of Ghana, geographically located on coordinates 5° 57' 0" N, 1° 0' 0" E. Tema is a city constructed on the site of a small fishing village with geographical coordinates as 5 ° 40' N, 0 ° 0' W and has the Greenwich Meridian passing directly through it whereas Jamestown, one of the oldest cities in Accra, Ghana is located on 5 ° 32' 1" N, 0 °12' 49" W. Tema and Jamestown fishing communities are home to various fishing methods including gill netting, purse seining, hooks, and line as well as drift gill netting by fishers from most coastal communities in Ghana. In all the four fish landing sampling stations, fishing and fishing related activities such as fish processing, fish trading, and fish marketing served as the main source of livelihood for the majority of the inhabitants. However, a minority of the indigenes indulge in alternative livelihoods such as trading, farming, driving and others.

Data collection

Samples of the targeted fish species were collected from fishers at the four fish landing sampling sites for eight months from June 2014 to January 2015, operating mostly with multifilament fishing gears. Preserved samples on ice in an ice chest were transported to the laboratory at the Department of Marine and Fisheries Sciences, University of Ghana. At the laboratory, samples were weighed to the nearest 0.01g using the electronic scale while the standard lengths were measured using the 100cm rule measuring board, to the nearest 0.1cm. Identification of fish samples was carried out to the species level using Fischer et al. (1981) as well as Kwei and Ofori-Adu (2005) identification keys. Overall, a total of 440 individuals of *Pagellus bellottii* were sampled.

METHODS

Growth parameters

Growth parameters including growth rate (K), asymptotic length (L_∞) and the growth performance index (ϕ) were obtained using the Von Bertanlaffy Growth Function (VBGF) fitted in FISAT II. The Powell-Wetherall Plot fitted in FISAT II was applied in estimating the Z/K ratio for the treated fish species (Pauly, 1984). The growth of individual fishes on the average towards the asymptotic length based on instantaneous growth rate (K) and length at any time (t) was identified using the Von Bertanlaffy Growth Function (VBGF): $L_t = L_\infty (1-e^{-k(t-t_0)})$ (Pauly, 1979). The theoretical age at birth (t_o) was estimated independently, using the equation: $\log_{10}(-t_0) = -0.3922 - 0.275 * \log_{10}L_\infty - 1.038 * \log_{10}K$ (Pauly, 1979). The longevity of individuals (tmax) was estimated using the expression: $t_{max} = 3/K + t_o$ (Pauly, 1983). The growth performance index was generated using the formula: (ϕ) $=2\log L_\infty + \log K$ (Munro & Pauly, 1983).

Modal Progression analysis

Bhattacharya's method (1967) fitted in FISAT II was used to split the age groups from the length frequency data (Gayanilo et al., 1995). This method was based on the function: ln (Ni+1) - ln (Ni) = aj + bj * Li, where: Ni and Ni+1 are successive frequencies of the same component of a group of fish in a sample (i.e., representing age group j) with Li representing the upper-class limit of Ni. As a result, the mean of the normal distribution was calculated as NL j = -aj/bj

Mortality parameters

Total annual instantaneous mortality rate (Z) was estimated using the Jones and Van Zalinge Plot (Sparre & Venema, 1992). Natural mortality rate (M) was computed using empirical equation of Pauly (1980) at a mean surface temperature (T) of 25.7°C: $\log_{10}M = -0.0066 - 0.279 * \log_{10}L_\infty + 0.6543 * \log_{10}K + 0.4634 * \log_{10}T$ (Pauly, 1980), where M is the instantaneous natural mortality, L_∞ is the asymptotic length, T is the mean surface temperature and K refers to the growth rate coefficient of the VBGF. Instantaneous fishing mortality (F) was estimated as F = Z – M (Beverton & Holt, 1957), where Z = instantaneous total mortality rate, F = instantaneous fishing mortality rate and M = the instantaneous natural mortality rate. The exploitation level (E) was obtained by the relationship of Gulland (1971): E = F/Z (Gulland, 1971). The maximum fishing effort (F_{max}) was estimated using the expression: F_{max} = 0.67K/0.67–Lc (Hoggarth et al., 2006), where $Lc=Lc_{50}/L_\infty$. The precautionary limit reference point (F_{limit}) was computed as F_{limit} = (2/3) * M (Patterson, 1992). The precautionary target reference point (F_{opt}) was calculated as F_{opt} = 0.4*M (Pauly, 1984).

Length at first maturity

The length at first maturity (Lm_{50}) for the assessed species was estimated using the procedure by Hoggarth et al. (2006) as Length at first maturity (Lm_{50}) = 2/3 * (L_∞). The input parameters for the model included asymptotic length only (L_∞). The age at first maturity (tm_{50}) was calculated using the age at length equation by Goonetileke & Sivasubramania (1987): $tm_{50} = -(1/K) \ln(1-Lm_{50}/L_\infty) + t_o$, where Lm_{50} is the length at first maturity.

Probability of Capture

The probability of capture was estimated using the procedure outlined in the FISAT II tool (Gayanilo et al., 2005). By plotting the cumulative probability of capture against mid-length, a resultant curve was obtained, from which the length at first capture (Lc_{50}) was taken as corresponding to the cumulative probability at 50%. Additionally, the lengths at which 25% and 75% of the stock is captured were taken as corresponding to the cumulative probability at 25% and 75% respectively. The age at first capture (tc_{50}) was estimated as $tc_{50} = -(1/K) \ln(1-Lc_{50}/L_\infty) + t_o$ (Beverton & Holt, 1957).

Recruitment pattern

The recruitment pattern was obtained following the procedure described in the FiSAT routine (Gayanilo et al., 2005). The length at first recruitment (Lr_{50}) was estimated as the midlength of the smallest length interval (Gheshlaghi et al., 1986). The age at first recruitment (tr_{50}) was estimated as $tr_{50} = -(1/K) \ln(1-Lr_{50}/L_\infty) + t_o$ (Beverton & Holt, 1957).

Virtual Population Analysis (VPA)

The estimated length structured VPA was carried out using the FiSAT routine (Gayanilo et al., 2005). The values of the L_∞, K, M, F, a (constant) and b (exponent) for the species were used as inputs. The t_0 value was approximated to be zero. The constants a and b (exponent) for the species were estimated from the length-weight relationship using the expression $W= aL^b$, where W is the body weight and Length is the corresponding standard length (Pauly, 1984). The length-based VPA was used to calculate the biomass (tons), the yield (tons), total and fishing mortality and exploitation ratios following the procedure by Jones (1984). The maximum sustainable yield (MSY) was calculated following the equation by Sparre and Venema (1998): MSY = 0.5 * (Y +MB), 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. The annual yield (Y) was estimated using the expression: $Y = \sum [W(L_1, L_2) * C(L_1, L_2)]$, where W is weight and C is the catch.

Relative yield per recruit (Y/R) and relative biomass per recruit (B/R)

Relative yield per recruit (Y/R) and relative biomass per recruit (B/R) values as a function of E were determined from the estimated growth parameters and the probability of capture by length (Pauly and Soriano 1986). As a result, 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 under which the stock is reduced to half of its virgin biomass were computed using the Knife-edge option incorporated in the FiSAT II Tool.

Yield Isopleth

Yield contours which characterize yield isopleth were plotted to identify the impact on yield based due to changes in exploitation rate (E_{max}) and critical which is length at first capture (Lc_{50}) to asymptotic length (L_∞) ratio (Lc_{50}/L_∞), using the FiSAT II Tool (Gayanilo et al., 2005).

Data Analysis

The length frequency data was pooled into groups with 1cm length interval. The resultant data was analyzed using the FiSAT II (FAO-ICLARM Stock Assessment Tools) software as explained in detailed by Gayanilo et al. (2005). The length at age graph was carried out using the Yield Software by Branch et al. (2000).

RESULTS

Growth parameters

The modified Wetherall plot gave a preliminary estimate of Z/K as 2.51 (Figure 2A). The maximum age (t_{max}) for *Pagellus bellottii* was 7 years with the theoretical age at birth (t_0) as – 0.44 (Figure 2B).

Figure 3 shows the restructured Length frequency data superimposed with the estimated growth curve. The reconstructed length frequency superimposed with growth curve portrayed 4 cohorts (Figure 3). The growth performance index (ϕ) of 2.20 was estimated. From ELEFAN I routines, the estimates of growth parameters obtained were L_∞ =19.43cm standard length, K = 0.42 per year, using data of 1 cm class intervals. Therefore, the VBGF for *Pagellus bellottii* was defined as:

$L_t = 19.43\ (1 - e^{-0.42\ (t- (-0.44))})$.

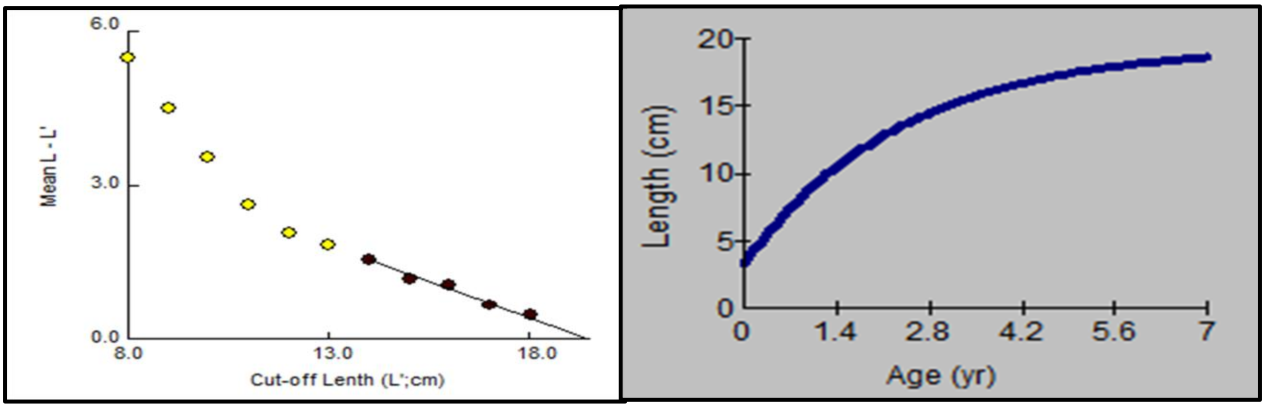

Figure 2: A) Powell-Wetherall plot for Z/K ratio; B) Length at age plot

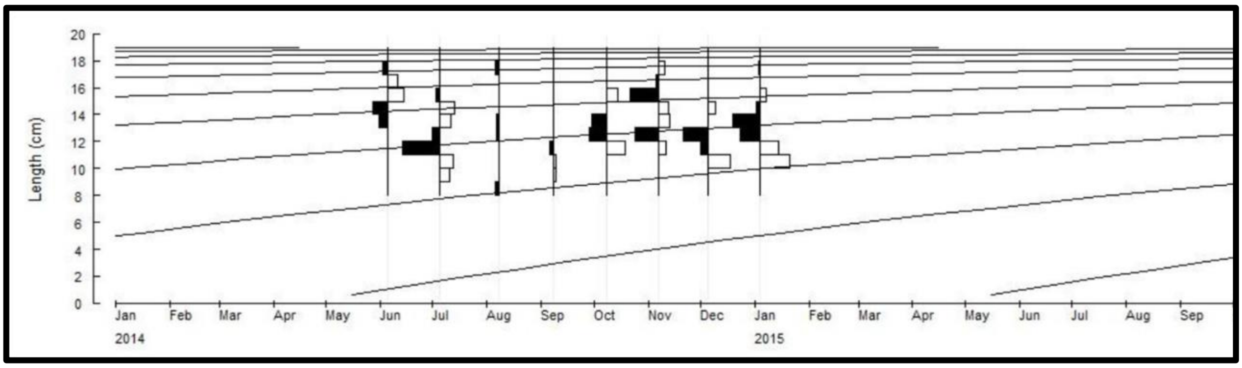

Figure 3: Restructured length-frequency data of *Pagellus bellottii* superimposed with the estimated growth curve

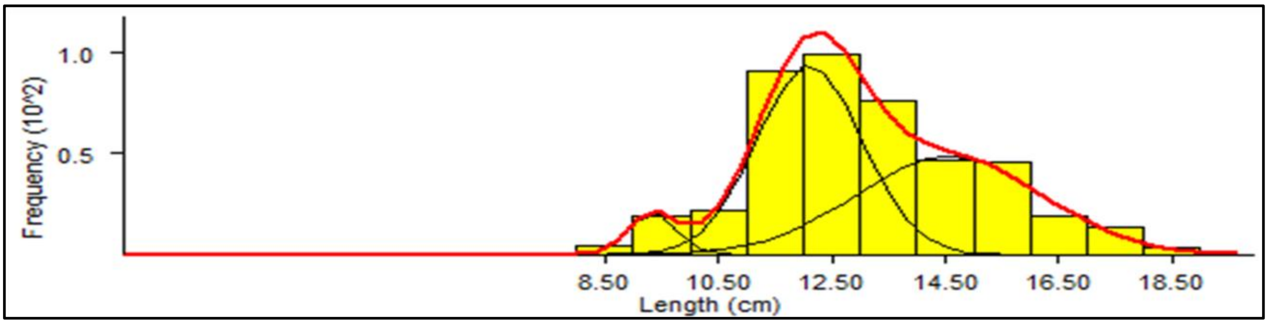

Figure 4: Modal length classes for *Pagellus bellottii* using the Bhattacharya option in FISAT Tool

Table 1: Separation of length frequency using NORSPERM method

Computed Mean	S.D.	Population	S.I.
9.3	0.415	21.2	n.a.
12.1	0.928	218.4	4
14.6	1.638	199.4	2

Modal Progression analysis

Using the Bhattacharya option for the modal progression analysis, three modal length classes were identified. These modal length classes for the assessed fish species were 9.3cm, 12.1cm and 14.6cm with a separation index greater or equal to 2 (Figure 4). From Table 1, the three identified modal lengths of 9.3cm, 12.1cm and 14.6cm recorded population (from the catch) size of 21, 218 and 199 respectively with samples of mean size 12.1cm forming majority of the catch.

Mortality Coefficients and Current Exploitation Ratio

Using the Jones and van Zalinge plot (Figure 5), the total mortality coefficient (Z) was estimated as Z = 2.58 per year. Natural mortality co-efficient (M) was 1.10 per year. Fishing mortality (F), current exploitation rate ($E_{current}$), maximum fishing effort (F_{max}), limiting fishing effort (F_{limit}) and optimum fishing effort (F_{opt}) were estimated as 1.48 per year, 0.57, 1.75 per year, 0.73 per year and 0.44 per year respectively.

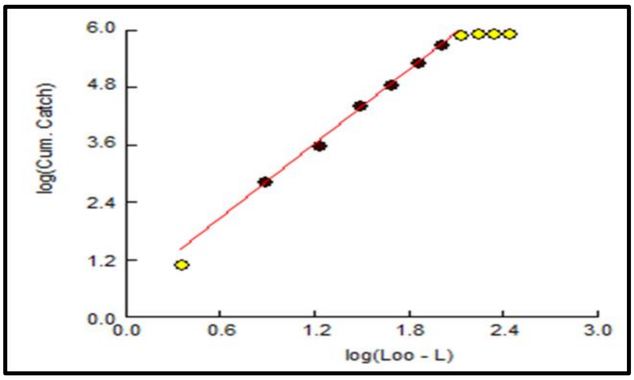

Figure 5: Estimation of Total mortality using Jones and van Zalinge plot from FiSAT Output

Length at first capture (L_{c50}) and maturity (L_{m50})

The selection length of L_{25} (25%) was 8.63cm, L_{50} (50%) was 9.91cm and L_{75} (75%) was 11.16cm (Figure 6). Therefore, the length at first capture (Lc_{50}) was calculated as 9.91cm. The length at first maturity (Lm_{50}) was estimated as 13 cm. The age at first maturity (tm_{50}) and first capture (tc_{50}) were estimated 2.2 years and 1.3 years respectively.

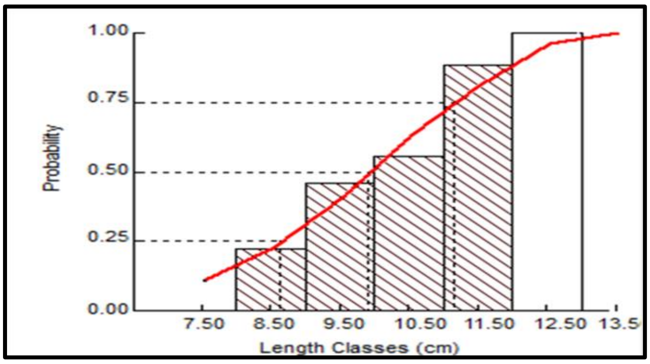

Figure 6: Probability of capture estimation from FiSAT Output

Recruitment pattern

The recruitment pattern of the FISAT II tool outlined a two-recruitment pulse with the minor pulse in April and the major pulse in July (Figure 7), using the estimated theoretical age (t_o = -0.44). The major pulse recorded 21.45% recruitment while the minor pulse recorded 13.20 %. The length at first recruitment (Lr_{50}) was estimated as 8.5cm while the age at first recruitment (tr_{50}) was calculated as 0.9 years.

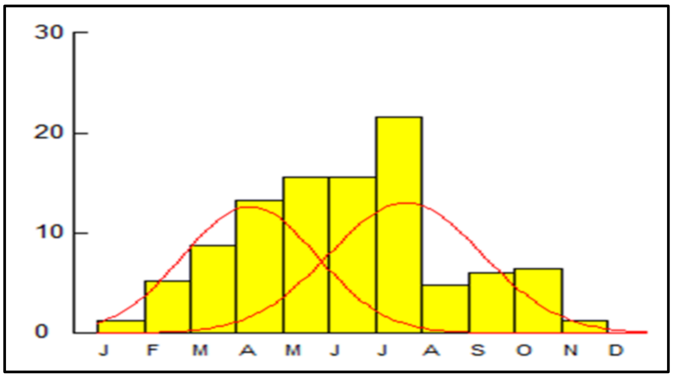

Figure 7: Recruitment pattern for *Pagellus bellottii* from FiSAT Output

Virtual population analysis (VPA)

VPA results revealed that majority of *Pagellus bellottii* were harvested between 11cm and 13cm with values of fishing mortality (F) exceeding 0.33 per year (Table 2). The highest peak of fishing mortality (F = 1.48 per year) occurred in the length range between 16cm and 17cm. Increasing fishing mortality (F) resulted in decreasing populations of *Pagellus bellottii* (Figure 8). The values of 'a' and 'b' constants from the Length-weight relationship were estimated as 0.032 and 2.979 respectively. The terminal fishing mortality (Ft) was 2.20 per year.

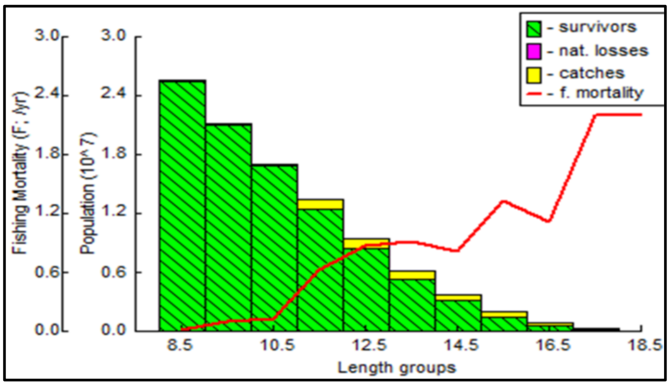

Figure 8: Population estimation using VPA from FiSAT output

Maximum sustainable yield (MSY)

The estimated total biomass and total yield were 7079.25tons and tons respectively. The mean body weight was calculated at 0.0762. The Maximum Sustainable Yield (MSY) using the length frequency distribution of *Pagellus bellottii* was estimated at 7864.18 tons (Table 3).

Table 2: Survivors and catches of *Pagellus bellottii* from VPA out in FISAT II

Mid-Length	Catch (in numbers)	Population (N)	Fishing mortality (F)	Steady-state Biomass (tonnes)
8.5	400000.00	404137280.00	0.01	1475.93
9.5	1900000.00	317619168.00	0.03	1752.15
10.5	2200000.00	242268784.00	0.04	1970.26
11.5	9100000.00	178738176.00	0.20	2058.97
12.5	9900000.00	120742752.00	0.30	1957.54
13.5	7600000.00	74570216.00	0.33	1702.32
14.5	4700000.00	41884032.00	0.32	1354.87
15.5	4600000.00	21043436.00	0.57	905.45
16.5	1900000.00	7599092.00	0.56	462.34
17.5	1300003.00	1950004.50	2.20	262.42

Table 3: Estimates of the total biomass (tons), the yield (tons) and the MSY (tons) for *Pagellus bellottii*

Mid-Length	Catch	XL1,L2	N	E	F	Z	Biomass/kg	Body weight/kg	Yield
8.5	400000.00	1.13	404137280.00	0.005	0.01	1.10	1694117.65	0.0188	7515.35
9.5	1900000.00	1.14	317619168.00	0.025	0.03	1.13	1440000.00	0.0262	49721.27
10.5	2200000.00	1.16	242268784.00	0.035	0.04	1.14	1203037.97	0.0353	77570.32
11.5	9100000.00	1.18	178738176.00	0.157	0.20	1.30	960234.49	0.0462	420736.55
12.5	9900000.00	1.21	120742752.00	0.214	0.30	1.40	712325.12	0.0593	586786.48
13.5	7600000.00	1.25	74570216.00	0.233	0.33	1.43	492529.25	0.0745	566536.46
14.5	4700000.00	1.31	41884032.00	0.226	0.32	1.42	316952.86	0.0922	433474.06
15.5	4600000.00	1.40	21043436.00	0.342	0.57	1.67	173675.93	0.1125	517494.74
16.5	1900000.00	1.57	7599092.00	0.336	0.56	1.66	73614.35	0.1355	257506.53
17.5	1300003.00	2.00	1950004.50	0.667	2.20	3.30	12763.67	0.1615	209944.59
							7079.25 tons	**0.0762**	**3127.29 tons**
MSY	7864.18 tons								

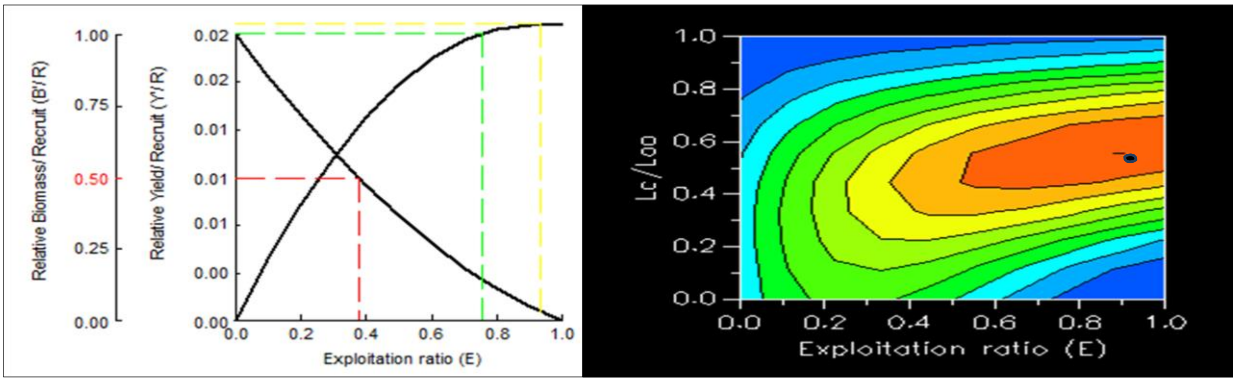

Figure 9: A) Relative yield and relative biomass per recruit (B'/R); B) Yield Isopleth per recruit (Y'/R)

Relative Yield per Recruit (Y'/R) and Relative Biomass per Recruit (B'/R)

Estimates of (Y'/R) and (B'/R) in Figure 9A, using the Knife-edge option in FISAT tool II were $E_{0.1}$ = 0.75, $E_{0.5}$ = 0.38 and E_{max} = 0.93. The optimum exploitation rate (E_{max} = 0.93) is indicated by the broken yellow line. The results indicated that, $E_{current}$ (0.57) was lower than E_{max} (0.93).

Yield isopleths

The yield isopleths are shown in Figure 9B, the yield contours predict the response of relative yield-per-recruit of the fish to changes in Lc and E_{max}; where Lc = 0.51 and E_{max} = 0.93.

DISCUSSION

The calculated asymptotic length (L_∞) was relatively lower than estimates from other studies as shown in Table 4. The variance in findings could also be due to the difference in the size of the largest fish individual sampled, period of sampling, the depth distribution of the stock, computational methods and other environmental factors (Pajuelo & Lorenzo, 1998; Rijavec, 1973). Though the growth rate (K) compared favorably with Rijavec (1973) as shown in Table 4, it was higher than the range (0.12–0.38 per year) documented by JICA (2003). The observed increased in growth rate (K) could be a response to the intense fishing pressure on the stock to avert extinction of its species (Amponsah et al., 2016a). However, the computed growth rate (K = 0.42 per year) was within the range 0.33-0.67 per year considered for intermediate fish growing species (Kienzle, 2005). Thus, *Pagellus bellottii* is considered as an intermediate fish growing species. The calculated growth performance index (ϕ = 2.20) was outside the range (2.65–3.32) designated for fish species with fast growing performance, indicating that *Pagellus bellottii* has a slow growth performance (Baijot et al., 1997; Montchowui et al., 2011). The estimated M/K ratio was found to be 2.62, showing that *Pagellus bellottii* is an r-configuration or generalist species. This observation was in line with finding by Pauly (1989) who reported that low M/K ratios (< 1) are unlikely of tropical fishes and precludes a K – configuration or specialist species.

Table 4: Comparison of growth parameters for *Pagellus bellottii* with estimates from other studies

Authors	Location	L_∞ (cm)	K/yr^{-1}	ϕ
Phan & Kompowski (1972)	Senegal	39.37	0.18	*
	Western Sahara	40.17	0.19	*
Rijavec (1973)	Ghana	30.76	0.44	*
Tomlinson & Abramson (1981)	Senegal	37.16	0.02	*
Franqueville (1983)	Senegal	37.18	0.24	*
Koranteng & Pitcher (1987)	Ghana	25.7-28.6	0.23-0.38	*
Asabere & Blay (1999)	Ghana	34.2 TL	0.53	*
Yarba et al (2004)	Mauritania	28.96	0.31	*
This study	Ghana	19.43	0.42	2.20

Length at first capture (Lc_{50}) by previous researchers (Table 5) was were greater than estimated from the present study. The differences in estimates could be linked to the mesh size of fishing gears used, the sex of harvested catch, environmental conditions, and the computation procedure applied. The calculated length at first capture (Lc_{50} = 9.9cm) was found to be lower than the minimum landing size of 14 cm (Ghana Fisheries Regulation, 2010), revealing that the stock may be under-protected by Ghana's Fishing regulations (2010). Estimated Lc_{50}/L_{∞} ratio from the study was 0.51, indicating that majority of the harvested catch was of relatively large sized individuals (> 10cm), although lower than legal minimum landing size of 14 cm (Pauly & Soriano, 1986). This finding is supported by the fact that the major modal mean length with the highest harvesting rate (50%) observed from the Bhattacharya analysis (Figure 4) was 12.1 cm which is less than the legal minimum landing size (Table 1). Further, with only two mean length groups (9.3cm & 12.1cm) representing more than 50% of the total exploitable population of *Pagellus bellottii*, the presence of overfishing can quickly deplete the stocks if necessary regulations are not put in place. The calculated length at first maturity (Lm_{50} = 13cm) was higher than the corresponding length at first capture (Lc_{50} = 9.9cm) suggesting the likelihood of growth overfishing within the population of *Pagellus bellottii* (Amponsah et al., 2016c). Evidently, the VPA output revealed that small-sized fishes (< 10cm) experienced relatively greater harvesting rate (Table 2). Such situation is indicative of growth overfishing, where small sized fishes are captured before adding to the biomass of the stock. Though, the computed length at first maturity (Lm_{50}) compared favorably with Rijavec (1973), it was below the estimates by Koranteng & Pitcher (1987) and Asabere-Ameyaw (2000) in Table 5. The observed reduction in length at first maturity (Lm_{50}) over time could be the reaction of the *Pagellus bellottii* stock to the possible occurring intense fishing pressure. More so, the ratio of length at first maturity to asymptotic length ($Lm: L_{\infty}$= 0.67), otherwise known as the reproduction load revealed that *Pagellus bellottii* becomes matured when it attains 67% of its asymptotic length (King & Etim, 2003). Again, with the reproduction load ratio less than 1, it implies that *Pagellus bellottii* invests more energy in growth than reproduction. Investing more energy into growth by *Pagellus bellottii* could be a surviving strategy against natural mortality situations.

Table 5: Comparison of derived population parameters for *Pagellus bellottii* with estimates from other studies

Authors	Location	Lc_{50} (cm)	Lm_{50} (cm)	Lr_{50}/ cm	tc_{50}/ years	tm_{50}/ years	tr_{50}/ years	t_{max}/ years	to
Phan & Kompowski (1972)	Senegal	*	*	*	*	*	*	*	-0.81
	Western Sahara	*	*	*	*	*	*	*	-0.63
Rijavec (1973)	Ghana	*	13.06	5	*	*	*	6-7	0.00
		*	12.22	*	*	*	*		
Franqueville (1983)	Senegal								-0.11
Koranteng & Pitcher (1987)	Ghana	16.1	19.5	8	2	2	1.5	6	0.59
		15.6	18.9						-1.45
Asabere-Ameyaw (2000)	Ghana	*	20	*	*	1.5	*	*	*
		*	21	*	*	1.3	*	*	*
Yarba et al (2004)	Mauritania	*	*	*	*	*	*	*	0.008
This study	Ghana	9.91	13	8.5	1.3	2.2	0.9	7	-0.44

Though the estimated age at first maturity (tm_{50}) agreed with Koranteng and Pitcher (1987), it was higher than estimated by Asabere-Ameyaw (2000) in Table 5. Such difference could be directed to computational procedure, period and frequency of sampling, environmental conditions and the genetic makeup of *Pagellus bellottii*. The estimated age at first maturity (tm_{50}) of 2.2 years suggested that *Pagellus bellottii* first becomes matured during their transition into the third year. Etim and Brey (1994) highlighted that when age at first maturity (tm_{50}) becomes greater than 1 year, the present state of exploitation will cause a severe collapse of the stock in future, especially if recruitment failure occurs. The calculated age at first maturity (tm_{50}) of the population was greater than 1 year which implies that effective regulations pertaining to level of fishing pressure are urgently required if collapse of the stock is to be averted. From Table 5, the age at first capture (tc_{50}) was lower than estimated by Koranteng and Pitcher (1987). Increased in fishing effort and constant application of small mesh-sized fishing gears mostly truncates the age at first capture (tc_{50}). The computed age at first capture (tc_{50}) of 1.3 years indicated that majority of the stock moving into their second year become vulnerable to capture by any fishing gears after their birth. The age at first recruitment (tr_{50}) of 0.9 years in population implied that newly produced *Pagellus bellottii* get recruitment into the stock before age 1. Meanwhile from Table 5, Koranteng and Pitcher (1987) recorded higher age at first recruitment (tr_{50}) than estimated from the present study. This observation could be due to reduced age at which fish are captured, possibly as a response to replenish the stock at a faster rate and to avoid extinction.

Pagellus bellottii showed two recruitment peaks which was in line with the assertion by Pauly (1984) that tropical species mostly portray two recruitment peaks. Report by JICA (2003) indicated that the median month of spawning for *Pagellus bellottii* is July. Having estimated the age at birth (t_0) to be -0.44 from the present study, the month with the highest recruitment percent by macro inspection was July, thus supporting the finding by JICA (2003). The recruitment pattern outlined in the study portrayed the presence of recruits throughout the months, thus showing that recruitment was all year round (Enin, 1995). Buttressing this observation was the overlapping nature of the recruitment pattern which also suggested a continuous recruitment (Etim et al., 1996). The computed length at first recruitment (Lr_{50}=8.5cm) was lower than the length at first capture (Lc_{50}=9.9cm), depicting that recruitment in *Pagellus bellottii* fishery is currently active since juveniles get recruited into the stock before been harvested (Amponsah et al., 2016b). Evidently, the outcome of the virtual population analysis (VPA) showed that majority of individuals at the length of first recruitment (Lr_{50} = 8.5 cm) became survivors (Figure 8), strengthening the assertion that recruitment within the fishery of *Pagellus bellottii* in the coastal waters of Ghana is functional.

Barry & Tegner (1989) documented that a Z/K ratio < 1 indicates that the population is growth dominated whereas a Z/K ratio > 1 is an indication that the population is mortality dominated. However, when the Z/K ratio = 1, then the growth and mortality of the population are in equilibrium. From the present study, the calculated Z/K ratio (Z/K = 2.51) was greater than 1 (Figure 1A), suggesting that the stock is mortality dominated. King & Etim (2004) highlighted that for a mortality dominated stock, Z/K ratio ≈ 2 denotes a lightly-exploited stock. Nonetheless, estimated Z/K ratio from the present study was slightly greater than 2 suggesting that *Pagellus bellottii* stock within Ghana's coastal waters is a lightly exploited population. Though the estimated limiting fishing mortality rate (F_{limit}) and optimum fishing mortality (F_{opt}) were lower than the fishing mortality rate (F), the maximum fishing rate (F_{max}) was greater than the computed fishing mortality (F). This observation supports the fact that *Pagellus bellottii* is lightly exploited. Compared to fishing mortality estimate by Koranteng and Pitcher (1987) in Table 6, the relatively high fishing mortality rate from the study signified increasing fishing effort evidenced by increased fishermen and geographical reach by fishermen in Ghana. Fishing mortality (F= 1.48 per year) was higher than natural mortality (M = 1.10 per year), accounting for 57% of the total mortality, thus indicating that the population is fishing mortality dominated. Asabere-Ameyaw & Blay (1999) observed a similar situation where the fishing mortality was higher than the natural mortality (Table 6). This observation portrayed that *Pagellus bellottii* could be less vulnerable to natural mortality related conditions. Natural mortality rate (M) computed from the study was higher than estimated by some researchers (Table 6) with the exception of Asabere-Ameyaw (1999) to which its compared favorably. Potential causes for the observed high natural mortality rate include increased temperature, high intensity of natural predators and climate variation induced decline in zoo-benthos which supports the productivity of the marine ecosystem. Pauly (1989) reported that fishes occurring in higher temperature regions have greater chances of encountering hungry predators who need to feed more to satisfy their high metabolic needs.

Table 6: Comparison of mortality parameters for *Pagellus bellottii* with estimates from other studies

Authors	Location	Z/K	M/ year	F/ year	Z/year	E
Taylor 1959	Senegal	*	0.24	*	*	*
Phan & Kompowski (1973)	Senegal	*	1.58	*	*	*
Franqueville 1983	Senegal	*	0.1 – 0.4	*	*	*
Koranteng & Pitcher (1987)	Ghana	*	0.38	0.25	0.58	*
			0.23	0.4	0.23	*
Caveriviere & Thiam (1993)	Senegal	*	0.51	2.09	2.60	0.8
Asabere-Ameyaw & Blay (1999)	Ghana	*	1.12	2.61	3.74	0.7
This study	Ghana	2.52	1.10	1.48	2.58	0.57

Estimated exploitation level ($E_{current}$=0.57) was below the estimates from other studies (Table 6), possibly due to the low estimates of fishing and total mortality. The variation in mortality coefficients maybe due to computational procedures. Additionally, the estimated exploitation ratio ($E_{current}$) of 0.57 depicted that the stock is in an unhealthy state, thus strengthening the assertion that the stock is unsustainably exploited both in terms of yield per recruit and biomass per recruit, though not intense (Enin, 1995). This is supported by the fact that the exploitation ($E_{current}$ = 0.57) is relatively lower than the exploitation level for maximum yield (E_{max}) = 0.93. The estimated Maximum Sustainable Yield (7864.18 tons) was relatively higher than the annual catch for 2014 from the artisanal (576.34 tons) and industrial fishing sector (3322.59 tons) in Ghana. Fish landings relatively lower than the MSY indicates that the stock is not prone to threats from recruitment overfishing. Concerning the stock status, the relationship between the E_{max}=0.93 and Lc_{50}/L_{∞}=0.51 placed the stock of *Pagellus bellottii* in quadrant C (Pauly & Soriano, 1986). This suggested that *Pagellus bellottii* is currently at the developed stage with its fishing regime as catching large sized fishes at greater fishing effort level. Further, Pauly (1989) indicated that at such stage of fishing, any attempts of maximizing yield per recruits will lead to low stock biomass and potential recruitment failures. Therefore, measures geared towards regulating fishing pressure such as reducing fishing effort, geographical reach and mesh size regulations should be implemented and enforced. Meanwhile, with longevity (t_{max}) and age at first maturity (tm_{50}) within 4–10 years and in the 2–4 years respectively, the resilience of *Pagellus bellottii* to fishing pressure fell in the medium category. This suggests that the minimum population doubling time for *Pagellus bellottii* is within 1.4–14 years. Having resilience within the medium category, it is projected that the recovery of the *Pagellus bellottii* will be rapid, hence predicted the incidence of overfishing should be mainly of economical and less of biological consequences (Rijavec, 1973).

CONCLUSION

The results revealed that *Pagellus bellottii* possess fairly fast growth rate (K = 0.42 per year), small maximum size (L_{∞}=19.43cm), short lifespan (t_{max}=7 years), early sexual maturity (tm_{50}=2.2), year-round recruitment pattern and high natural mortality to asymptotic length ratio (M/K > 1); these are all r-configuration or generalist traits. In relation to the estimated maximum fishing mortality (F_{max}) and the exploitation ratio ($E_{current}$), the *Pagellus bellottii* population is lightly exploited, though its stock is fishing mortality dominated. However, the comparatively lower length at first capture in relation to the length at first maturity exposed the existence of growth overfishing within the *Pagellus bellottii* population. Meanwhile, the strong presence of recruits evinced by the VPA as well as relatively lower age at first recruitment (tr_{50}) compared to the age at first capture (tc_{50}) showed the absence of recruitment dysfunctional. The fishery of *Pagellus bellottii* fell within the developed, as such any increase in fishing effort to maximize yield per recruit will breakdown the fishery.

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