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Growth, Mortality and Exploitation Rates of *Sarotherodon melanotheron* in the Dominli Lagoon of Ghana

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ABSTRACT

Sarotherodon melanotheron population of Dominli Lagoon in the Western Region of Ghana was studied for its growth and mortality parameters as well as exploitation rate. The study generally aimed at providing basic information necessary for the assessment and management of the fish stock in the lagoon. Using FiSAT programme, estimates of the prominent growth and mortality parameters of *S. melanotheron* were: L_∞ = 20.48 cm, SL and K = 0.97yr^{-1}. Total, natural and fishing mortalities of the population were determined as 3.86 y^{-1}, 2.02 y^{-1} and 1.84 y^{-1}, respectively. The growth estimates and the maturity-length ratio (≈ 0.7) suggested that the *S. melanotheron* population was not stunted. The fast growth rate and continuous recruitment exhibited by *S. melanotheron* were indicative of its suitability for culture. The present exploitation rate (0.48) indicates that the black-chinned population is not overexploited. The Y′/R and B′/R curves as well as all-year-round recruitment show that the current exploitation rate could be maintained for sustainable and rational exploitation of the black-chinned tilapia stock.

Keywords: Exploitation rate, Maturity-length ratio, Asymptotic length, Biomass-per-recruit, Over exploitation.

1. INTRODUCTION

Excessive level of fishing and its attendant damaged aquatic ecosystems mostly implicate in poor condition of fish stocks (Wootton, 1998). Thus, the numerical composition of mature fish may be reduced to a level where reproduction and recruitment seldom replace losses culminating in decreased fish stocks. According to CRC/FON (2011), the finfish fishery of the Dominli Lagoon is dominated by *Sarotherodon melanotheron*. These fish are constantly exploited by fishermen in the area throughout the year without any regulations. This situation could adversely plunge the fish stocks in the lagoon into poor fishery conditions.

Knowledge of growth and mortality parameters of fish stocks is one of the key contributors to identification and implementation of fisheries management policies for sustainable fishery. Currently, few reports have been documented on *S. melanotheron* populations with respect to their growth and mortality characteristics. The maximum lengths of the species in some coastal water bodies of Ghana have been reported: Sakumo Lagoon (Pauly, 1976), Fosu Lagoon (Blay and Asabere-Ameyaw, 1993), Benya Lagoon and Kakum River Estuary with their stocks described as stunted, short-lived and overexploited (Blay, 1998). *S. melanotheron* populations in different water bodies are known to grow at varied growth rates (Iles, 1970; Blay, 1998).

Although some efforts have been made to assess the growth, mortality as well as exploitation rates of *S. melanotheron* in the Ghanaian brackish water bodies, information on the population parameters of this species in the Dominli Lagoon is presently scarce. Against this background, this study sought to assess the population characteristics of *S. melanotheron* in the lagoon so as to provide basis for stock assessment of the Dominli Lagoon fishery as well as information for proper management of the fishery.

2. MATERIALS AND METHODS

2.1. Study Area

The study was conducted in the Dominli Lagoon located at Bonyere in the Jomoro District, Western Region of Ghana. The geographical location of the lagoon is between latitudes 5° 1´, 5° 2´ N and longitudes 2° 44´, 2° 47´ W with an area of 465,724.14 m^2 (Fig 1). The lagoon is endowed with valuable aquatic resources such as fish, reptiles, crabs, molluscs, mangroves and crude oil.

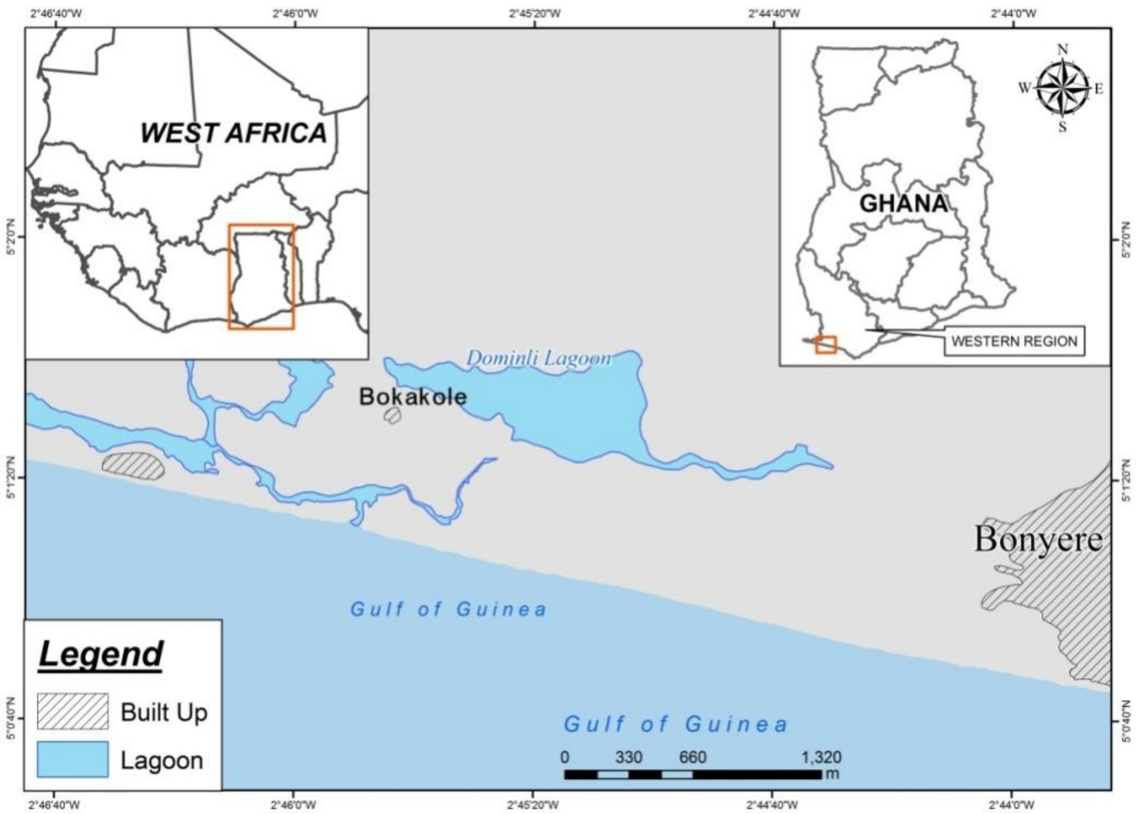

Figure 1. Map of Ghana showing the study area, Dominli Lagoon.

It is one of the most important coastal lagoons in the Western Region of Ghana providing critical goods and services including provision of fish products and water for domestic purposes to the surrounding communities such as Bonyere, Old Kabenla Suazo, Bokakole and Egbazo (Yankson and Obodai, 1999; Aggrey-Fynn et al., 2011). It also provides important habitats for commercially important species. All year-round fishing activities occur in the lagoon. Fishing gears used in the lagoon are mainly cast nets and funnel-shaped-entrance fish traps made of wire mesh.

2.2. Collection of Fish Samples

Monthly fish samples were collected from the local fishermen who set their fish traps in the lagoon and harvested their catches the next morning. The samplings took place within a period of 12 months (October, 2011- September, 2012) during which monthly trips were made to the study area for data collection. Fish samples obtained from the fishing operation were kept in an ice chest containing ice cubes and transported to the laboratory for analysis. The specimens were sorted and identified to the species level using manuals such as Dankwa et al. (1999) and Paugy et al. (2003a, b). Each specimen was counted and measured for its standard length (SL) and total length (TL) to the nearest 0.1 cm by using a fish measuring board. The fish specimens were individually weighed to the nearest 0.01g using an electronic weighing balance model FEL-500S.

Length-frequency distribution and length-weight relationship were generated for the fish. A linear regression analysis was used to establish the relationship between weight and standard length of the specimens using the equation:

$W = aSL^b$ (Blay, 1998) (1)

Where, W = weight of fish specimen (in grammes), SL = standard length of fish (in cm), a = growth constant; and b = exponent of the equation.

2.3. Determination of Mean Length at First Sexual Maturity, L_m

The mean length of the fish at first sexual maturity (L_m) defined as the length at which 50 % of all individuals were sexually matured (Pitt, 1970) was assessed for the females only. Four stages of gonad maturation were determined for the female specimens using histological procedures described by Witte and Van Densen (1995). Based on these gonadal maturity stages, individuals with gonads staged as III or IV (Arizi et al., 2014) were considered sexually matured. The length at which 50 % of the individuals were mature was estimated using cumulative length-frequency plot fitted with logistic regression curve (Sendecor, 1956; Sparre and Venema, 1992).

2.4. Mortality and Growth Parameters

The Electronic Length Frequency Analysis (ELEFAN) computer programme incorporated into FAO-ICLARM Stock Assessment Tool (FiSAT) was used to estimate population parameters (mainly growth parameters, mortality and exploitation rates).The growth of *S. melanotheron* was determined using the von Bertanlanffy growth function (vBGF) given below:

$L_t = L_\infty [1-e^{-K (t-to)}]$ (Sparre and Venema, 1992) (2)

Where, L_t = length (cm) at age, t; L_∞ = asymptotic length (cm); K = growth constant (yr^{-1}); t_o= theoretical age at length zero.

The estimates of $L\infty$ and K were obtained using ELEFAN in the FiSAT software (Gayanilo and Pauly, 1997), while t_0 was estimated using:

$Log(-t_o) = -0.392-0.275LogL_\infty -1.038LogK$ (Pauly, 1979) (3)

Using FiSAT programme, the total mortality coefficient (Z) was estimated by linearized length-converted catch curve analysis (Sparre and Venema, 1992). Natural mortality of the fish stock in the lagoon was estimated using:

$Log M = -0.0066-0.279 LogL\infty + 0.6543LogK + 0.4634LogT$ (Pauly, 1980) (4)

Where, M = natural mortality and T (^0C) = annual mean water temperature

The fishing mortality (F) describing the rate of mortality due to fishing activities was estimated from the relationship:

$Z = F + M$ (Ricker, 1975) (5)

The exploitation rate (E) was calculated from the equation:

$E = F/Z$ (Ricker, 1975) (6)

The longevity or natural life span (t_{max}) of the stock was estimated from the equation:

$t_{max} = 3/K$ (Pauly,1984) (7)

Where, K = von Bertalanffy growth co-efficient.

The mean length at first capture (L_{50}) defined as the length at which 50 % of the fish were entering the gear was determined using FiSAT. In addition, the selection factor (SF) of the species using catch data was estimated from the relationship:

$SF= L_{50}$ / Mesh size (Pauly, 1984) (8)

The ratio L_{50}/SF representing an estimate of appropriate mesh size for catching the species was calculated (Gulland and Holt, 1959). Beverton and Holt Y′/R model with selection ogive-opted routine incorporated into FiSAT programme was used to analyse the relative yield-per-recruit (Y′/R) and relative biomass-per-recruit (B′/Y) of the fish stock in the lagoon.

3. RESULTS

3.1. Length-Frequency Distribution and Length-Weight Relationship

The size distribution of *S. melanotheron* caught from the lagoon during the study period indicated that, of 1046 specimens of *S. melanotheron* sampled from the Dominli Lagoon, the standard lengths ranged from 7.9 to 19.8 cm. The overall length-frequency distribution showed a modal length class of 10.0 – 10.9 cm indicating a unimodal distribution of *S. melanotheron* exploited in the Dominli Lagoon (Fig 2).

The relationship between body weight and standard length of *S. melanotheron* was established with the use of scatter plots. The length-weight relationship of the *S. melanotheron* population was described by the equation: $BW = 0.0814\ SL^{2.6869}$ ($r = 0.96$), where BW = body weight in grammes and SL = standard length in centimetres (Fig 3). The power of the equation ($b = 2.69$) was significantly different ($p < 0.05$; $t = 110.3$) from the hypothetical value (3). However, the regression coefficient (r) of the equation (0.96) indicated that there was a strong positive correlation ($p < 0.05$) between weight and length of the *S. melanotheron* population in the lagoon.

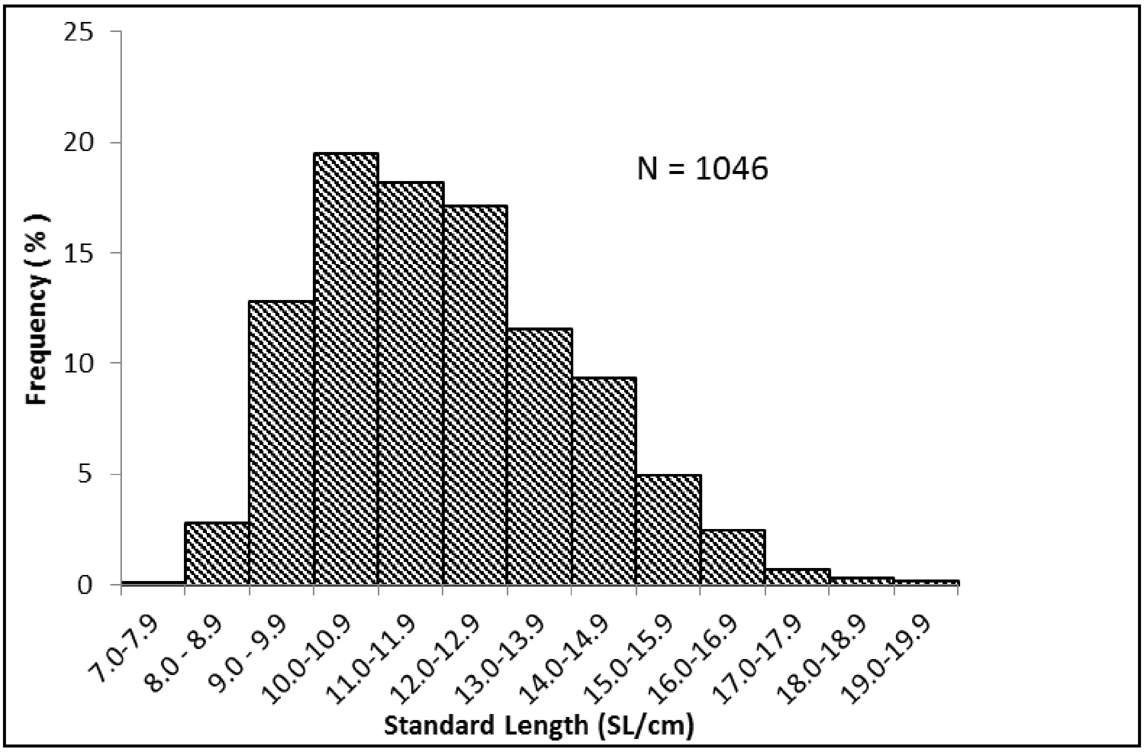

Figure 2. Length-frequency distribution of *Sarotherodon melanotheron* in Dominli Lagoon.

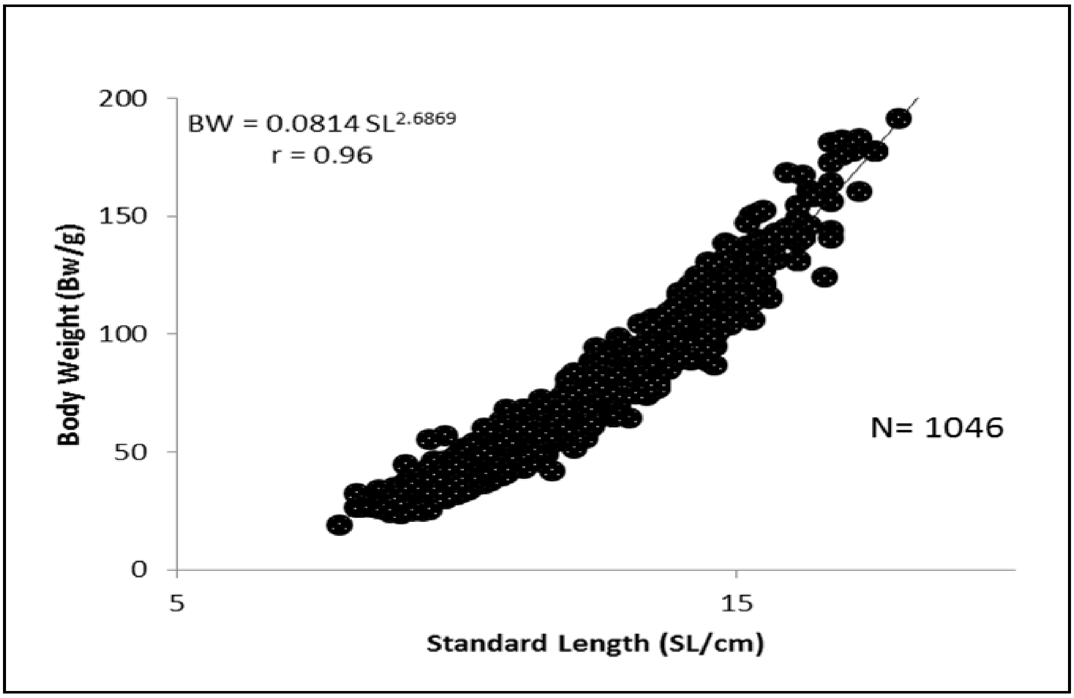

Figure 3. Length-weight relationship of *Sarotherodon melanotheron* in Dominli Lagoon.

3.2. Mean Length at Sexual Maturity (L_m)

From figure 4, the mean size at sexual maturity was determined as 13.4 cm SL. However, the observed sexually mature female *S. melanotheron* with the smallest size (28.68 g) had a standard length of 9.2 cm whereas the biggest observed mature fish (177.68 g) recorded a standard length of 17.1 cm.

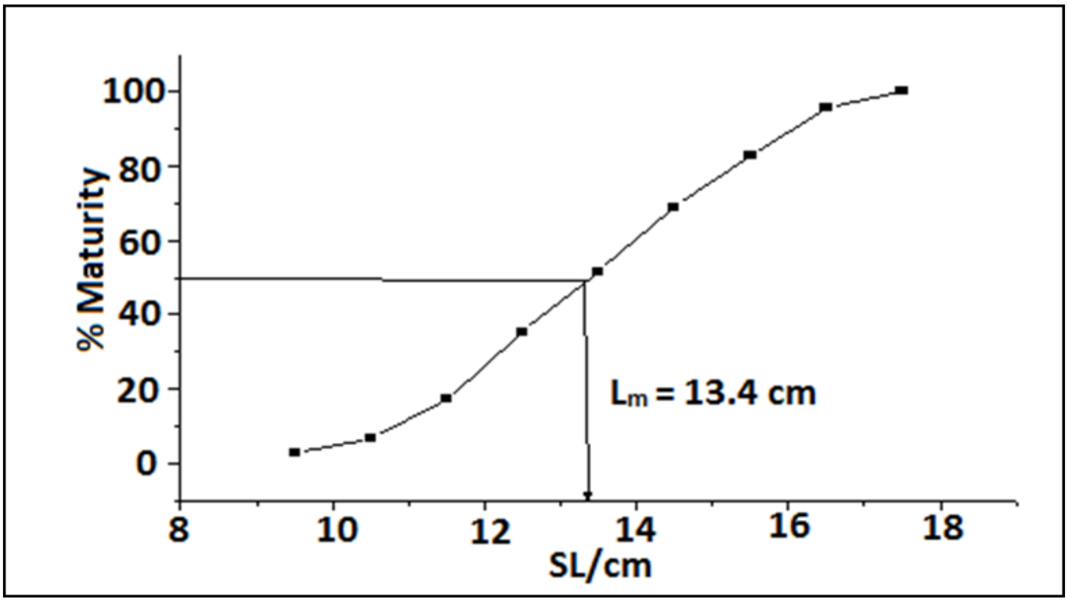

Figure 4. Mean length at sexual maturity of female *Sarotherodon melanotheron* in the Dominli Lagoon.

3.3. Population Growth, Mortality and Exploitation Parameters

Figure 5 illustrates the resultant growth curves fitted to the monthly length-frequency distribution of *S. melanotheron* in the Dominli Lagoon. This distribution exhibited a haphazard pattern in the modal standard length classes of *S. melanotheron* in the lagoon.

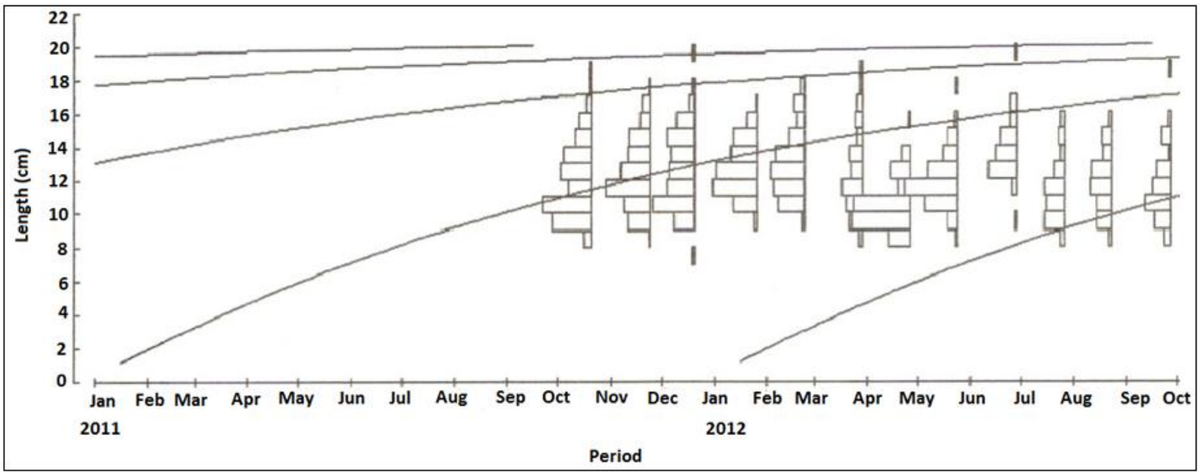

Figure 5. Monthly length-frequency distribution of *Sarotherodon melanotheron* fitted with growth curves.

Table 1. Growth and mortality parameters of *Sarotherodon melanotheron* in the Dominli Lagoon and other coastal water bodies elsewhere in Ghana.

Parameter	***Dominli Lagoon***	***Benya Lagoon (Blay, 1998)***	***Kakum River Estuary (Blay, 1998)***
Asymptotic length [L_∞ (cm)]	20.48	16.4	10.0
Growth rate [K (yr^{-1})]	0.97	0.61	1.25
Theoretical age [t_o (yr)]	-0.81	-0.31	-0.18
Longevity [t_{max} (yr)]	3.1	4.7	2.4
Growth performance [ø']	2.6	2.14	2.05
Mean length at first sexual maturity [L_m (cm)]	13.4	5.5	4.6
Mean length at first sexual maturity/ Asymptotic length ratio [L_m/ L_∞]	0.65	0.34	0.40
Mean length at first capture [L_{50} (cm)]	10.13	6.0	5.0
Selection factor	2.0	-	-
Mean length at first capture/Selection factor (cm)	5.1	-	-
Total mortality [Z (yr^{-1})]	3.86	3.49	5.17
Natural mortality [M (yr^{-1})]	2.02	1.51	2.83
Fishing mortality [F (yr^{-1})]	1.84	1.98	2.83
Exploitation rate [E]	0.48	0.57	0.55

An index of goodness of fit (Rn) by ELEFAN I programme was 0.23 with estimates of the growth parameters from the length-frequency data giving an asymptotic length of 20.48 cm SL and growth constant (K) of 0.97 yr^{-1} for the species (Table 1).

The longevity (t_{max}) and growth performance (ø') of *S. melanotheron* in the Dominli Lagoon were also calculated as 3.1 years and 2.61, respectively.

As shown in figure 6, the total instantaneous mortality rate (Z) was determined only for the individuals that were fully exploited. Individuals that were not fully recruited to the catches (represented as backward projected points) and groups whose lengths were close to L_∞ (points on descending arm of the curve) were excluded from the regression analysis (Pauly, 1983). The slope of the regression analysis suggested a total mortality rate of 3.86 yr^{-1} for *S. melanotheron* in the Dominli Lagoon.

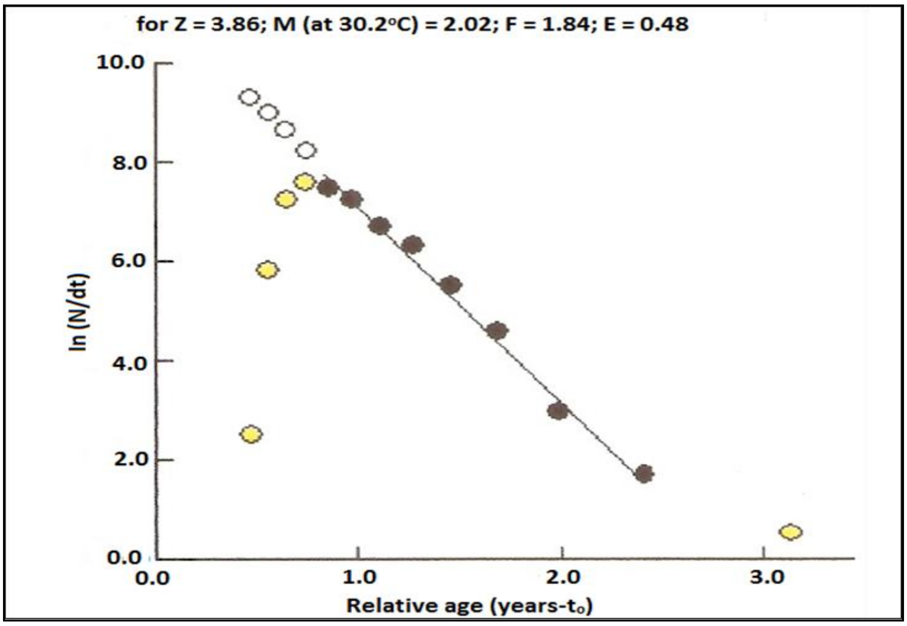

Figure 6. Length-converted catch curve for *Sarotherodon melanotheron* in the Dominli Lagoon.

Through substitution of the annual mean water surface temperature (30.2^{0}C) of the Dominli Lagoon and growth parameters into the empirical equation of Pauly (1980), the natural mortality (M) of the population was calculated as 2.02 yr^{-1}. On the basis of the Ricker's (1975) equation, Z = F + M, fishing mortality of the *S. melanotheron* population was determined as 1.84 yr^{-1}.

The selection curve generated by the ascending part of the length-converted catch curve for *S. melanotheron* is shown in Figure 7. From the curve, the mean length at first capture (L_{50}) was extrapolated as 10.13 cm SL, which parenthetically falls within the modal length class of *S.*

melanotheron. The estimated mesh size, L_{50}/SF, of the gear for catching the species was 5.1 cm fixed-stretched diagonally. The exploitation rate (E) of *S. melanotheron* population in the Dominli Lagoon was estimated at 0.48.

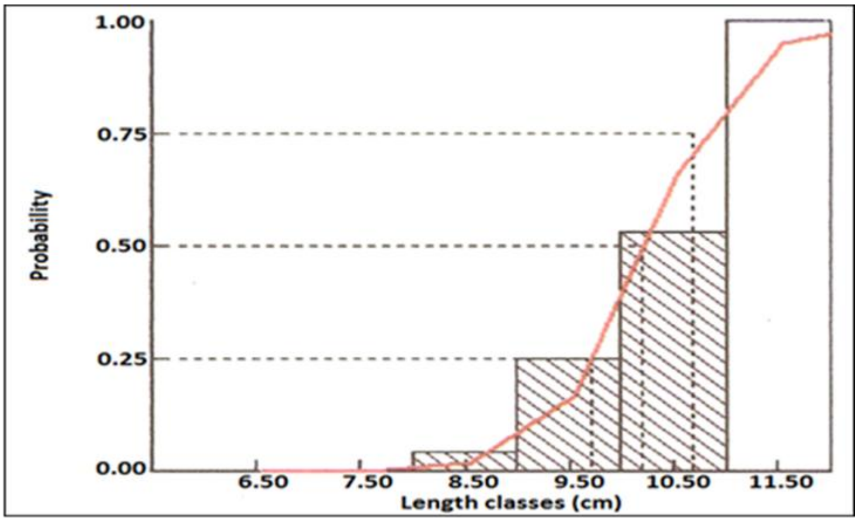

Figure 7. Selection curve for *Sarotherodon melanotheron* in Dominli Lagoon.

The plot of relative yield-per-recruit against exploitation rate showed that the present exploitation rate ($E_{present}$) was less than the maximum exploitation rate (Fig 8). However, the present exploitation rate was higher than the rate of exploitation at which 50 % of the biomass-per-recruit was fished ($E_{present} > E_{50}$).

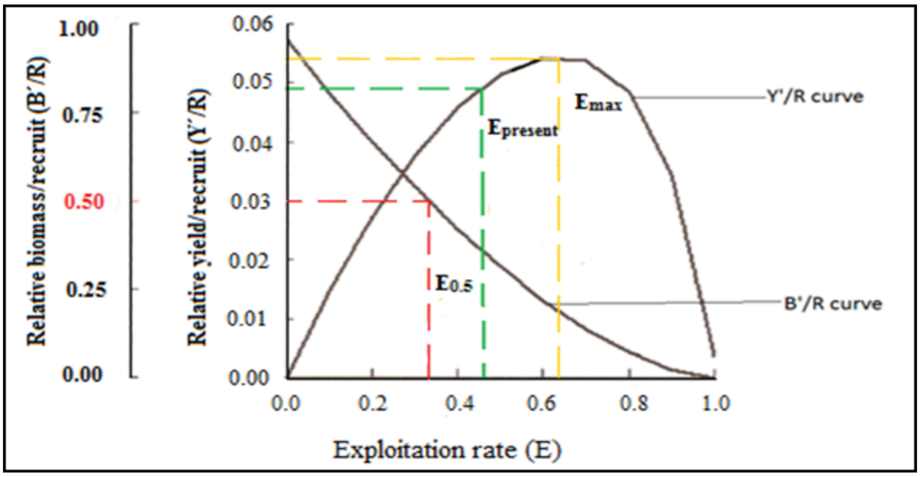

Figure 8. Relative yield-per-recruit (Y′/R) and biomass-per-recruit (B′/R) plot for *S. melanotheron* at different rates of exploitation in the Dominli Lagoon.

As shown in figure 9, the annual recruitment pattern of *S. melanotheron* in the Dominli Lagoon indicated that recruitment occurred throughout the year with the major and minor ones occurring in the rainy season (April-July) and the dry season (October-January), respectively. The highest recruitment occurred in June, 2012 with the lowest in February, 2012.

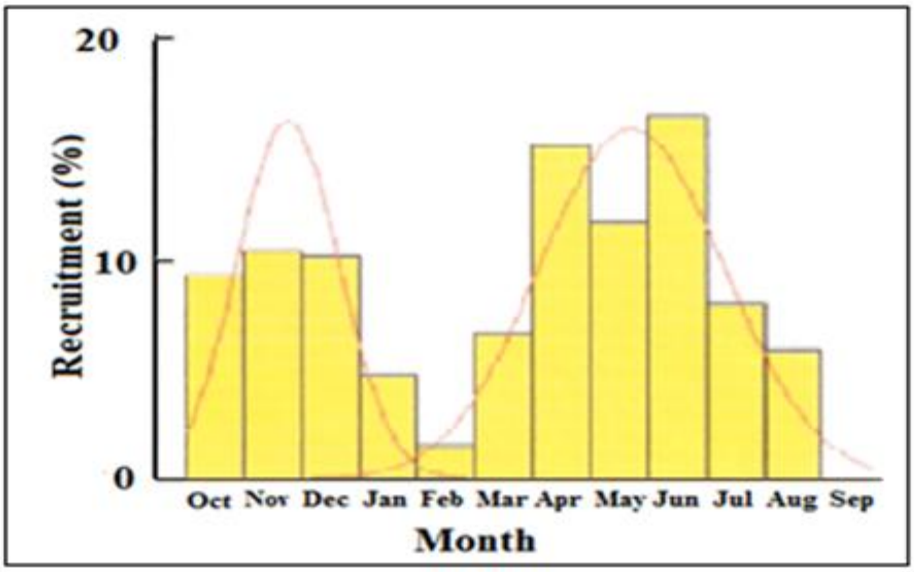

Figure 9. Recruitment pattern of *Sarotherodon melanotheron* in the Dominli Lagoon from October, 2011 to September, 2012.

4. DISCUSSION

Length and weight data are of great importance in fisheries research because they are often associated with provision of population parameters necessary for proper fisheries management and sustainable yield of fish stock (Ecoutin et al., 2005). Blay (1998) reported modal lengths of 6.0 and 5.0 cm SL for *Sarotherodon melanotheron* in the Benya Lagoon (Elmina) and Kakum River Estuary (Iture), respectively. Comparatively, a modal length of 10.0 cm SL was observed for the same species in the Dominli Lagoon suggesting that *S. melanotheron* in the lagoon for the present study grow larger than the same species in the Benya Lagoon and Kakum River Estuary. Pauly (1976) obtained a maximum total length of 19.0 cm TL in the Sakumo Lagoon whereas Blay and Asabere-Ameyaw (1993) reported a maximum length of 15.9 cm TL in Fosu Lagoon. By comparison, the maximum total length of 23.8 cm TL observed for *S. melanotheron* in the present work is relatively longer than those reported for the similar species in the Sakumo and Fosu Lagoons. However, the observed total length for *S. melanotheron* in the Dominli Lagoon is smaller than the maximum lengths (25.0 – 27.0 cm TL) documented for certain lagoon and freshwater *S. melanotheron* populations in other parts of West Africa (Ugwumba and Adebisi, 1992).

Length-weight relationship plays a major role in assessing the biology of fish fauna (Abowei and Hart, 2005; Akintola et al., 2010). The relationship also provides both applied and pure applications in the fisheries sector. Pauly (1993) reported that length-weight relationship (LWR) provides pertinent information on habitat where fish live whereas Kulbicki et al. (2005) highlighted the importance of the relationship in modeling aquatic ecosystems. The growth constant (b value) in this relationship ranging between 2.5 and 3.5 notably demonstrates normal growth dimensions or interpretation of well-being of fish population (Carlander, 1969; Bagenal, 1978; King, 1996). The b value (2.7) estimated for *S. melanotheron* in the Dominli Lagoon was within this expected growth constant range.

Blay (1998) described the relationship between standard length and body weight of *S. melanotheron* population in the Benya Lagoon by the equation: $BW = 0.0380\ SL^{3.03}$. The power of the equation (b = 3.03) and regression coefficient (r = 0.99) indicated isometric growth and strong correlation between length and weight, respectively. The relationship between standard length and body weight of the same species in the Dominli Lagoon was however, described by the equation: $BW = 0.0814\ SL^{2.7}$ (r = 0.96). *S. melanotheron* in the Dominli Lagoon had strong length-weight correlation as that of the same species in the Benya Lagoon. However, the *S. melanotheron* in the Dominli Lagoon exhibited negative allometric growth pattern (b < 3) implying that the fish grew relatively more slender as it increased in weight or the rate of increase in length was higher than the rate of increase in weight. This conforms to the findings by Agboola and Anetekhai (2008) but disagrees with Blay (1998), Ayoade and Ikulala (2007), Kumolu-Johnson and Ndimele (2011) and Obodai et al. (2011).

Blay (1998) reported lengths at first sexual maturity (L_m) of 5.5 cm SL and 4.6 cm SL for *S. melanotheron* populations in the Benya Lagoon and the Kakum River Estuary, respectively. L_m observed for the same population in the Dominli Lagoon is higher than those reported by Blay (1998). It could be inferred that *S. melanotheron* in both Benya Lagoon and Kakum River Estuary relatively mature sexually at a smaller size as compared to the Dominli Lagoon.

Blühdorn and Arthington (1990) indicated that length at first sexual maturity could help to assess the occurrence or absence of stunting in tilapias. An assertion by Iles (1970) indicates that tilapias whose growth is normal usually attain asymptotic length of approximately 35 cm with their L_m/L_∞ averaged as 0.70. Iles (1973) further suggests that tilapias experiencing stunted growth normally grow at a relatively faster rate with consequent lower asymptotic length as compared to normal populations. The maturity-length ratio (L_m/L_∞) of 0.65 for *S. melanotheron* in the lagoon which is approximately 0.7 implies that *S. melanotheron* in the Dominli Lagoon are possibly not stunted. Stunted growth in tilapia populations have been ascribed to high natural mortality rates resulting from intense predation perpetrated by birds and reptiles in a significant number of water bodies (Amarasinghe et al., 1989). The relatively low natural mortality (2.02 yr^{-1}) and fishing mortality (1.97 yr^{-1}) rates observed for *S. melanotheron* coupled with the favourable environmental conditions of the lagoon (Arizi, 2013) might have contributed to the absence of stunted growth in the fish population evidenced from the relatively large value of length at first sexual maturity (L_m).

The estimate of the natural mortality (2.02 yr^{-1}) for *S. melanotheron* in the Dominli Lagoon could be considered as normal in as much as M/K ratio (2.08) for the lagoon specimens is within the range of 1.12 – 2.50 calculated for most fish populations (Beverton and Holt, 1957). The natural (2.02 yr^{-1}) and fishing (1.97 yr^{-1}) mortalities were almost similar for the *S. melanotheron* in the lagoon. This further confirms the contention by Gulland (1971) stating that fishing mortality be equal to natural mortality in an aquatic system to pave way for attainment of the optimal exploitation rate (0.5) with resultant sustainable yield of fish. The natural mortality observed for *S. melanotheron* in the Dominli Lagoon may be due to the presence of few piscivores and predatory reptiles and birds. The daily fishing activities by the local fishermen coupled with constant predation by birds and reptiles (CRC/FON, 2011) could be considered for the tilapias in the lagoon as unfavourable situations. This may cause stunting in the population on the horizon if the necessary precautionary actions inter alia regulations of fishing activities in the lagoon and mesh size increment of fishing gears are not taken.

The longevity of *S. melanotheron* in the Dominli Lagoon describes the population as short-lived fish concurring with Blay (1998) and Blay and Asabere-Ameyaw (1993). The short life span of 3.1 yr depicted by *S. melanotheron* in the lagoon probably influences their growth in a way that makes them reach the asymptotic length at a faster rate. *S. melanotheron* in the Dominli Lagoon had a better growth performance (ø' =2.6) than the same species in the Benya Lagoon (ø' =2.14) and Kakum River Estuarine (ø' =2.05).

Based on substitution of the estimated growth parameters into Pauly's (1983) empirical equation indicated already as equation (3), age (t_0) at which length is zero (Gulland, 1983) was calculated as -0.18 yr. Hence, on yearly basis, the growth of *S. melanotheron* of the Dominli Lagoon could be described by the von Bertalanffy growth equation as:

$L_t = 20.48[1-e^{-0.97(t+0.18)}]$, where L_t is the length of fish at age t.

According to Koranteng (1993), estimation of length at first sexual maturity (L_m) for female fish is considered as a vital tool in management of fish stock. Mehanna (2007) has shown that L_m is of great importance in the determination of optimum mesh size for sustainable exploitation of fish stock. Fish should be allowed to reach sexual maturity prior to exploitation. This is best achieved by making their L_c (L_{50}) larger than L_m (Sendecor and Cochran, 1980; Koranteng, 1993). The mesh size (5.1 cm) of fishing gear estimated for *S. melanotheron* in the present study suggests that the legal minimum mesh size, 5 cm, recommended by the Ghana Fisheries Act 625 (2002) is appropriate for rational exploitation of *S. melanotheron* in the Dominli Lagoon. However, L_c of 10.13 cm SL estimated for the fish population in the lagoon was less than its L_m (13.4 cm SL) with an implication that several sexually immature fish are fished before reproduction. On this basis, the current mesh size utilised for exploiting *S. melanotheron* stock in the lagoon could be increased to allow the fish to spawn at least once in their lifetime. This could lead to a possible sustenance of the *S. melanotheron* ichthyomass in the lagoon.

The optimal exploitation rate, E_{opt} = 0.50 in comparison with the current rate of exploitation (E = 0.48) of *S. melanotheron* indicates that the stock is not overexploited (Pauly, 1984). However, the closeness of the two values suggests that continuous and intensive fishing in the lagoon could lead to overexploitation of the fish stock. Blay (1998) reported high natural mortality (2.83 yr^{-1}) and fishing mortality (2.34 yr^{-1}) for *S. melanotheron* in the Kakum River Estuary resulting in higher total mortality (5.17 yr^{-1}) as compared to a total mortality of 3.86 yr^{-1} observed for *S. melanotheron* in the Dominli Lagoon.

From the Y′/R curve, the current exploitation rate ($E_{present}$) which has not reached the maximum level of exploitation (E_{max}) suggests that $E_{present}$ could be applied for sustainable exploitation of the *S. melanotheron* fishery. However, the B′/R curve of *S. melanotheron* in the lagoon which indicated that $E_{present} > E_{50}$ implies that a considerable increase in the current exploitation rate of the *S. melanotheron* stock could lead to depletion of the fish stock.

Diverse ecological niches and abundant food materials are commonly observed in water bodies during the rainy season. These phenomena which possibly prevailed in the Dominli lagoon over the raining days might have triggered the high natural recruitment of *S. melanotheron* in the lagoon.

5. CONCLUSION

S. melanotheron in the Dominli Lagoon had a fast growth rate. The nature of the asymptotic length (20.48 cm SL) and L_m/ L_∞ (≈ 0.7) implied that *S. melanotheron* population in the lagoon was not stunted. *S. melanotheron* population is not overexploited (0.48). Moreover, Y′/R and B′/R curves implied that the current exploitation could be strategically applied for rational exploitation of *S. melanotheron* fishery. Hitherto, there is no fishing ban on any of the days suggesting that all-year-round fishing activities occur in the lagoon. It is therefore recommended that fish-conserving-aimed ban should be imposed on some of the fishing days in order to regulate the fishing activities of the local fishermen as the present exploitation rate (0.48) is nearing the optimal exploitation rate (0.5).

6. ACKNOWLEDGEMENTS

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