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Gill Length-Volume Relation of Cichlids *(Sarotherodon melanotheron)* in Two Ghanaian Lagoons

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ABSTRACT

In sub-Sahara African nations like Ghana, *Sarotherodon melanotheron* is steadily gaining attention as an alternative to the popularly over-burdened cultured cichlid species *Oreochromis niloticus* for animal protein. We investigated the relation between gill length and gill volume as well as the relation between some morphometric parameters of the *S. melanotheron* inhabiting Benya (an open lagoon) and Fosu (closed lagoon) lagoons in Central Ghana. All relations were positively correlated, with the strongest correlation occurring between body weight and standard length. We also describe a "Five-Step Approach to Extracting Gill from Cichlids". Analysis of morphometric parameters indicated that the *S. melanotheron* populations from Fosu lagoon were generally bigger (15.35 g, S.E. = 0.42) than those from Benya lagoon (9.54 g, S.E. = 0.64), although very big size fish were absent in the former, coupled with significantly wider size distribution from probability plots for length (AD = 8.471; $p < 0.005$) and weight (AD = 18.877; $p < 0.005$) for the latter. Mean condition indices were 3.39 and 3.51 for Fosu and Benya Lagoons respectively. Gill length and volume (GL – GV) relation had a fairly strong association and was better defined by the expression GV (mL) = 0.1596GL (cm) $^{1.4599}$ ($R^2 = 0.45$) for the Benya population, GV (mL) = 0.1401GL (cm) $^{2.0521}$ ($R^2 = 0.3343$) for the Fosu population.

Key Words: Gills; Morphometric Relations; Food Security; *Sarotherodon melanotheron*; Ghana

INTRODUCTION

The Family Cichlidae is one of the most species rich families of vertebrates, with conservative estimates citing more than 2,000 extant species (Stauffer et al. 2006) that are largely noted to tolerate a wide range of water quality from brackish to fresh water, with several species known to move freely between the sea and fresh water systems. They are spiny-rayed fish and prefer live foods but will accept many substitutes. Lagoons sometimes serve as natural habitats for some cichlids like the *Sarotherodon melanotheron.* In Africa, cichlid flocks characterise such great lakes as Lakes Malawi, Victoria and Tanganyika (Lowe-McConnell 2009), where hundreds of cichlid species are found.

Sarotherodon melanotheron (Rüppell 1852), the blackchin tilapia, is a pale (variable light blue, orange, golden yellow) cichlid whose common name refers to the dark pigmentation usually (but not always) concentrated on the underside of the head (the chin) in adults (Trewevas 1983). Melanic pigmentation is usually also present on the posterior edge of the gill (the cleithrum) and on the tips of the soft dorsal rays. Irregular bars, spots or splotches on the body are also typical. The mouth is small and filled with up to several hundred very small teeth arranged in 3-6 rows (Trewevas 1983). Sexual dimorphism is minimal in the blackchin tilapia (Trewevas 1983), although the heads of adult males are usually slightly larger than those of females and some males also have some gold coloration on their opercula (Seiyaboh et al. 2013). *S. melanotheron* is a tropical species whose native range in the northern hemisphere extends from the equator to 18ºN and winter temperature extremes are likely the most limiting factor northward range expansion (Shafland and Pestrak 1982; Jennings and Williams 1992). Blackchin tilapia is broadly euryhaline, primarily inhabiting estuarine habitats such as mangrove marshes, and travel freely between fresh and saltwater environments (Trewevas 1983; Shafland 1996). They frequent the saline lower reaches of streams and are also tolerant of hypersaline conditions that may arise in closed lagoons and impounded marshes (Page and Burr 1991). In its native range, *S. melanotheron* is found only in freshwater lagoons and brackish (or slightly salty) waters along the coast of West Africa from Senegal to southern Cameroon. This species has been introduced in Europe, Asia and the southern United States (Pullin and Lowe-McConnell 1982).According to Moyle (1976), members of the cichlid family have been promoted as game fish and for aquatic weed control in some areas of the United States and have also, consequently been released throughout the southern part, often without consideration of the long-term effects.

As is the case in most fishes, the gill is the chief respiratory organ for *S. melanotheron*. It is a multi-purpose organ that, in addition to providing for aquatic gas exchange, plays dominant roles in osmotic and ionic regulation, acid-base regulation, and excretion of nitrogenous wastes. Thus, despite the fact that all fish groups have functional kidneys, the gill epithelium is the site of many processes that are mediated by renal epithelia in terrestrial vertebrates (Evans 2002). The gills have structures and mechanisms that allow about 80% - 90% of the initial dissolved oxygen in the water to be extracted (Oram 1989; Mader 1993).

In contrast to several aquaculture species, tilapias are important in local and export markets as well as food fish by rural farmers. In Ghana, the main tilapia species cultivated are the *Oreochromis niloticus, Sarotherodon melanotheron* (Blackchin Tilapia), *Sarotherodon hornorum* and *Sarotherodon aureus.* Other species, for example, *Clarias gariepinus* and *Heterotis niloticus* have been making steadily increasing contributions to the supply of proteins to man locally and the world at large (FAO 2012).Tilapine cichlids rank high in global aquaculture production and the FAO fisheries statistics for 2004 to 2008 revealed total world tilapia production from all sources had been on a steady rise. Carps are the only category of fish species with greater production than tilapias. Tilapias are a hardy species produced by two different culture methods under a wide range of environmental conditions. Through a combination of technologies, systems development and innovation, aquaculture has been the fastest-growing food production sector over the past three decades, expanding by almost twelve times at an average annual rate of 8.8 percent (FAO 2012).

In spite of this, there is a large gap between demand and supply of fish protein for the local Ghanaian consumption. Research into aquaculture inputs including quality seed and species diversification of the industry will go a long way to deepen the intensity of aquaculture. Diversifying the culture species has the potential to reduce the over-dependence of the aquaculture industry on a single species; a practice, which poses a serious risk to the sustainability of the industry. For example, single species aquaculture (monoculture) systems are known to be prone to disease outbreaks (Rönnbäck, P. 2000), which can inflict huge economic losses to the industry. An attempt to diversify aquaculture, therefore, needs in-depth knowledge on the biology and culture potential of the species of interest.

This study attempts to assess some other aspect of the biology of the important cichlid *(Sarotherodon melanotheron)*. The species is currently receiving increasing attention since it promises to be of very palatable taste and an option in the wake of aquaculture species diversification and increasing demand and supply deficit of global protein requirements. Knowledge of the gill length-gill volume to body length relation for instance can help provide information about the volume of fish flesh that could be obtained from a fish species, vital information in determining the profitability of an aquaculture business, and adding extra information to already established principles such as length-weight relationships which help to convert growth-in-length equations to growth-in-weight in stock assessment models (Morato et al. 2001, Stergiou and Moutopoulos 2001). Information on Gill length-volume ratio (GLVR) to standard length (SL) relation could also be an interesting indicator of the condition of cichlids, yet very few studies have investigated this, further propelling this study.

MATERIALS AND METHODS

Study Sites

This study was undertaken at the Fosu and Benya Lagoons along the Gulf of Guinea in the Central Region of Ghana in West Africa. These lagoons serve as habitats for several marine and freshwater organisms including *S. melanotheron.* Benya Lagoon located in Elmina (Latitude 5° 4' 60 N and Longitude 1° 22' 0 W) is an open (or tidal) lagoon with an average elevation of 38 m above the sea level. Fosu Lagoon, located in Cape Coast

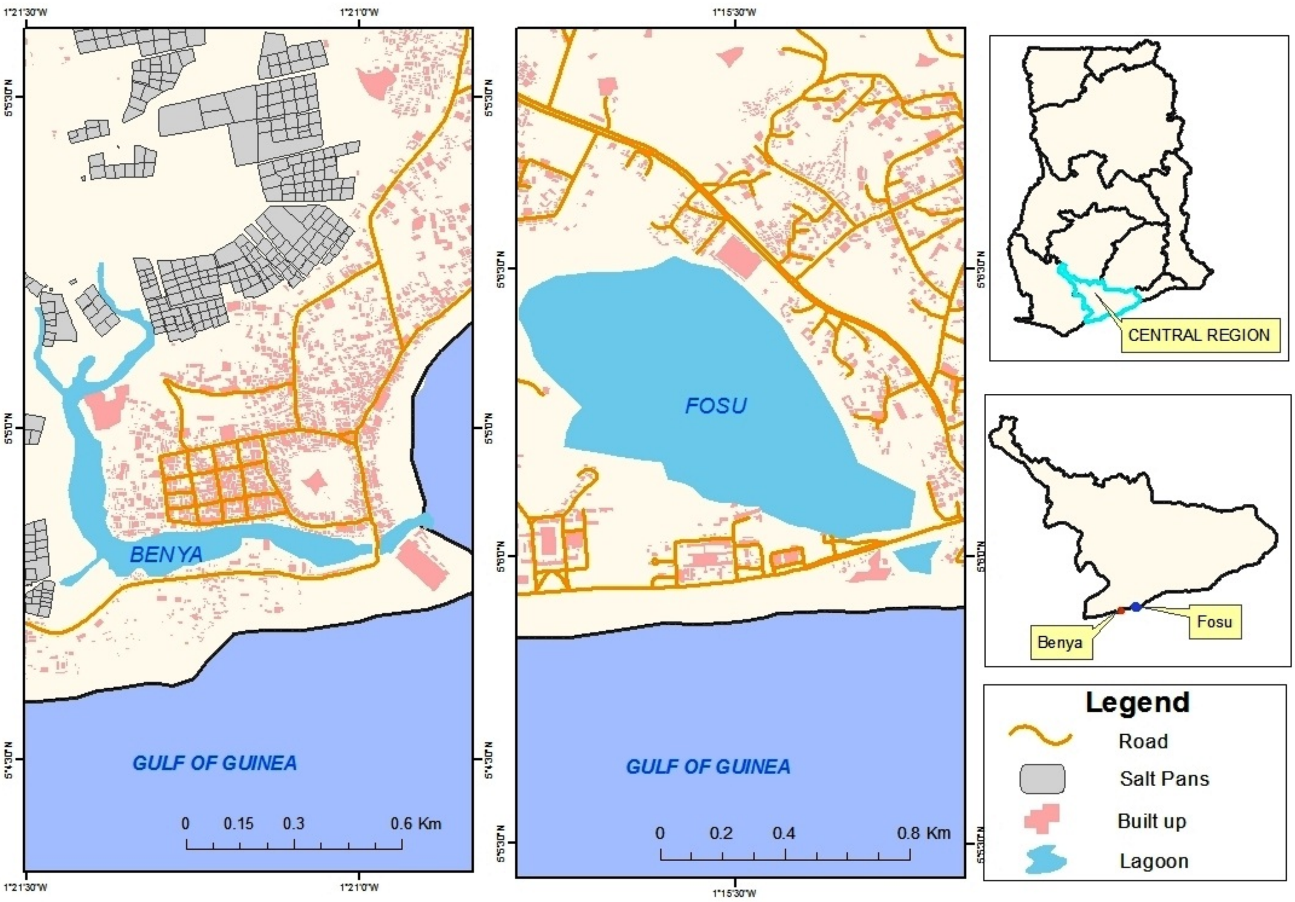

Figure 1. Benya and Fosu Lagoons in the Central Regions of Ghana, West Africa.

(Latitude 5° 6' 40.02" N and Longitude 1° 15' 29.96" W), is a closed coastal lagoon. The Fosu Lagoon is a shallow brackish water body, separated from the Gulf of Guinea by a sand bar that is usually broken during the peak of rainfall or manually as part of the rituals during the Fetu Festival in Cape Coast (Armah et al. 2009).

Sampling Procedure

Fish samples were collected from the Fosu and Benya lagoons twice a month for two months, making four samplings in the period. *S. melanotheron* samples were collected from fishermen who were found fishing in the two lagoons on each sampling day. A total of 110 specimens of *S. melanotheron* were sampled from the Fosu lagoon and 163 from the Benya lagoon. Fish samples were preserved on ice and immediately transported to the Department of Fisheries and Aquatic Sciences' laboratory at the University of Cape Coast, for analysis.

Measurement of body parameters

Fish weight was measured with a sensitive electronic balance (FEL - 500 S; max 500g) in the laboratory. Standard Length (SL) of fish was measured from the tip of the snout to the posterior end of the last vertebra or to the posterior end of the midlateral portion of the hypural plate. This measurement excluded the length of the caudal fin (De Mitcheson et al. 2008). Total length of the fish was measured from the tip of the snout to the tip of the longer lobe of the caudal fin, with the lobes compressed along the midline.

Extraction of gills and measurement of gill parameters

The gill of each specimen was carefully removed with a pair of scissors and forceps. Meticulous steps were followed in extracting all 273 gills from studied specimens to ensure whole gills were removed for accurate volumetric determinations. A five-step approach to easily extracting these gills is presented in Table 1 and gills shown in Figure 2.

Table 1: A simple five-step approach to extracting gill from cichlids *(S. melanotheron)* used in this study

Step	Action
1	Gently open and cut midway through base of jaw and through the lower lip with a pair of scissors
2	Separate left and right opercula apart, away from gill and even wider apart, with forceps, to expose gill.
3	Hold upper part of head and pull backward till it breaks away from gill using forceps.
4	Tear ligaments holding gill filaments to flesh off with a blade to the tip of gill arch and cut to release gill.
5	Cut base of gill arch attached to upper inner head of fish. Gill freely falls off.

Gill length was measured using a piece of thread. The tip of the thread was placed at one end of the gill and bent along the gill curvature to the opposite end of the gill. The thread was then stretched fully along a meter rule to determine the actual length of the gill. Gill volume was measured using simple water displacement method based on Archimedes' Principle, which states that 'the water volume displaced is equal to the volume of the object immersed in the water'. The gill was therefore immersed in a specific initial amount of water (V_1) contained in a measuring cylinder. After immersion there was a rise in the level of water and this new volume (V_2) was recorded. The volume of water displaced by the gill was calculated as the difference between the final volume reading and the initial volume reading ($V_2 - V_1$) and this was recorded as the volume of the gill.

Data analysis

The correlation coefficients, coefficient of determination and regression analysis were performed using Minitab. Pearson's Bi-variate correlation analysis method was employed for relationships between the various parameters measured. Probability plots were used to assess the distribution of populations from the two lagoons. The relationships between fish parameters were estimated by fitting the data to a potential relationship.

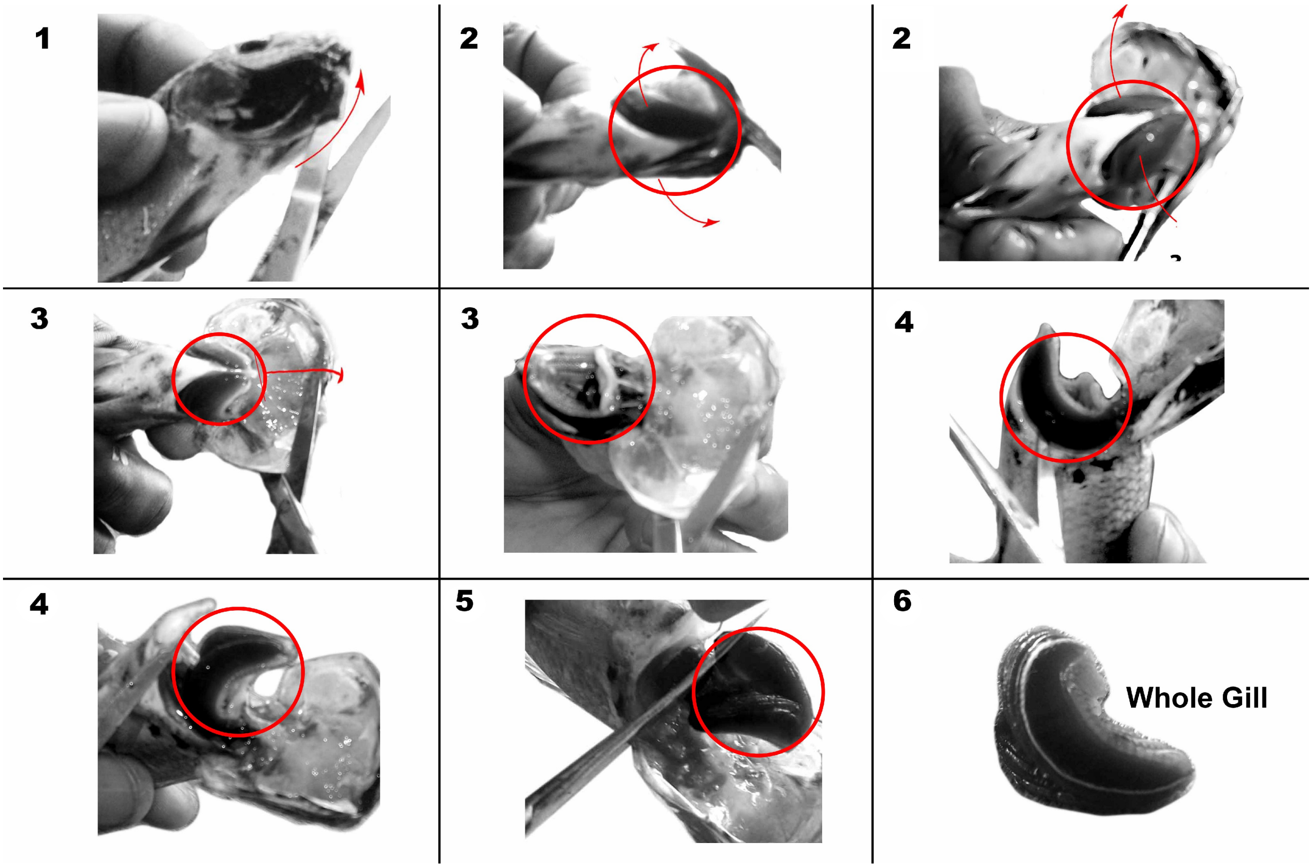

Figure 2. An illustration of the five-step approach to extracting gill from cichlids *(S. melanotheron)*

The *t*-test analysis was carried out for the length and weight data of each species to confirm the significance of the relationship at P < 0.001 (Zar 1984). The mean condition indices *(K)* for each population was calculated by adopting Fulton's condition factor, ; where *W* is body weight, *L* is total length and *n* is the number of individual fish sampled from the lagoon. Fulton's condition factor assumes isometric growth and has been applied to fish species in many studies.

RESULTS AND DISCUSSIONS

Relationships were established for various length-weight parameters between body and gill of fish using scatter graphs. The parameters were standard length-body weight (SL-BW), gill length-body weight (GL-BW), gill volume-body weight (GV-BW), standard length-total length (SL-TL), standard length-gill length (SL-GL), standard length-gill volume (SL-GV) and gill length-gill volume (GL-GV) relationships. Standard Length (SL) was chosen over Total Length (TL) due to the likelihood of alteration and reduction in length of the caudal fin of fish resulting from external factors and injuries and affecting TL measurements. TL was used only when it was being compared to SL.

Length and weight distributions and condition of the two populations

S. Melanotheron samples from Fosu and Benya Lagoons weighed from 7.38 g – 26.04 g and 2.74 g – 60.55 g respectively. Specimens from Fosu had larger weights, 15.35 ±0.42 (mean ± S.E), than those from Benya 9.54 g ±0.64 (mean ± S.E) in contrast to an earlier study by Obodai et al. (2011);however, a limited number of relatively larger sizes of range 26.05 g – 60.55 g were recorded in specimens form the Benya Lagoon. Fish lengths from the Fosu lagoon were higher, and ranged from 5.8 cm to 11.2 cm SL, than those from Benya lagoon which ranged from 4.3 cm to 13.2 cm SL, with body weights ranging from 7.38 g – 43.71 g and 2.74 g – 60.55 g, respectively. The absence of larger specimens in the Fosu population, however, could be ascribed to overfishing resulting in stunting as reported by Blay and Asabere-Ameyaw (1993).

Benya Lagoon showed wider distribution of size (with total length and weight from 5.3 cm, 2.74 g – 16.4 cm, 60.55 g) as compared to that of Fosu Lagoon (7.2 cm, 7.38 g – 11.4 cm, 26.04 g). This distribution was, however, significant and skewed to the right in the Benya populations as depicted by the downward bend of plotted points in the probability plots for length (AD =

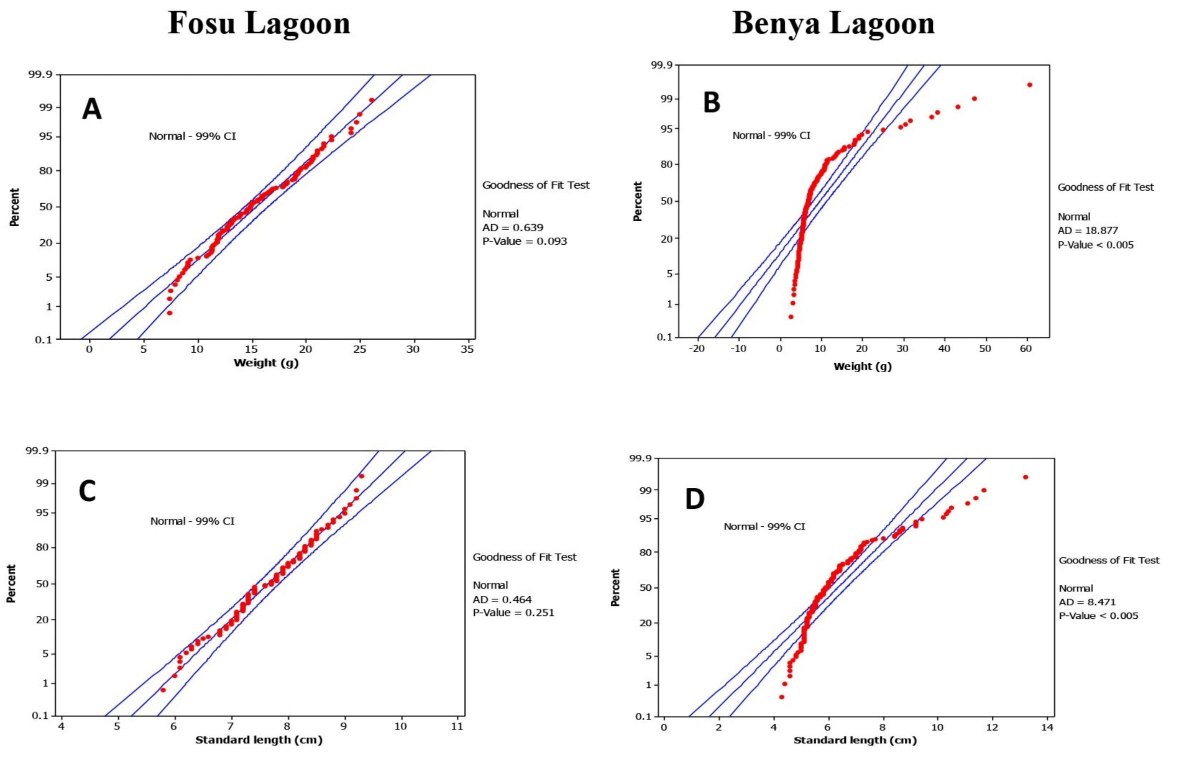

Figure 3. Weight and length probability plots for *S. melanotheron* from Fosu and Benya Lagoons

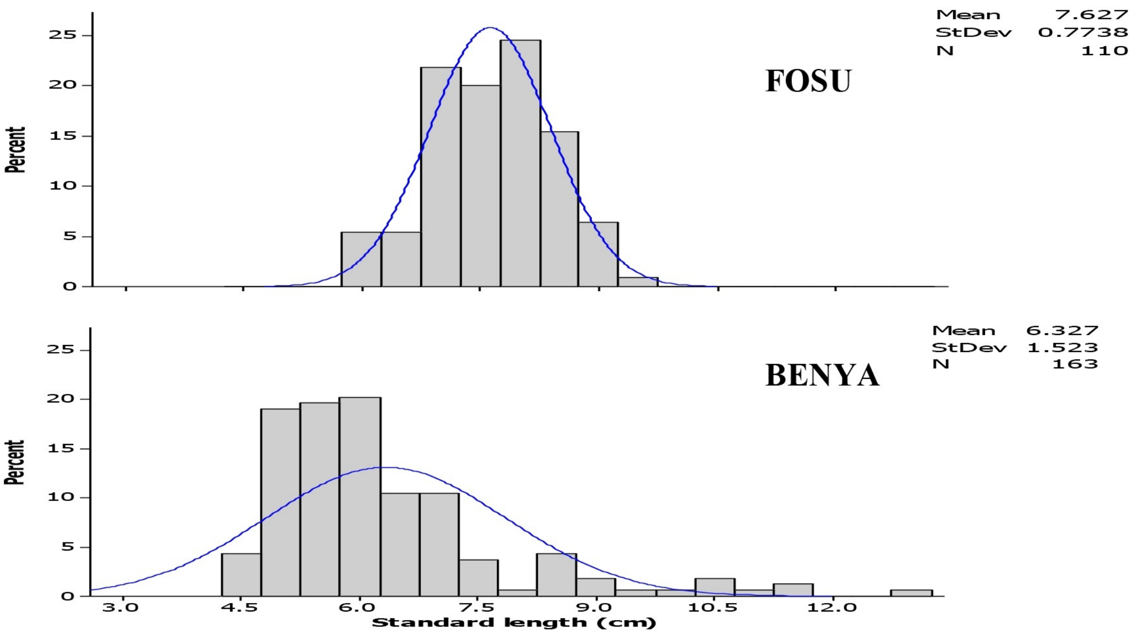

Figure 4. Length frequency distribution for *S. melanotheron* Fosu Lagoon and Benya Lagoon

8.471 ; $p < 0.005$) in Figure 3B and weight (AD = 18.877 ; $p < 0.005$) in Figure 3D, indicating the dominance of smaller sizes. Fosu Lagoon populations showed an insignificant normal size distribution for length and weight with *p*-values of 0.251 and 0.093 respectively (Figures 3A and 3C). Further analysis of length frequency distribution indicates that majority of Fosu population fell between 6.0 cm and 9.0 cm whereas majority of Benya population were between 4.5 cm and 7.5 cm (Figure 4). Mean condition indices for *S. melanotheron* were 3.39 and 3.51 for Fosu and Benya Lagoons respectively.

Standard Length (SL) – Body Weight (BW) Relation

Figure 5 shows SL-BW relationships for *S. melanotheron* populations from the Fosu and Benya Lagoons. It indicates the existence of a relation between the two variables, SL and BW, with strong positive correlations in both populations, i.e. r = 0.925 and r = 0.890 for (A) Fosu and (B) Benya Lagoons respectively. Hence, BW is directly proportional to SL and an increase in SL leads to a likely increase in BW in both cases. These relations were defined by the exponential equations BW (g) = 0.0592 SL (cm) $^{2.7216}$ for Fosu and BW (g) = 0.1216 SL (cm) $^{2.2865}$ for Benya.

Regression coefficient (b) value for *S. melanotheron* population in Fosu was b=2.7216, close to the isometric growth value of 3.0 and within the expected range of $2.5 < b < 3.5$ (Carlander 1969), which means that regardless of non-prominent growth, the species were growing at considerable proportions of length and weight thus isometric. Regression coefficient was b= $2.2865 < 3$ for the Benya population which fell below the isometric growth range, implying a negative allometric growth.

Gill Length (GL) – Body Weight (BW) Relation

Figure 6 shows GL – BW relations for *S. melanotheron* species from the (A) Fosu and (B) Benya lagoons. Both graphs show a fair relation between the two variables (r = 0.608 and r = 0.809 for Fosu and Benya lagoons, respectively) with specimens from Benya Lagoon having a stronger association between gill length and body weight. It can be seen that BW is generally directly proportional to GL and an increase in BW leads to a somewhat increase in GL in both cases.

Gill Volume (GV) – Body Weight (BW) Relation

There was a strong positive correlation between GV and BW for *S. melanotheron* in the Fosu Lagoon (r=0.693) whilst in the Benya Lagoon there was a very strong positive correlation between those parameters for *S. melanotheron* (r=0.938) (Figure 5 A and B respectively).

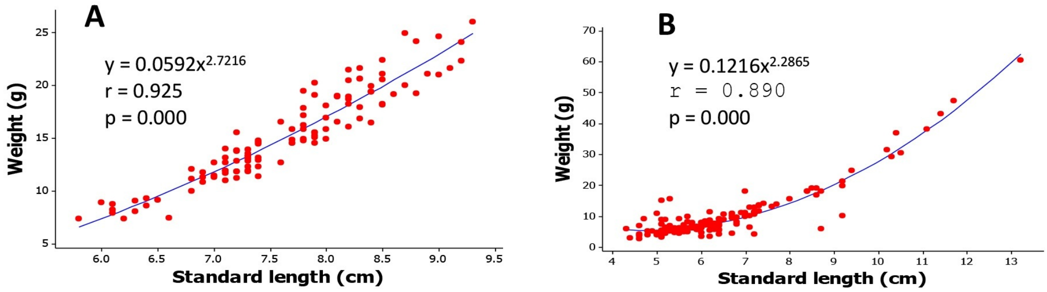

Figure 5. Relationship between standard length and body weight of *S. melanotheron* from (A) Fosu (n=110) and (B) Benya (n=163) Lagoons along the coasts of the Gulf of Guinea, *p*- Value = 0.000

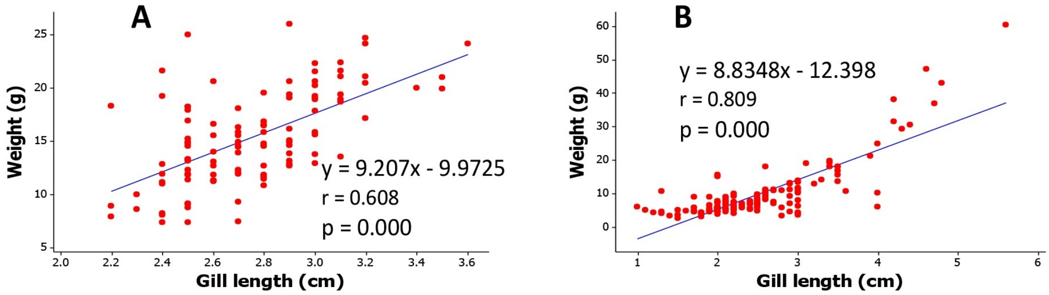

Figure 6. Relationship between gill length and body weight of *S. melanotheron* from (A) Fosu (n=110) and (B) Benya (n=163) Lagoons along the coasts of the Gulf of Guinea, *p*- Value = 0.000

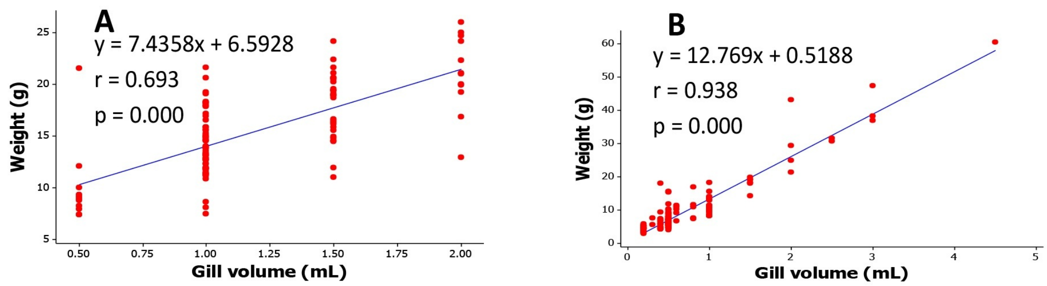

Figure 7. Relationship between gill volume and body weight of *S. melanotheron* from (A) Fosu (n=110) and (B) Benya (n=163) Lagoons along the coasts of the Gulf of Guinea, *p*- Value = 0.000

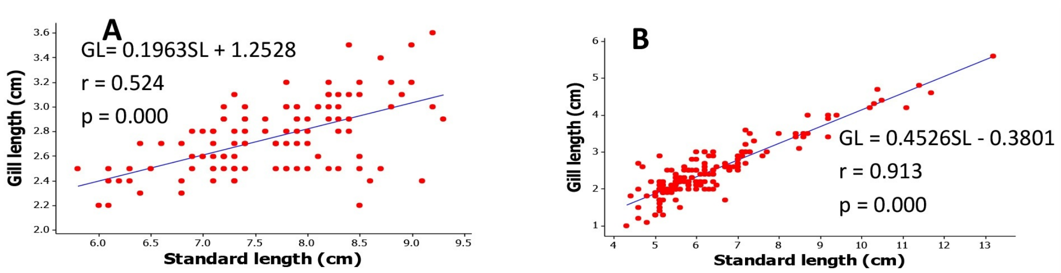

Figure 8. Relationship between standard length and gill length of *S. melanotheron* from (A) Fosu (n=110) and (B) Benya (n=163) Lagoons along the coasts of the Gulf of Guinea, *p*- Value = 0.000

BW is therefore directly proportional to GV and an increase in BW leads to a subsequent increase in GV in lagoons. However, less than 50% (0.693^2) of variations in BW was explained by GV in Fosu populations whereas in Benya populations, 88% (0.938^2) of the population determined the relation. According to Pauly (1997), gills grow in fish in proportion to powers of their body weight ranging from 0.5 to 0.9. This study, however, reveals a strong linear relation the two parameters. The relatively strong GV – BW relation in Fosu populations and an even stronger correlation between GV and BW in Benya populations buttress the point that fish growth positively influences the volume of the gill than the length and this may be an adaptation to enhance respiratory and feeding activities (Obodai et al. 2011).

Standard Length (SL) – Gill Length (GL) and Volume (GV) Relation

From Figures 8A and 8B, it was clear that Fosu Lagoon populations showed a weak association of the SL and GL since only 27% (0.524^2) could explain the established relation; GL (cm) = 0.1963SL (cm) + 1.2528. Benya populations, on the other hand, related well for SL and GL (83%). This relation was defined by the relation GL (cm) = 0.4526SL (cm) - 0.3801.

Figures 9A and 9B showed SL – GV relations for *S. melanotheron* species from the Benya and Fosu lagoons respectively. The two graphs show that there were relations between the two variables, GV and SL. This was shown by the positive coefficient of determination (R^2) values in both lagoons. *S. melanotheron* population from Fosu lagoon had 51% (0.714^2) correlation between SL and GV. Benya lagoon, on the other hand, showed a higher 75% (0.864^2) correlation between GL and BW. GV was therefore directly proportional to SL and hence an increase in SL will lead to a subsequent increase in GV in both lagoons. The relations were defined by the linear equations GV (mL) = 0.378SL (cm) - 1.7059 and GV (mL) = 0.3431SL (cm) - 1.4643 for the (A) Benya and (B) Fosu populations, respectively.

The linear relations for SL – GL and SL – GV in Figures 8 and 9 respectively for both populations suggest that gill length and volume of the species increases with increase in fish length. Margolis et al. (1982) and Obodai et al. (2011) have all made similar findings that longer fish specimens have larger gill length and volume. This is in line with what was expected in this study, since bigger fishes require more dissolved oxygen for respiration and feeding: the two main functions of the gill of a fish. Standard length, however, had a higher correlation with both gill length and gill volume in Benya population ($r > 0.8$).

Standard Length (SL) – Total Length (TL) Relation

From Figure 10, there was a very strong positive linear relation between TL and SL for the *S. melanotheron* populations from both (A) Fosu ($r = 0.98$) and (B) Benya ($r = 0.995$) Lagoons, defined by the linear equations SL (CM) = 0.8065 TL (cm) + 0.0139 and SL (cm) = 0.796 TL (cm) + 0.0221 respectively. In both systems, more than 95% of weight measurements were explained by the

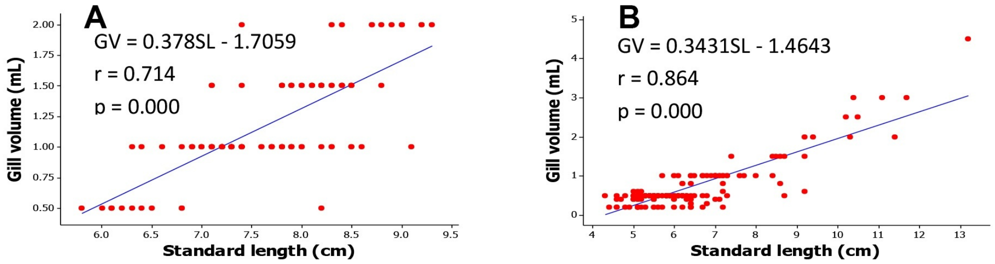

Figure 9. Relationship between standard length and gill volume of *S. melanotheron* from (A) Fosu (n=110) and (B) Benya (n=163) Lagoons along the coasts of the Gulf of Guinea, *p*- Value = 0.000

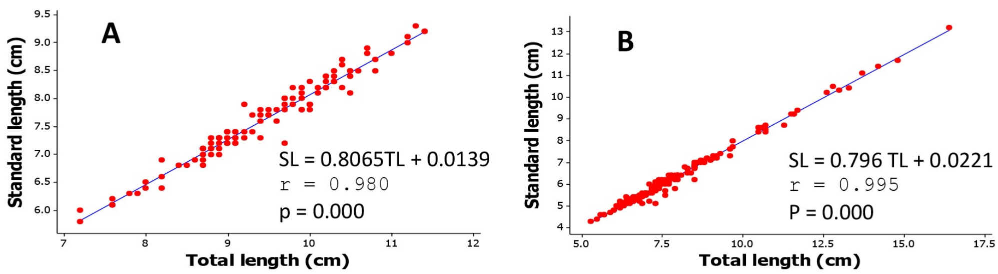

Figure 10. Relationship between standard length and total length of *S. melanotheron* from (A) Fosu (n=110) and (B) Benya (n=163) Lagoons along the coasts of the Gulf of Guinea, *p*- Value = 0.000

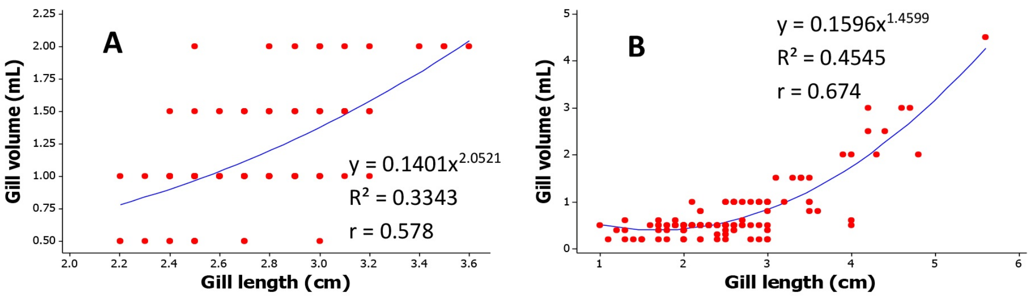

Figure 11. Relationship between gill length and gill volume of *S. melanotheron* from (A) Fosu (n=110) and (B) Benya (n=163) Lagoons along the coasts of the Gulf of Guinea, *p*- Value = 0.000

length measurements. This presents a greater tendency for predictions made by the equations to be accurate. Benya population, however, showed a stronger relation between TL and SL than those in Fosu. Fish total length and standard length are strongly correlated in a linear function (Obodai et al. 2011); hence, the similarity of these parameters in the two populations of the same species is expected. SL is more reliable than TL because the caudal fin may be damaged by poor handling. The relation established in this study shows that in such incidences in fisheries management where cichlids have lost whole or parts of their caudal fins, SLs could be used to extrapolate the TL from respective SLs. There is a very high and significant ($p < 0.00001$) tendency for near precise predictions of TL using the SL in both populations ($R^2 = 0.96$, Fosu; 0.99, Benya).

Gill Length (GL) – Gill Volume (GV) Relation

From Figure 11, a fairly strong positive correlation was observed between GV and GL for *S. melanotheron* populations sampled from both the (A) Fosu and (B) Benya Lagoons. Thus, GV was generally directly proportional to GL and 33% (0.578^2) and 45% (0.674^2) of the specimens from Fosu and Benya Lagoons could be fully aligned with the power expressions GV (mL) = 0.1401 GL (cm) $^{2.0521}$ and GV (mL) = 0.1596 GL (cm) $^{1.4599}$ respectively.

The gill is the main respiratory organ for *S. melanotheron*. The gills have structures and mechanisms that allow about 80% - 90% of the initial dissolved oxygen in the water to be extracted (Oram 1989; Mader 192093). Total surface area increases with increasing volume given a specific length. Gills with larger volumes will have a larger surface area, which is more effective in diffusing dissolved oxygen across gill filaments. This in effect makes the efficacy of a slender gill for oxygen diffusion lesser than one that is rounded. A 'b' value of 2.05 indicates that the gills of *S. melanotheron* populations from Fosu Lagoon are more rotund than those from Benya lagoon (b = 1.46). This disparity in gill morphology could be an adaptation to dissolved oxygen concentrations in the two lagoons as Armah et al. (2012) have described the Fosu Lagoon to be less saline with higher levels of dissolved oxygen than the Benya Lagoon.

CONCLUSION

Sarotherodon melanotheron populations sampled from Fosu (a closed lagoon) were found to be generally bigger than those sampled form Benya (open lagoon). Bigger sized fishes were encountered in the latter but absent in the former. The absence of very big fish could be ascribed to the stunting phenomenon in fish where there is a retardation of growth coupled with early maturation and spawning because of prevailing unfavourable environmental conditions. In spite of this, both lagoons 'housed' cichlids with good body conditions indicated by relationships between morphometric parameters of the cichlid amidst isometric and negative allometric growths for Fosu and Benya Lagoon populations respectively.

Correlation was strongest between body weight and standard length whilst all relations remained positive (direct). The core interest of the study was to ascertain gill volume and gill length relation which turned out to have a staggering association between the two parameters. The association was better defined by the expression **GV (mL) = 0.1596 GL (cm)** $^{1.4599}$ ($R^2 = 0.45$) from the Benya populations. Gills of *S. melanotheron* from Fosu Lagoon were comparatively more rotund than the gills of those in Benya Lagoon.

Extraction of whole gills from cichlids can best be done in five simple steps described in the study as the "Five-Step Approach to Extracting Gill from Cichlids". This approach presents fisheries scientists and managers with a simple efficient technique of extracting fish gills for analysis.

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