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Population parameters of *Oreochromis niloticus* (L) from a semi-open lagoon (Sakumo II), Ghana and its implications on management

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ABSTRACT

Population parameters of *Oreochromis niloticus* in the Sakumo II Lagoon, Ghana were investigated using the FiSAT software. Data were collected quarterly from August 2017 to June 2018. The measured total length of 229 specimens ranged from 4.5 to 18.5 centimeters (cm). The growth parameter (K) was estimated as 0.54 $year^{-1}$ with asymptotic length ($L\infty$ = 19.4 cm). The recruitment pattern was continuous year-round with two peaks. The total (Z), natural (M) and fishing (F) mortalities were 1.83 $year^{-1}$, 1.50 $year^{-1}$ and 0.33 $year^{-1}$ respectively. The exploitation rate (E) was 0.29 and the relative yield/biomass per recruit (E_{max}) was 0.48. The fishing effort was found to be low, with catches dominated by small size individuals. The study revealed the growth-overfishing, thus, an increase in the mesh diameter should complement reduced fishing effort to preserve the population of the species.

INTRODUCTION

The Nile Tilapia fish known scientifically as *Oreochromis niloticus* belongs to the family Cichlidae (Froese and Pauly, 2010). There are several species of tilapia in Ghana. These include *Oreochromis niloticus*, *Tilapia zillii* , *Sarotherodon galilaeus* and *Hemichromis fasciatus*. Nile Tilapia is omnivorous, with diets ranging from insects, herbs, fishes to detritus **(FAO, 2012).** It is a rapid breeder with a frequency of three to four times in a year **(Mirza, 1990; Luna 2012)** and can live longer than ten (10) years **(Mayank and Dwivedi, 2016)**. Tilapia serves as prey for Catfish (i.e. *Clarias gariepinus*), the second most economically important fish in Ghana's freshwater systems **(Asiedu *et al.*, 2015; Amenyogbe *et al.*, 2018; Issifu 2018;**).

In Ghana, the most economically important freshwater species is the Nile Tilapia, and doubles as the most consumed freshwater fish species, providing consumers with 60% of their animal protein needs (particularly the poor inland fishing households) **(Ahiah, 2008; MoFAD 2016; Sarpong 2005**). The tilapia fishery is heavy exploited through the use of different fishing gears such as gillnets, seine nets, and hooks. However, given its resilience to harsh aquatic conditions (**Jeffery *et al.*, 2010**) and its attractive cultural attributes (**Owusu-Frimpong *et al.*, 2005**), culturing of Nile Tilapia in Ghana has been considered as a panacea for bridging the gap between fish and fish demand (**Hiheglo, 2008; Asiedu *et al.*, 2015**). In view of this, most of the studies carried out on the Nile Tilapia in Ghana, focused on various aspects of its biology and feed formulation (e.g. **Lutterodt, 2018; Anane-Taabeah *et al.*, 2015; Asase, 2013; Kaliba *et al.*, 2007)** with little research conducted on its population parameters and other stock assessment indicators (e.g. **Ofori-Danson, 1999; Kwarfo-Apeyah *et al*., 2009**) necessary for sustainable management of this commercially important freshwater species.

Stock assessment of commercially important fishes, if not monitored will lead to a collapse of all fish species caught for food and commercial purposes (**Worm *et al.*, 2006**). This is because, stock assessment gives the baseline information for determining the status of commercially important fishes and managing their fishery sustainably (**Ecoutin *et al.*, 2005**). The objective of this paper is to estimate some population parameters of *Oreochromis niloticus* including growth rates, mortality rates, recruitment patterns, and exploitation rates, using length-frequency distribution data. This information will assist in the formulation of sound fisheries management measures for *O. niloticus* in the Sakumo II Lagoon of Ghana. It should be noted that the Lagoon has undergone a lot of changes recently leading to a reduction in it salinity level, making it possible for *O. niloticus* and *Clarias sp*. to exist. *O. niloticus* is the most dominant species in the lagoon largely based on its invasiveness.

MATERIALS AND METHODS

Study area:

Sakumo II Lagoon (Fig. 1) is a semi-open lagoon located on the eastern part of Greater Accra, along the Accra-Tema coastal road 3 kilometers (km) west of Tema (**Koranteng *et al.*, 1997**). It is situated within latitudes (5^o 36.5" N and 5^o 38." N and between the longitudes 1^o 30" W and 2^o 30" W). It has a surface area of 2.7 km^2 (**Tumbulto and Bannerman, 1995**), and its catchment area covers a total area of 350 km^2 although the effective catchment area is 127 km^2 because of damming of the streams leading towards the lagoon (**Tumbulto and Bannerman, 1995**). On the West, the area extends from Madina to Oyarifa and is bordered by the western side of the Tema township on the East (**Biney, 1995**). The Aburi highlands are in the North, as the Atlantic Ocean borders the South. Annually, there are two rainy periods – a major and minor season-spanning period between March to mid-July and mid-August to October, respectively. It is characterized by an average annual rainfall of about 753 mm and temperatures with monthly averages ranging between 24.7 ˚C in August to an utmost high of 28.1 ˚C in March. According to **Kwei (1974)**, the Sakumo II lagoon has been labeled as one of the five coastal Ramsar sites in Ghana.

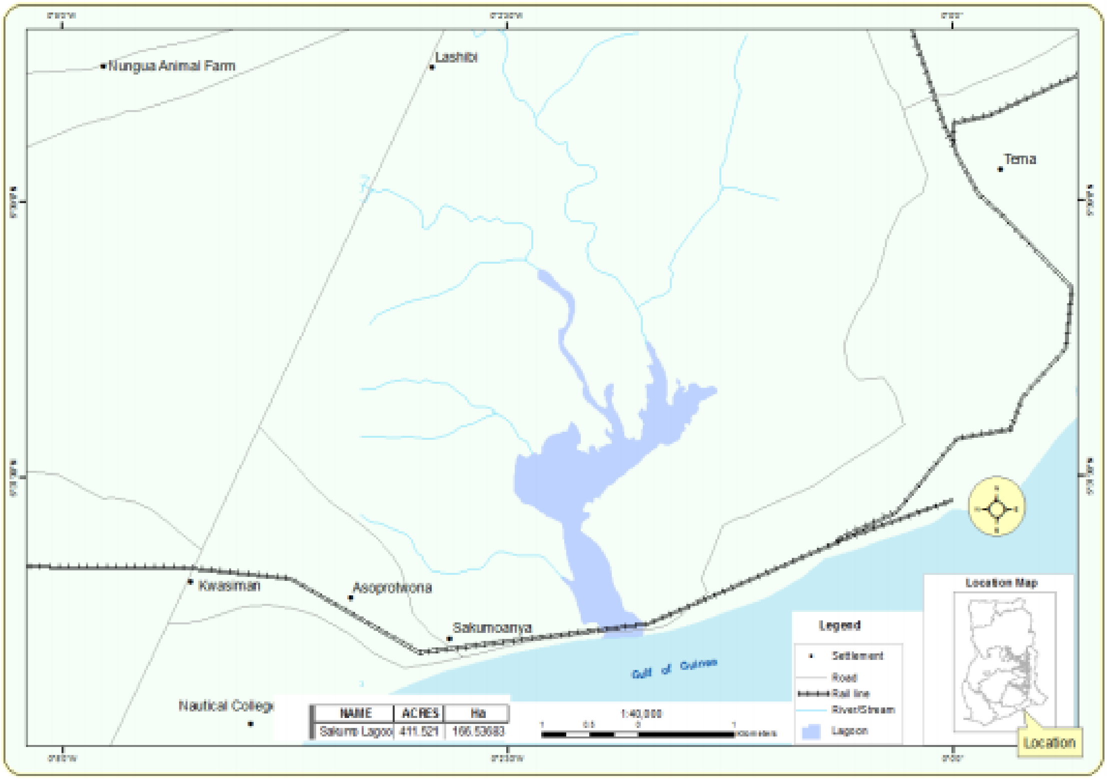

Fig. 1. Map showing the study area (adopted from Mensah, 2013)

Data collection:

Length frequency data on *O. niloticus* was undertaken in August 2017 to June 2018 from commercial catches the Sakumo II Lagoon, Ghana (Fig. 1). The collected samples represented the stock taken from the upper, mid- and downstream sections of the lagoon. In all, about two hundred (229) specimens were obtained and identified to the species level using relevant taxonomic keys (e.g. **Holden and Reeds, 1972**). Identified samples were conserved and transported in ice to the laboratory for morphometric measurement. At the laboratory, a 100-cm measuring board was used to measure the length (TL) while a top-pan electronic scale was used to record the weight.

Growth parameters:

Growth coefficient (K), asymptotic length ($L\infty$) and the growth performance index (ϕ) were calculated following the Von Bertalanffy Growth Function (VBGF):

$$L_t = L\infty\,(1-e^{-k(t-t0)})$$ **(Pauly, 1979).**

Estimation of the theoretical age at zero length (t_o) followed the equation:

$$\log_{10}(-t_o) = -\,0.3922 - 0.275 * \log_{10}L\infty - 1.038 * \log_{10}K$$ **(Pauly, 1979).**

Longevity (T_{max}) was valued as 3/K + to (Pauly, 1983).

Growth performance index was determined using the expression:

$$2\log L\infty + \log K$$ **(Munro & Pauly, 1983).**

Mortality parameters:

Total annual instantaneous mortality rate (Z) was estimated using the Length converted catch curve **(Sparre & Venema, 1998)**. Natural mortality rate (M) was ascertain as:

$\log_{10}M = - 0.0066 - 0.279 * \log_{10}L\infty + 0.6543 * \log_{10}K + 0.4634 * \log_{10}T$ (**Pauly, 1980**),

where M = instantaneous natural mortality,
L∞ = asymptotic length,
T = mean surface temperature (25.7^{o} C)
K = growth rate.

Fishing mortality rate (F) was estimated as

$$F = Z - M$$ **(Beverton & Holt, 1957).**

Exploitation rate (E) was obtained using the relationship: $E = F/Z$ **(Gulland, 1971).**

Maximum fishing effort (F_{max}) was determined as:

$$0.67K/_{0.67} - Lc$$ (**Hoggarth *et al.*, 2006**),

where $Lc=Lc_{50}/L_{\infty}$.

Precautionary limit reference point (F_{limit}) was set at:

$$^{2}/_{3} * M$$ (Patterson, 1992).

Precautionary target reference point (F_{opt}) was taken as 0.4*M (**Pauly, 1984**).

Length and age at first maturity:

Determination of length at first maturity (Lm_{50}) and age at first maturity (tm_{50}) followed Hoggarth *et al.* (2006) and Goonetileke and Sivasubramania (1987), respectively.

Length and age at first Capture:

The probability of capture was estimated following Gayanilo *et al.*, (2005). Length at first capture (Lc_{50}) corresponded to cumulative probability at 50 %, whereas lengths at which 25% and 75% paralleled to 25 % and 75% respectively. Estimation of age at first capture (tc_{50}) was done using Beverton & Holt, (1957).

Recruitment and age at first capture:

The recruitment pattern was estimated using **Gayanilo *et al.*, (2005)**. Length at first recruitment (Lr_{50}) was taken as the mid-length of the smallest length interval (**Gheshlaghi *et al.*, 2012**) while age at first recruitment (tr_{50}) followed **Beverton & Holt (1957).**

Virtual Population Analysis (VPA):

VPA (Length structured) was undertaken by applying the values of growth and mortality parameters as well as 'growth pattern from the length-weight relationship. The length-weight relationship was done using the expression:

$$W = aL^b$$ (Pauly, 1984)

where W = body weight
L = length.

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) were calculated as a function of exploitation. Further to this, exploitation rate at the maximum (E_{max}), exploitation rate at 0.1 of the virgin biomass ($E_{0.1}$) and $E_{0.5}$ tallying to the exploitation rate at 0.5 of the virgin biomass were worked out through the application of Knife-edge option.

Data analysis

The FAO-ICLRAM Stock Assessment Tool (FISAT) (**Pauly 1987; Gayanilo *et al.*, 1996**) was used to estimate population parameters.

RESULTS

Growth parameters:

Asymptotic length (L_∞) was 19.4 cm, growth coefficient (K) was 0.54 year^{-1} and theoretical age at zero length (t_0) was – 0.34 years. Index for growth performance was 2.309 year^{-1} with longevity (T_{max}) calculated as 6 years.

Mortality parameters:

Total instantaneous mortality rate (Z) was 1.84 year^{-1}. The instantaneous natural rate (M) was 1.30 year^{-1} and fishing mortality rate (F) estimated at 0.54 year^{-1}. Exploitation rate (E) was 0.29. F_{max} was estimated at 0.31 year^{-1}. F_{limit} was 0.87 year^{-1} while the precautionary target reference point (Fopt) was 0.52 year^{-1} (Fig. 2).

Length at first maturity:

Length at first maturity (Lm_{50}) was 13.0 cm with corresponding age (tm_{50}) as 1.7 years.

Probability of capture:

Length at first capture (Lc_{50}) was 4.1 cm with length at 25 % and 75 % capture estimated as 3.1 cm and 5.1 cm respectively. The corresponding age at first capture (tc_{50}) was 0.1 years. The critical length at capture (Lc) was 0.23 (Fig. 3).

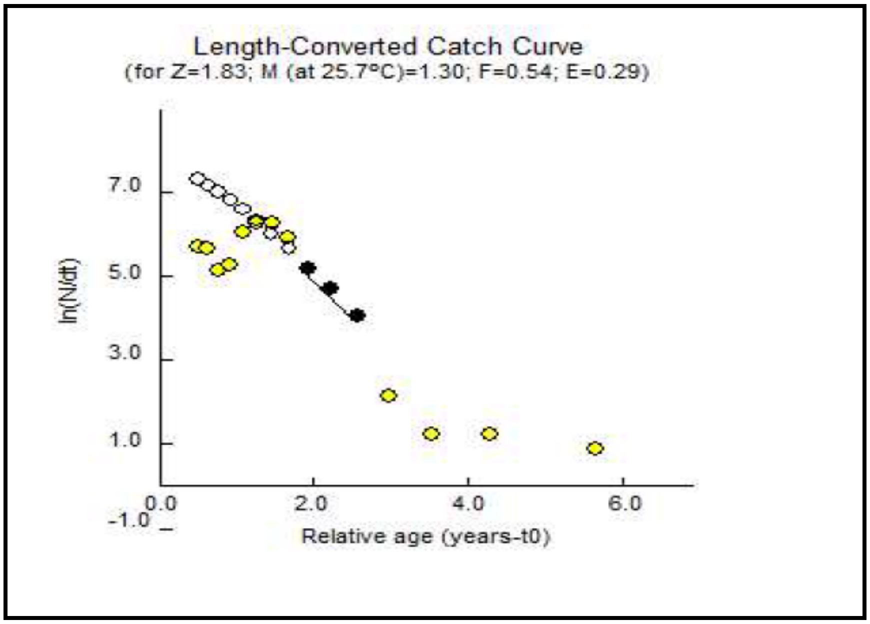

Fig. 2. Total mortality using Length converted catch curve from FiSAT Output

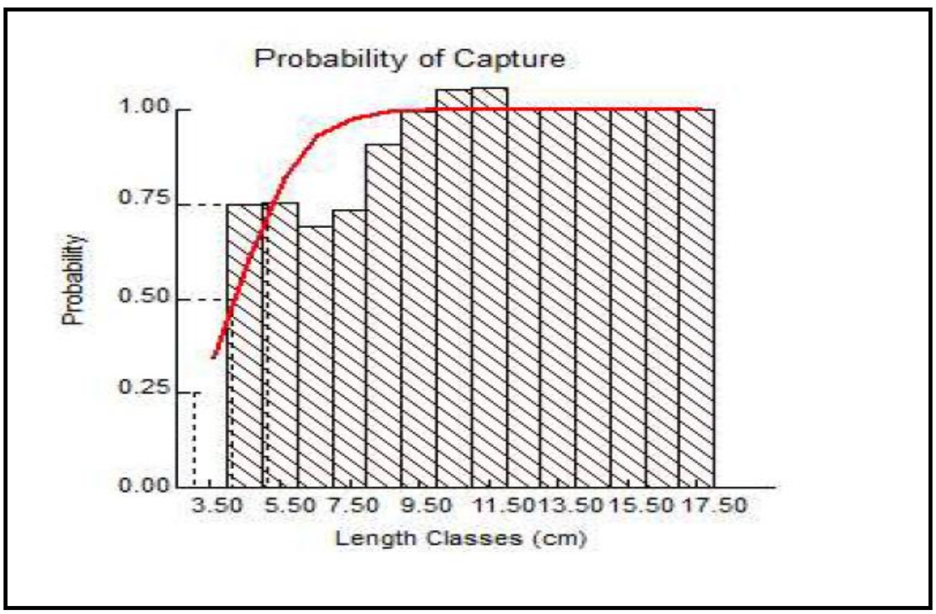

Fig. 3. Probability of capture estimation from FiSAT Output

Recruitment:

The recruitment pattern was continuous with a major and minor peak (Fig. 4). The major peak occurred in March with a recruitment strength of 14.2 % whereas the minor peak occurred in September with a recruitment strength of 10.7 %. The length at first recruitment was 4.5 cm with the respective age at first recruitment (tr_{50}) computed as 0.15 years.

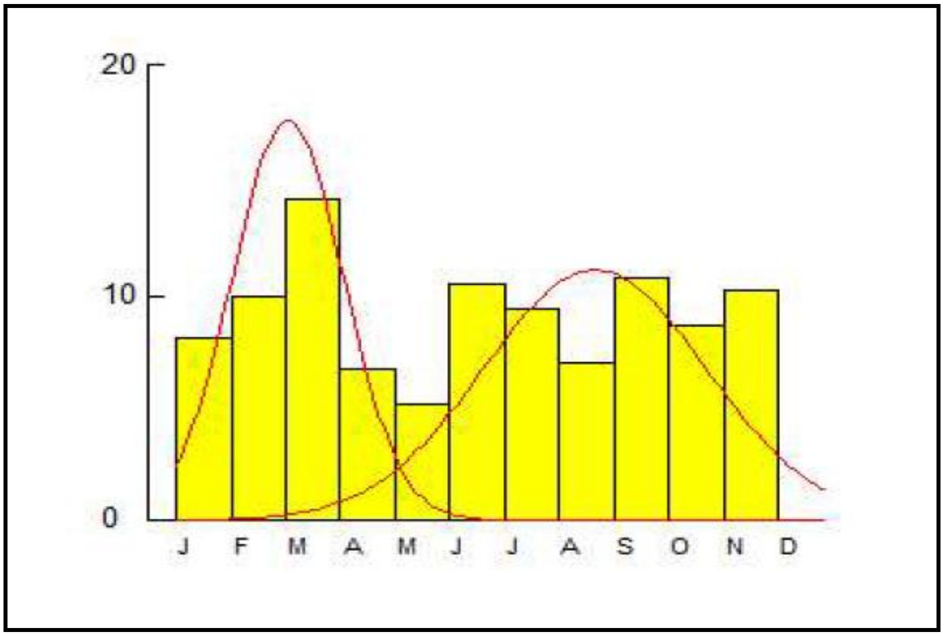

Fig. 4. Recruitment pattern from FiSAT Output

VPA:

Most of the specimen were caught between 10 cm and 11 cm at fishing rate (F) of 1.8 year^{-1}. The highest peak of fishing rate (2.7 year^{-1}) ensued between 14 cm and 15 cm length interval. The values of '*a*' and '*b*' from the length-weight relationship were 0.02 and 2.96, respectively. The terminal fishing rate (Ft) was 0.54 year^{-1} (Fig. 5).

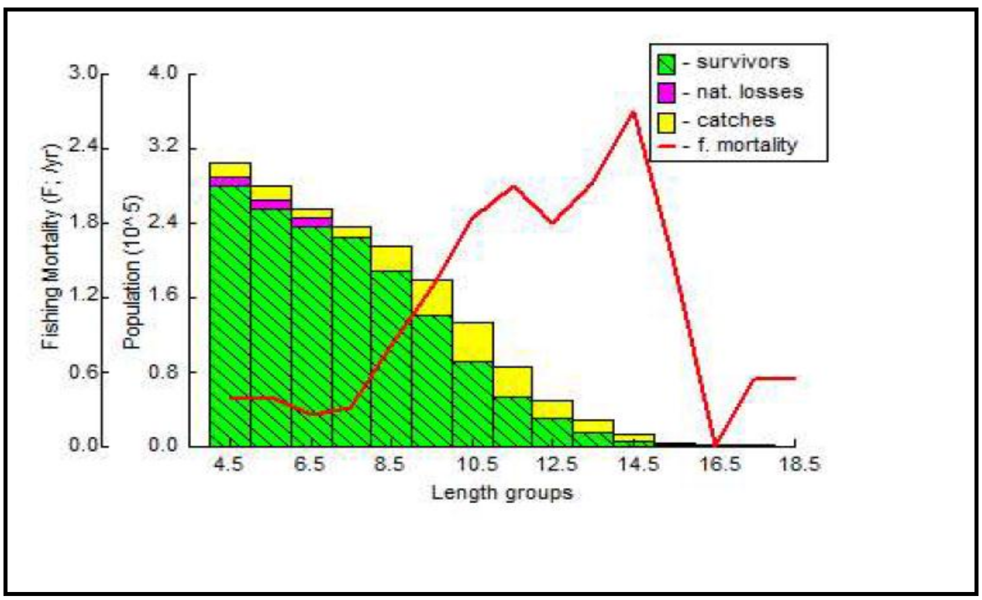

Fig. 5. Population estimation using Length-based VPA from FiSAT output

Relative Yield per recruit and Biomass per recruit:

The estimated exploitation rates, including E_{max}, $E_{0.5}$ and $E_{0.1}$ were 0.48, 0.28 and 0.35, respectively (Fig. 6).

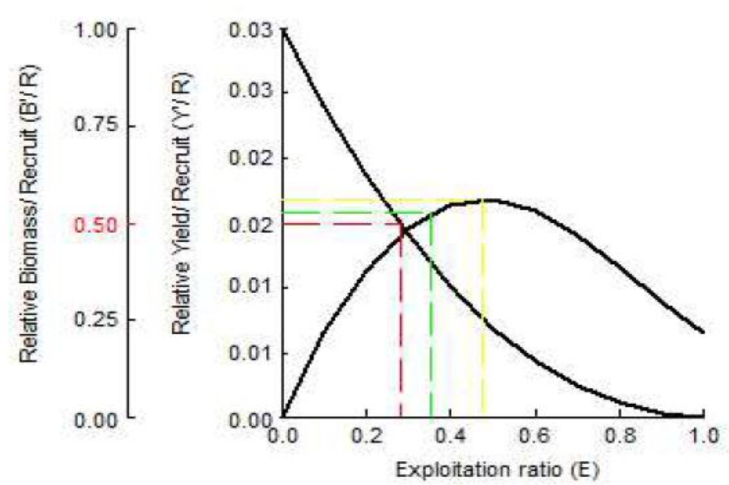

Fig. 6: Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R)

DISCUSSION

The asymptotic length and growth rate obtained from the present study were lower than the results reported by the researchers who worked on *O. niloticus* from the Bontanga Reservoir in the Northern part of Ghana (i.e**. Kwarfo-Apegyah *et al*., 2008**). This observation could be due to climatic variations and continuous fishing of relatively larger sized individuals over time. The growth rate (K) of this study was within the range: 0.34 $year^{-1}$ and 0.67 $year^{-1}$. This signifies that the species is an intermediate growing fish species, evinced by its short life expectancy of 6 years, although slightly higher than the findings by **Kwarfo-Apegyah *et al*. (2008)**. The growth performance index (ϕ') values of African freshwater fishes have been recorded to be between 2.65 and 3.32, portraying low growth performance (**Baijot *et al.*, 1997**). The ϕ' value (2.31) from the present study fell outside the range documented by **Baijot *et al.* (1997)** which indicates a high growth performance of *O. niloticus* in Sakumo II Lagoon. This observation could be attached to factors such as temperature, food availability, metabolic activity, fluctuation in water level and reproductive activity, amongst a host of others as shown in parameters $L\infty$ and K (**Jiménez-Badillo, 2006**). The changes in the water level may be due to tidal fluctuations due to its closeness to the sea.

The length at first capture (Lc_{50}) recorded by **Kwarfo-Apegyah *et al.* (2008)** was 5.5 cm, slightly higher than observed from the current study (Lc_{50} = 4.1 cm). Concerning the current study, the variation in length at first capture of this species may reflect differences in the mesh size of fishing gears used by fishermen (i.e. fishing gears with smaller mesh sizes by fishermen at Sakumo II Lagoon). Additionally, from the current study, the calculated age at first capture (tc_{50} = 0.1 years) was lower than the age at first maturity (tm_{50} = 1.7 years). Also, the VPA output showed that specimens of small sizes (i.e. juveniles) observed greater harvesting rates. Furthermore, the critical length at capture (Lc = 0.27) was lower than 0.5, buttressing the existence of juveniles. These features reveal the presence of growth overfishing. **Ofori-Danson (1999**) and **Kpelly (2010)** studied the population of this species in the Yeji area (Stratum VII) of the Volta Lake and Weija Reservoir, Ghana respectively. Both studies observed an Lm_{50} value of 19.73 cm SL and 13.5 cm – 16.3 cm, respectively. These findings were higher than the value obtained from the current study (Lm_{50} = 13.0 cm). This may be a response to a high level of competition, unfavorable environmental conditions and intense fishing pressure **(Kpelly, 2010).**

The maturity – length ratio of the assessed species from the study was 0.67, approximately 0.7 which corroborates the findings by **Iles (1970)** who documented that tilapias (Cichlidae) with normal growth usually attain an average maturity – length ratio ($Lm_{50}/L\infty$) of 0.70. Again, it was significantly higher than recorded by **Ofori-Danson and Kwarfo-Apegyah (2008)** from the Bontanga Reservoir in the Northern part of Ghana ($Lm_{50}/L\infty$ = 0.40). The normal growth experienced by this species from Sakumo II Lagoon could be linked to the ban on fishing at a certain period of the year **(Ntiamoah-Baidu, 1991).** This traditional management measure allows the species to undergo biological processes like growth without any anthropogenic disturbances. Nonetheless, **Etim and Brey (1994)** documented that when age at first maturity (tm_{50}) becomes greater than 1 year, the collapse of the stock is bound to occur given the present state of exploitation. From the study, tm_{50} was greater than 1 year - signaling the future collapse of the stock if proper management measures are not put in place. To strengthen this claim, Lr_{50} and age tr_{50} were higher than Lc_{50} and tc_{50}, respectively.

The two peaks of recruitment conformed to earlier claims by **Pauly (1984)** that fish species in tropic zones exhibit two peaks. Studies by **Ofori-Danson (1999)** also documented that the population of species follows a bimodal form of recruitment pattern. The presence of a continuous recruitment pattern shows that the population of the assessed species is far from recruitment overfishing. In furtherance to the above, the VPA output showed that the majority of individuals become survivors (recruits) into the stock at Lr_{50} – an indication of active recruitment.

The natural mortality rate was significantly higher than fishing mortality, accounting for 74.1 % of the total mortality rate, thus indicating that the population of the species is natural mortality dominated which could be attributed to the abundance of small sized-individuals (juveniles). Juvenile fishes are most prone to natural mortality induced conditions such as high temperature, predators and fluctuations in climate. Fishing mortality was slightly higher than the optimum fishing mortality rate but lower than the precautionary limit. This suggests that the population of the species is not highly exploited.

Regarding mortality parameters, **Kwarfo-Apegyah *et al*. (2008)** reported similar findings for the population of this species from the Northern part of Ghana. Fishing rate satisfying optimal exploitation of E = 0.5 largely leads to reduced fish stocks, hence to maintain optimum exploitation of fish stock, **Patterson (1992)** suggested that an exploitation rate of E = 0.4 should be maintained. From the study, it appeared that the exploitation rate of *O. niloticus* was lower than 0.4. This finding points to the fact that the species from the Sakumo II Lagoon is under-exploitation. A similar observation was documented by **Kawrfo-Apegyah *et al.* (2008)** who reported an exploitation level of 0.29 for the species from the Bontanga Reservoir in Ghana. The estimated exploitation rate was highly lower than the exploitation ratio at the MEY ($E_{0.1}$) and the MSY (E_{max}), though slightly higher than the biological conservation level ($E_{0.5}$). This supports the earlier assertion that the exploitation of the species is low. Moreover, the ratio low E to the critical length at first capture (Lc) value obtained from the present study suggests the dominance of small-sized individuals (juveniles) in the catch. This observation shows fact that current E is lower than E_{max} which portrays that the fishing techniques applied at Sakumo II Lagoon do not allow the majority of fish the ability to spawn, at least once before being captured **(Froese, 2004**).

CONCLUSION

The study has revealed that *O. niloticus* in the Sakumo II Lagoon, is experiencing growth-overfishing, despite the low level of exploitation. Furthermore, recruitment failure was revealed to be a critical issue in the future, if no proper management measures like mesh size regulation, reduction in fishing effort, reduction in number of working days and enforcement of the ban on ‘no fishing period’ are put in place by relevant authorities such as the Fisheries Commission of Ghana. It is therefore expected that the present results will contribute to the appropriate management of this commercially important resource.

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