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Length based-stock assessment and Spawning Potential Ratio (LB-SPR) of exploited tilapia species (*Coptodon zillii*, Gervais, 1848) in Lake Volta, Ghana

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A B S T R A C T

Length based stock assessment parameters and LBSR of *C. zillii* in Lake Volta were investigated for the purpose of sustainable management. The lengths of 517 individuals were measured from the lake from January to December 2020 and analyzed using TropFishR. The von Bertalanffy parameters including asymptotic length (L_∞), growth rate (K), and growth performance index (Φ) were estimated as 30.4 cm, 0.38 per year, and 2.73 respectively. Total mortality rate (Z), natural mortality rate (M) and fishing mortality rate (F) were 4.58 per year, 0.89 per year and 3.96 per year respectively. The exploitation rate (E) was highly above the exploitation rate at the maximum sustainable yield (Emax) which shows that the fishery of the stock is facing high unsustainable fishing pressure. Based on the findings of the study, it is recommended that fishing pressure be reduced and, mesh size regulation be strictly enforced to ensure sustainability of the stock.

Keywords: *C. zillii*, growth, mortality, TropFishR, Lake Volta, LB-SPR

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Introduction

Native to Africa and the south-western Middle East, are three key taxonomic groups including *Oreochromis*, *Sarotherodon*, and *Coptodon* (Gophen, 2016). They inhabit a variety of fresh and less commonly brackish water habitats, from shallow streams and ponds through the rivers, lakes, and estuaries (Soliman et al. 2017; Komolafe 2008). Tilapia is the common name of more than 70 fish species belonging to the family Cichlidae which undergo under three genera (*Sarotherodon*, *Oreochromis*, and *Tilapia*) (Meyer 2002). It is known that the family Cichlidae have a high economic significance in tropical inland waters in Africa, and they play important role in the ecology of freshwater bodies (Ikomi and Jessa 2003).

Coptodon zillii (Gervais, 1848) is distinguished by its ability to adapt to freshwater, brackish, and hyaline conditions (Mohamed and Abood 2020; Eddine et al. 2016). In Africa, its distribution extends from Morocco and Egypt in the North, Côte d'Ivoire and Nigeria in the West to the Democratic Republic of Congo in Central Africa, reaching a maximum length of 26.0 cm, 289 g weights, and can live for about seven years and, usually found in water depth of up to 1m (Dadebo et al. 2014). It can tolerate a wide range of temperature and salinity and can utilize aquatic vegetation. The family Cichlidae plays an important role in commercial fisheries and aquaculture worldwide. The total landing of cichlid fishes in the world was about 1.6 million tons in 2016 (FAO 2018), and it was the second most important fish in fish farming in the world after carps, with a production of 6.3 million tons in 2018 (FAO 2019). Despite the importance of *C. zillii* and its widespread occurrence, information about its reproductive biology and dynamics is scarce. Nonetheless, in Ghana, numerous studies have been done on the growth, biology, and physiology of *C. zillii* (e.g., Atindana et al. 2014), but there are few studies (e.g., Danson and Apegyah 2009) on its stock assessment.

Stock assessment by Sparre and Venema (1992) provides advice on the optimum exploitation of aquatic living resources. Hilborn and Walters (1992) defined it as a method that involves the use of various statistical and mathematical expressions to make quantitative predictions about the reactions of fish populations to alternative management choices

(Abdul and Omonyi 2011). So, this study was undertaken to provide the basic data on some aspects of the stock assessment including growth parameters, mortality parameters, and exploitation rate for its sustainable management in Ghana.

Materials and Methods

Study Area

The study was undertaken in some selected fishing communities in Yeji which geographically is located between longitude 0°10' and 1°05W and latitude 8°8' and 8°20'N. The selected fishing communities included Tonka, Vutideke, Brekente, and Fante Akura (Figure 1). With a population of 28,515, Yeji is the capital of Pru District in the Brong-Ahafo Region (GSS, 2014). The selection of these sampling inland fishing communities was based on geographical isolation and the level of fishing activities based.

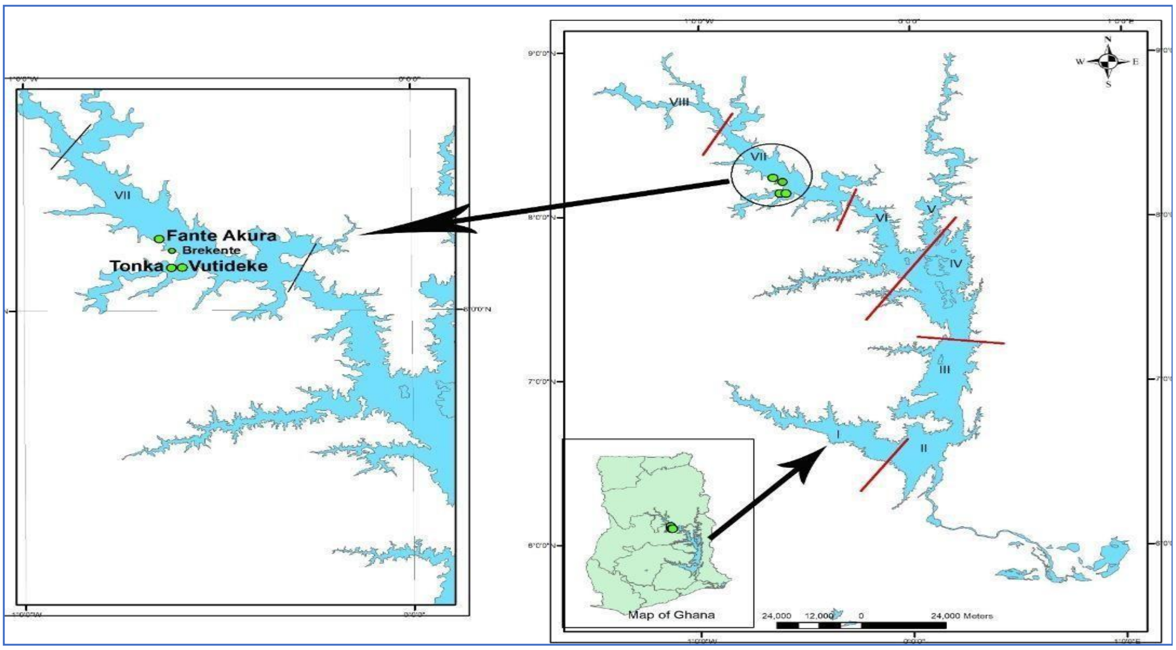

Figure 1. Map showing the study areas within Stratum VII of the Volta Lake, Ghana

Data Collection

Samples of *C. zillii* from Lake Volta, Ghanawere collected from fishermen who landedtheir catch at any of the four sampling locations, over twelve (12) months (i.e., January 2020 to December 2020). Species were identified in-situ using Dankwa et al. (1999) and Lowe-McConnell and Wuddah (1972) identification keys. Measurements of length and weight were performed using a 100 cm graduated wooden measuring board and to the nearest gram of 0.1 g using the digital balance.

Estimation of Parameters Growth Parameters Formulas

Growth parameters including curvature parameter (*K*), asymptotic length (L_∞), growth performance index and theoretical age at length zero (t_o) the growth performance index (Φ′) were estimated using the ELEFAN_ SA. Longevity (t_{max}) of the species was calculated as $t_{max} = 3/K$ (Anato 1999). The growth performance index was estimated as $\Phi' = 2\log L_\infty + \log K$ (Munro and Pauly, 1984). T - zero (t_o) $\log_{10}(-t_0) = -0.3922 - 0.2752 \log_{10} L_\infty - 1.038 \log_{10} K$ (Pauly, 1984).

Mortality Parameters

The total mortality (*Z*) was estimated using linearized length-converted catch curve (Sparre and Venema, 1992). The estimation of natural mortality rate (*M*) followed, $M = 4.118K^{0.73}L\infty^{-0.333}$ (Then et al. 2015). Fishing mortality (*F*) was calculated as Z – M (Qamar et al. 2016). The exploitation rate (*E*) was calculated as F/Z (Georgiev and Kolarov 1962).

Virtual Population Analysis (*VPA*)

VPA is a method that allows for the reconstruction of the population from total catch data by age or length. The initial step was to estimate the terminal population (*Nt*), followed by the successive estimation of F values and finally, the population sizes are computed for each length class (midpoint). These procedures were estimated using the VPA method (Pope 1972).

Yield per recruit

The relative yield-per-recruit was estimated using the knife-edge method (Beverton and Holt 1957).

Length based spawning ratio

The length spawning potential parameters including the length at maturity, gear selectivity at Lc_{50} and Lc_{95} and spawning potential ratio (SPR) were determined using barefoot ecologist toolbox application software by CSIRO (2020) that are commonly used and access directly through a public link via http://barefootecologist.com.au/lbspr.

Results

Length distribution

Table 1 shows the length distribution of *C. zillii* with February, May, July, August and December recording the highest number of samples (i.e N = 53 samples), whereas in September the lowest number of samples were recorded (i.e., N = 24 samples). Overall, 517 samples of *C. zillii* were recorded during the study period. The mean, minimum and maximum lengths of *C. zillii* were estimated as 10.4 cm, 4.7 cm and 22.7 cm respectively.

Table 1. The length-frequency distribution data of *C. zillii*

Lengt hClass (cm)	2020-01-01	2020-02-02	2020-03-03	2020-04-04	2020-05-05	2020-06-06	2020-07-07	2020-08-08	2020-09-09	2020-10-10	2020-11-11	2020-12-12
6	0	3	0	0	0	1	0	0	1	0	0	0
8	6	4	1	7	0	5	0	27	7	5	2	15
10	19	5	24	10	15	4	8	15	5	18	21	20
12	6	16	17	5	18	6	32	5	10	12	13	17
14	3	17	4	3	14	10	7	2	0	8	3	0
16	1	7	1	1	5	1	5	3	1	4	4	0
18	0	1	1	0	0	0	1	1	0	0	1	0
20	0	0	0	0	0	0	0	0	0	0	0	1
22	0	0	0	0	0	1	0	0	0	0	0	0
24	0	0	0	0	1	0	0	0	0	0	0	0
Total	35	53	48	26	53	28	53	53	24	47	44	53

Restructured length frequency of *C. zillii* with superimposed growth curves is shown in Figure 2. The asymptotic length (L_∞) was 30.4 cm with a growth rate (K) of 0.57 per year. Growth performance index (Φ') was 2.73. The longevity (t_{max}) was approximately seven (7) years. The age at zero length (t_o) was estimated as 0.38 years. The Powell Wetherall plot showed Z/K to be 3.03 with a 95% confidence interval of 2.83 – 3.24 (Figure 3).

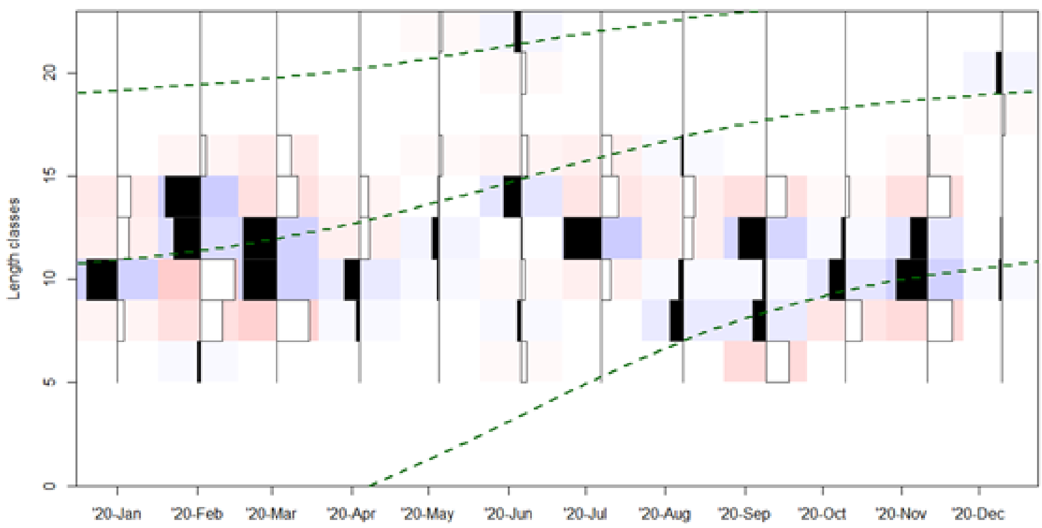

Figure 2. Reconstructed length-frequency distribution with growth curves.

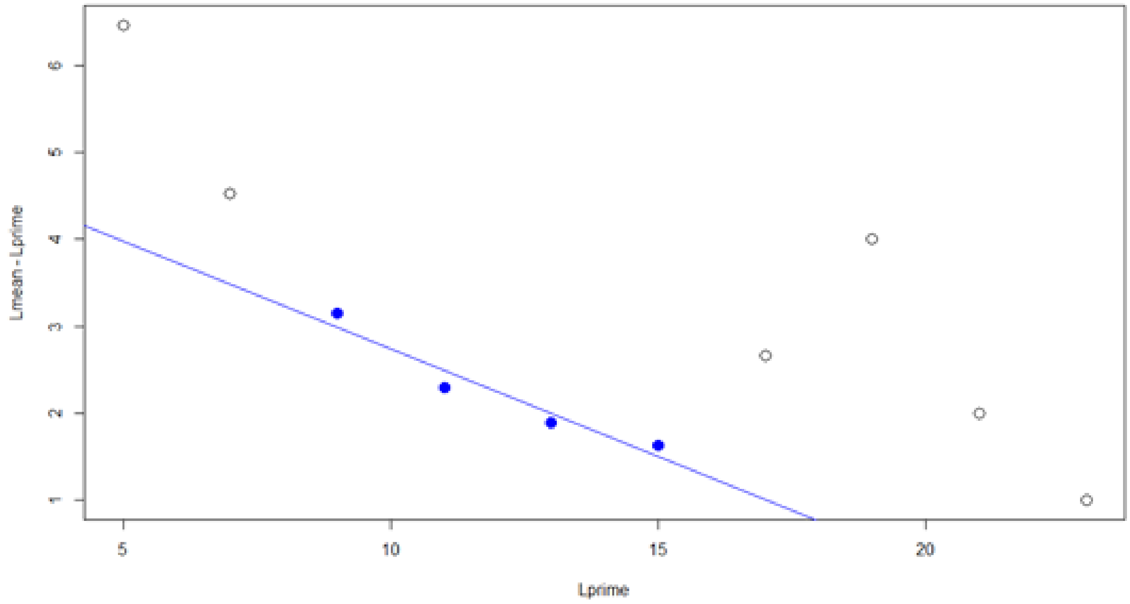

Figure 3. Powell Wetherall Plot of *C. zillii*

Mortality parameters

The linearized length-converted catch curve was used for the estimation of instantaneous total mortality (*Z*) as shown in Figure 4. The total mortality rate (*Z*) was calculated as 4.58 ± 0.68 per year. The natural and fishing mortality rates were estimated at *M*= 0.89 per year and *F* = 3.65 per year respectively. The current exploitation rate (*E*) was obtained at 0.81.

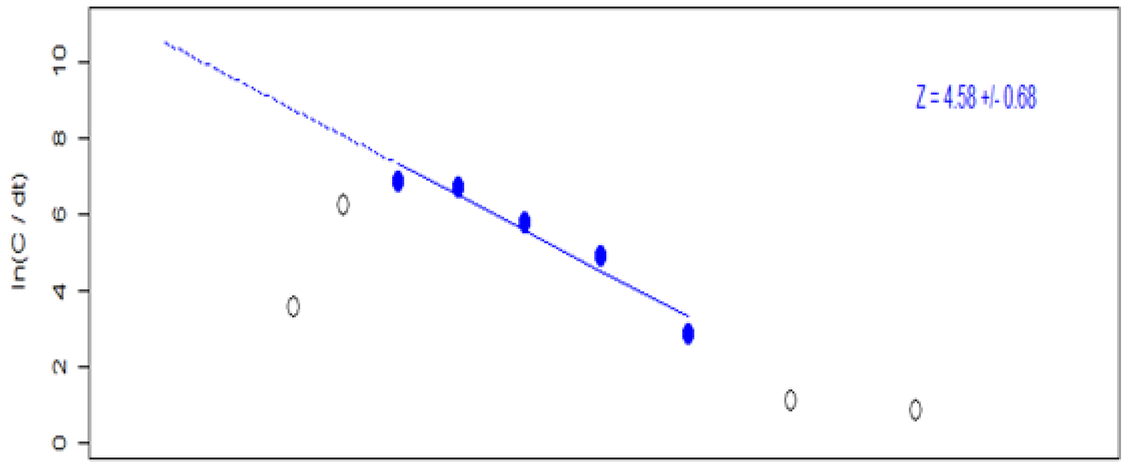

Figure 4. Linearized length-converted catch curve for total mortality estimation (Z).

Virtual Population Analysis

The virtual population analysis of *C. zillii* is shown in Figure 4. Individuals within the range of 16 cm experienced the highest level of exploitation (catch = $7x10^5$ per year). Natural losses were the highest among individuals within the length range of 12 cm. Surviving individuals in the stock exhibited a declining trend with rising fishing pressure. The highest number of survivors in the stock was observed in the length range of 8 cm. Fishing effort was the highest (F = 4.67 per year) on individuals within the length range of 16 cm and the lowest (*F* = 0.04 per year) on individuals at length range of 8 cm (Figure 5).

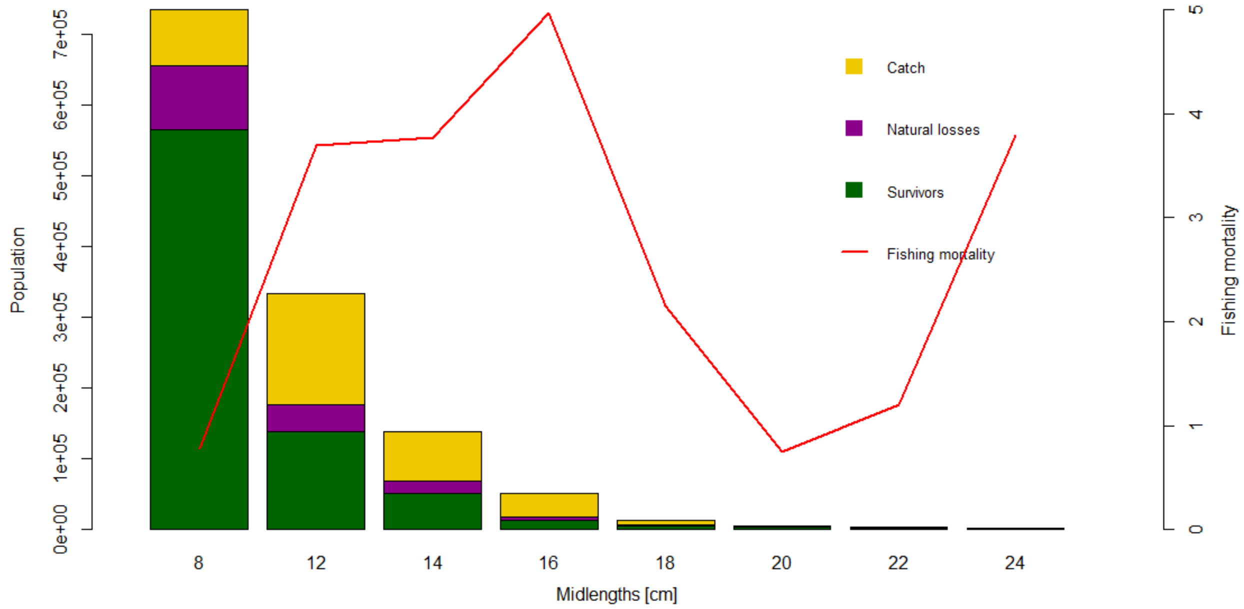

Figure 5. Length structured virtual population analysis of *C. zillii* in Lake Volta

Relative yield per recruit

The plot of relative yield per recruit against fishing mortality showed that the indices for sustainable yield were 0.43 for $F_{0.5}$ and 0.66 F_{msy} as indicated in Figure 6a. The corresponding F0.5 and Fmsy was estimated 0.68 per year and 1.70 per yield.

The isopleth plot in Figure 6b shows that 50% of catch are retained in the gear at a high fishing mortality rate.

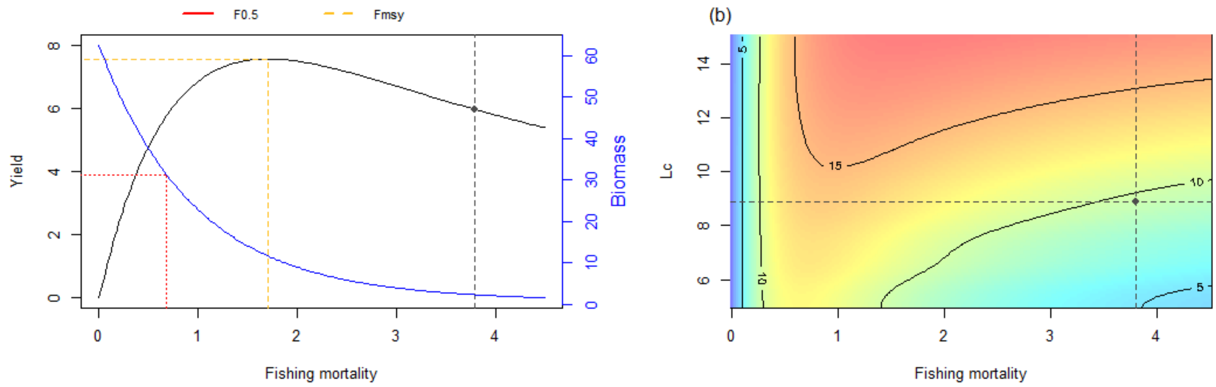

Figure 6. a) Yield-per-recruit plot of *C. zillii* in the Lake Volta. b) Isopleth plot of *C. zillii*

Length based spawning ratio

Observation from Figure 7 shows that the length at first maturity of *C. zillii* was approximately 9.5 cm. The corresponding lengths at capture (Lc) for *C. zillii* were estimated as Lc_{50} = 8.2 cm, and Lc_{95} = 10.4 cm (Figure 7). The Length Based-Spawning potential ratio (LB-SPR) analysis of *C. zillii* was 4% for the total population (Figure 8).

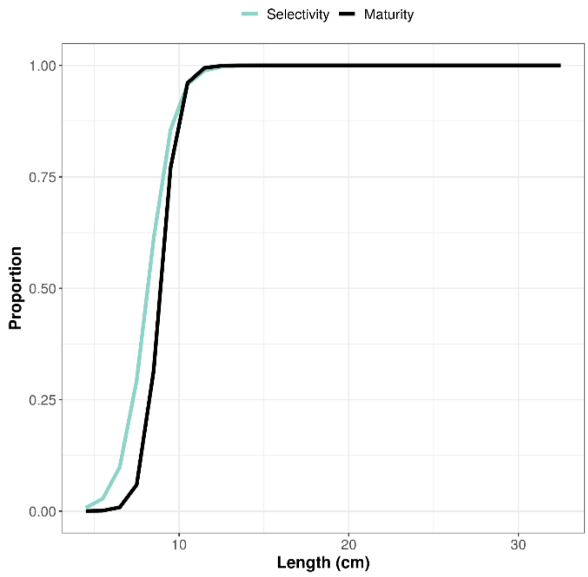

Figure 7. Length at first at maturity (Lm_{50}) and selectivity (Lc_{50})

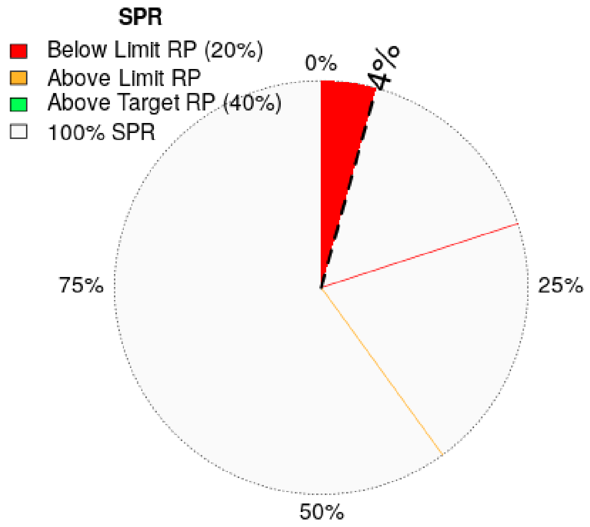

Figure 8. Percentage of SPR of *C. zillii*

Discussion

The growth rate for *C. zillii* estimated for the study was 0.57 per year, relatively higher than estimates from other studies. For instance, Mohamed and Abood (2020), Mehanna (2004), Uneke and Nwani (2014) recorded 0.32 per year, 0.49 per year and 0.46 per year from Iraq, Egypt and Nigeria respectively. Studies by Adeyemi and Akomb (2012) from Nigeria and Mehanna (2004) recorded higher asymptotic length values (i.e., 34.5 cm and 33.5 cm) than recorded from the current study (i.e., 30.4 cm). Nonetheless, the growth performance index from the study (i.e., 2.73) compared favourably with estimates from Adeyemi and Akomb (2012) and Mehanna (2004) who documented 2.72 and 2.74. Factors such as variation in ecological parameters of the habitats, metabolic activity, availability of feed items, genetic constitution of the individuals, fishing pressure and sample size retrieved for analysis (Mohamed and Abood 2020; El-Kasheif et al. 2015) could be the reason for the variation in growth rates. The growth rate from the present study (0.57 per year) signified that *C. zillii* in Lake Volta is a fast-growing species. This characteristic of the species could be a compensation for the existing high level of mortality (Adeyemi and Akombo 2012). This is evinced by the Z/K > 1 which suggests that the population is a mortality dominated one.

From the present study, the fishing mortality rate (F = 3.69 per year) was greater than the natural mortality rate (M = 0.89 per year). Again, the fishing mortality surpassed the fishing rate at the maximum sustainable yield (F_{max} = 1.70 per year). These findings suggest that the population of *C. zillii* in the Lake Volta is exposed to high fishing pressure. Furthermore, the estimated fishing mortality rate from the study was greater than estimates from other locations (i.e., Uneke and

Nwani (2014) and Mohamed and Abood (2020) recorded 2.02 per year and 0.68 per year). This explains that the impact of fishing activities on this species appears to be extremely higher than in these locations and can possibly lead to collapse of its population in the future. In support of this, the current exploitation rate E = 0.81 was significantly higher than the exploitation at the maximum sustainable yield (E_{max} = 0.67).

The estimated length at first capture from the current study for *C. zillii* was 8.20 cm, lower than the length at first maturity (Lm_{50}) of 9.5 cm. This suggests that many of the individuals of this species are not given the opportunity to spawn at least once before becoming vulnerable to the fishing gear. In such cases, growth overfishing maybe present with recruitment overfishing becoming possible in the future.

Length-based VPA analysis showed that the number of individuals of the species subjected to natural losses as well as the number of survivors declined as they matured. This clearly shows that recruitment into the stock may be reduced to the barest minimum in the future if proper measures are not put in place. The SPR was lower than the limit reference point of 20% which shows low proportion of mature stock to be recruited into the population. The decrease in the SPR level maybe assigned to the decline in selectivity and matured stock. The threshold value of SPR is 40% which can be accepted as a proxy for the Maximum Sustainable Yield (MSY) for recruitment overfishing in a less resilient fish population. This alludes to the earlier claim that recruitment overfishing within the population is possible in the future.

The study has shown that *C. zillii* from Lake Volta is a fast-growing species with a growth rate of 0.57 per year. Findings from the mortality parameters suggests that species is overexploited ($E > E_{max}$). Furthermore, findings from the SPR, Lm_{50} and Lc_{50} revealed that population of the species is exposed to growth overfishing and consequently recruitment overfishing which could have serious implications on food security and economic wellbeing of dependent households. Summarily proper fisheries management measures such as mesh size regulations should be put in place in order to ensure sustainable exploitation of the species.

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