Assessment of Growth, Reproduction, Recruitment and Virtual Population Analysis of Invasive Species, *Coptodon zilllii* in Garmat Ali River, Iraq

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Abstract: Coptodon zillii has been an invasive fish in Iraqi waters since 2007 and now well established and dominating in different water bodies of the country. The aim of this article is to evaluate the growth, mortality, probability of capture, recruitment pattern, reproduction, yield-per-recruit and virtual population analysis of this species in the Garmat Ali River, Iraq from September 2018 and August 2019. The length and weight of the species were between 7.7 cm and 23.2 cm and 50 g to 144.0 g, respectively. The results of the relationship between them indicate positive allometric growth. The population parameters, including asymptotic length (L_∞= 27.0 cm), growth coefficient (K= 0.270), and growth performance index (Φ'= 2.294) were computed. The estimated total length at first capture (L_c) was 14.87 cm, and the first maturity (L_m) lengths were 8.2 and 8.4 cm for males and females, respectively. The recruitment pattern of *C. zillii* was continuous throughout the year with bimodal recruitment. This study showed higher fishing mortality than natural mortality. The current exploitation rate was lowly elevated compared to $E_{0.1}$ and E_{max}. Virtual population analysis exhibited that mid-lengths (14-18 cm) were exposed to the highest fishing mortality. Thus, the fishing activities must be increased to obtain higher yields that could be considered from the species for use as animal forage or for export by increasing the fishing activities through increasing fishing efforts and decreasing the mesh-size nets used by the fishermen.

Key-Words: - Coptodon zillii, Growth, Reproduction, Mortality, Yield-per-recruit, Garmat Ali River, Iraq.

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1 Introduction

The Cichlidae family is one of the major families of fish with 348 genera, 2332 available species and 1755 valid species [1]. Cichlids are a group of subtropical to tropical freshwater fish of Cichlidae that are native to Africa and the south-western Middle East and inhabit a variety of fresh and less commonly brackish water habitats, from shallow streams and ponds through the rivers, lakes and estuaries [2]. Cichlids have been intentionally dispersed worldwide for the biological control of aquatic weeds and insects, as well as baitfish, ornamental and commercial purposes [3], but their invasion into non-native freshwater ecosystems may alter phytoplankton community structure, nutrient availability and water quality, causing the deterioration of the ecological state of the impacted ecosystems [4; 5; 6; 7].

The redbelly tilapia, *Coptodon zillii* (Gervais, 1848) is a member of the Cichlidae family that invaded Iraqi waters and early recorded from the Euphrates River near Musaib City, middle of Iraq [9; 10]. Later, *C. zillii* was documented in the main outfall drain in south Iraq in 2009 by Mutlak and Al-Faisal [11] and became widely distributed in different natural waters of the country [12; 13; 14; 15; 16]. The total landing of *C. zillii* within other invaded tilapia species, *Oreochromis niloticus* and *O. aureus* in Basrah province in 2021 was 394.9 t, about 16.7% of the total fish landings [17].

Several studies have been conducted on the stock assessment of *C. zillii* by different authors in its distribution areas using FiSAT II software, especially in the Egyptian waters such as Mehanna [18] in Wadi El-Raiyan Lakes, Mahmoud and Mazrouh [19] in Rosetta branch, Nile River, Mahomoud et al. [20] in Lake Timsah, Mahmoud et al. [21] in Nozha Hydrodrome and El-Bokhty and El-Far [22] in Nile River, Aswan, and the Cross River basin, Nigeria [23], and Lake Volta, Ghana [24]. In Iraq, the growth, mortality, recruitment and yield-per-recruit of *C. zillii* from the Shatt Al-Arab River have been studied by Mohamed [25], and the current study is the second study on the species.

The present work covers growth, mortality and exploitation rates, length at first capture, recruitment pattern, reproduction, biological target reference points and virtual population analysis of the *C. zillii* population in the Garmat Ali River, north of Basrah, to provide information for proper management of this species.

2 Materials and Methods

Monthly random samples were collected from three sites along the Garmat Ali River, north of Basrah city. The first site is located near Al-Najeebia Bridge opposite the Naval Academy site, the second site is located near Garmat Ali Bridge, and the third site is located at the upper river before its confluence with the East Hammar marsh (Fig. 1). The sampling was performed with the help of local fishermen using gill nets, cast nets and electro-fishing from September 2018 to August 2019 [26]. At the time of the catch, the water surface temperature was recorded with a simple thermometer. The samples were taken fresh and examined in the laboratory.

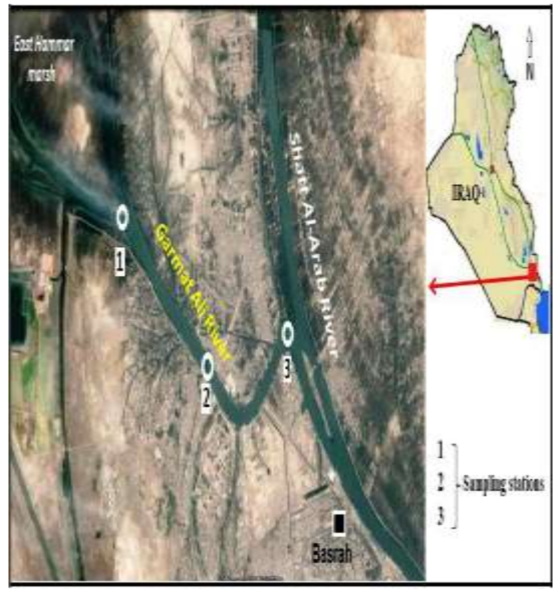

Fig. 1: Map of Garmat Ali River with locations of study sites.

The total length of the individual samples was measured with the help of a measuring board to the nearest 0.1 cm. The body weight of the individual was also determined to the nearest 0.1g. The length-weight relationship was computed using the power equation following Le Cren [27]: $W = a \times L^b$, where a the intercept and b is the slope (growth coefficient). To test the b (slope) value against the value of 3, the Student's t-test was employed to predict the type of growth, isometric or allometric [28]. However, the length-weight relationship was established on Microsoft Excel version 10.

The individual fish specimen was dissected and the gonads were removed to determine sex and weighed to the nearest 0.001 g to calculate the gonad-somatic index (GSI) as:

GSI= (Gonad weight/Body weight)*100 [29].

The length at first sexual maturity for both sexes was estimated from the length at which 50% of fish were mature [30].

The length frequency data were pooled into bimonthly periods from the three stations, subsequently categorized into class intervals of 1.0 cm, which were used to calculate the population characteristics using the FiSAT II computer software package (FAO-ICLARM Stock Assessment Tools) as explained by Gayanilo et al., [31].

The parameters of the von Bertalanffy growth function (VBGF), asymptotic length (L∝) and growth coefficient (K) were estimated using the ELEFAN-I routine incorporated in the FiSAT software. The K scan routine was conducted to assess a reliable estimate of the K value. The estimates of L_∞ and K were then used to estimate the growth performance index (Ǿ) using the equation $\log_{10} K + 2 \log_{10} L_\infty$ [32]. The potential longevity was estimated as $t_{max} = t_o + 3/K$ [33].

The instantaneous rate of total mortality (Z) was estimated by the length converted catch curve module of the FiSAT-II program, and the natural mortality was calculated by the same program using the mean annual water temperature in the study area as 24.6ºC. The fishing mortality (F) was estimated by the following equation, F= Z-M, and the present exploitation rate ($E_{present}$) was calculated by the following equation, i.e., E= F/Z [34].

The Probability of capture at different lengths was estimated from the length-converted catch curve using L∞ and K parameters as in the FiSAT-II package. The estimates of the values of L_{25}, L_{50} and L_{75} represent different lengths at which 25%, 50% and 75% of the fish will be vulnerable to the fishing gear [32]. The L_{50} represents the size at which 50% of the catches are retained by the gear or 50% of the recruits are under full exploitation.

The recruitment pattern of the stock was determined by backward projection on the length axis of the set of available length frequency data as described in FiSAT software. With the length-frequency data, asymptotic length (L∞), growth coefficient (K) and growth performance index (Ǿ) as input parameters to fit the recruitment pattern with one or two normal distributions (pulses) per year, indicating the relative strength of each pulse.

The relative yield-per-recruit (Y'/R) and relative biomass-per-recruit (B'/R) models were estimated for the species using the knife-edge analysis of Beverton and Holt [35] as modified by Pauly and Soriano [36] and incorporated in FiSAT software. The data of L_c/L_∞ and M/K values were used to estimate $E_{0.1}$ (maximum economic yield), $E_{0.5}$ (optimum sustainable yield) and E_{max} (maximum sustainable yield). The present exploitation rate ($E_{present}$) and the biological target reference points ($E_{0.1}$ and E_{max}) were used to indicate the stock status [37].

The length-frequency data also were used to carry out virtual population analysis (VPA) for the species using a routine modified from Jones and van Zalinge [38] and incorporated in the FiSAT package to reconstruct the population from size-wise total catch data in the length-frequency samples raised to the total catch [31]. The input parameters in the VPA analysis were L∞, K, M and F, in addition to the constants of the length-weight relationship (a and b), and the outputs were the biomass (tons), the yield (tons), total and fishing mortality and exploitation ratios.

3 Results

3.1 Growth

In the present study, 702 specimens of *C. zillii* were collected, with the length and weight being 7.7 to 23.2 cm and 5.0 to 144.0 g, respectively. The relationship between length and weight was estimated as $W=0.009*L^{3.237}$, $r^2= 0.954$. The t-test revealed that the regression slope (b) was significantly different from value 3 (t= 8.798, P>0.05), which indicates positive allometric growth.

The initial extreme length (L_{max}) value was used in ELEFAN-I, incorporated in the FiSAT package producing the optimum growth curve. The best value of VBGF growth constant (K) was estimated as 0.270 by ELEFAN-I (Fig. 2). The response surface (R_n) was calculated as 0.192 which selected the best combination of growth parameters L∞= 27.0 cm and K= 0.270. The optimized growth curve was superimposed on the restructured length-frequency histograms (Fig. 3). The t_o was estimated as -1.148 years, and the calculated value for the growth performance index (Ǿ) was 2.294, while longevity (t_{max}) was 9.96.

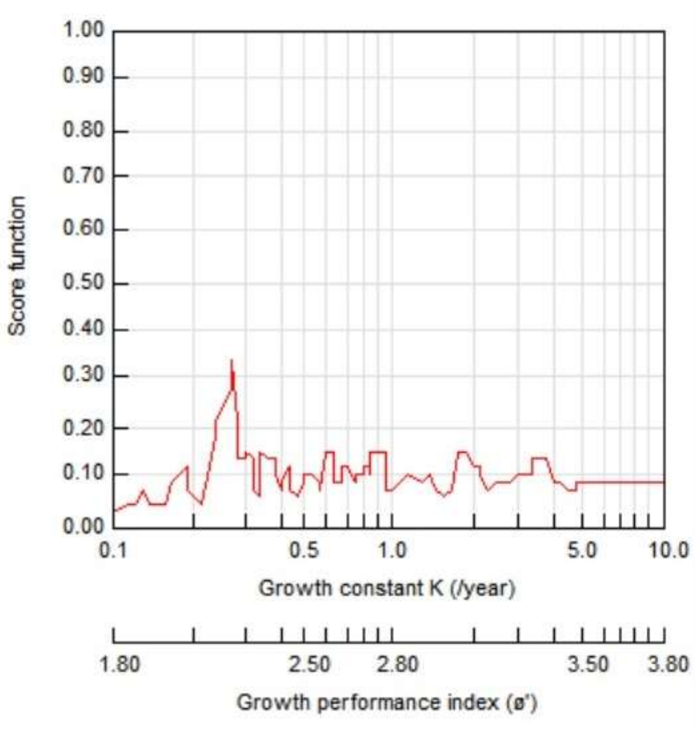

Fig. 2: K-scan routines of *C. zillii.*

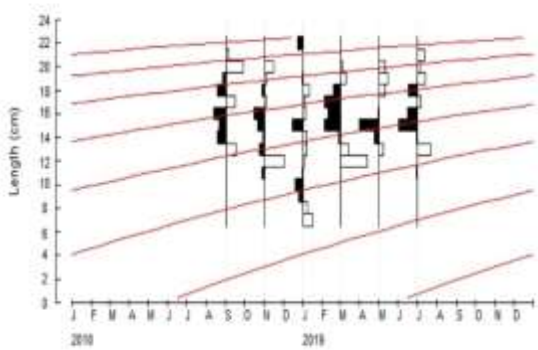

Fig. 3: Restructured length-frequency distribution with growth curves superimposed using ELEFAN-1 for *C. zillii.*

3.2 Mortality and exploitation rates

The total mortality rate *(Z)*, the natural mortality (M) and the fishing mortality (F) were estimated using a length-converted catch curve (Fig. 4). The darkened quadrilaterals represent the points used in calculating *Z* through least squares lines regression. The blank circles represent points either not fully recruited or nearing *L∞* and hence discarded from the calculation. A good fit to the descending right-hand limits of the catch curve was considered. The values of Z, M and F obtained were found to be 1.86, 0.74 and 1.13, respectively. The present exploitation rate ($E_{present}$) was estimated at 0.60.

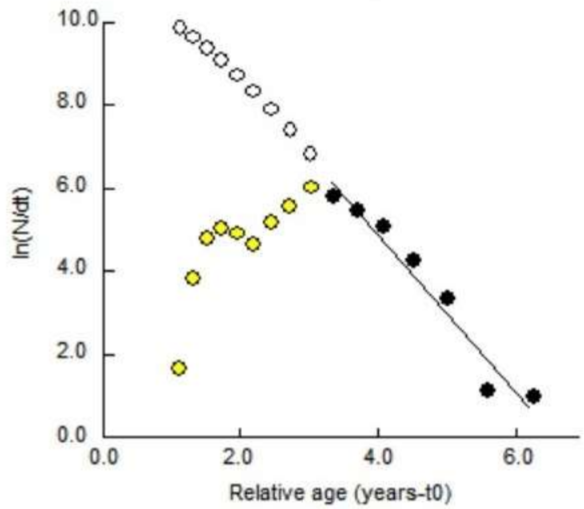

Fig. 4: Length converted catch curves of *C. zillii.*

3.3 Length at first capture (L_{c50})

Figure 5 illustrates the probability of capture of each size class of *C. zillii* for L_{25}, L_{50} and L_{75} based on the length-converted catch curve. The length at first capture (the length at which 50% of the fish are vulnerable to capture) was estimated as L_{c50}= 14.87 cm and the values of L_{25} and L_{75} were found to be 14.07 and 15.75 cm.

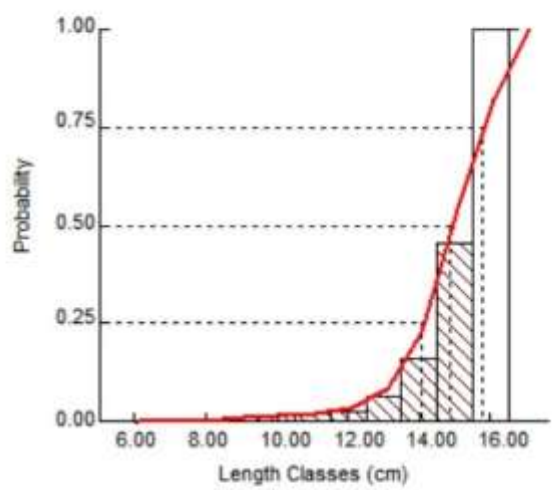

Fig. 5: Probability of capture for *C. zillii.*

3.4 Recruitment

The recruitment pattern of *C. zillii* is presented in Figure 6. There are two modes, i.e. bimodal recruitment of unequal pulse strengths in a year. The first mode occur in March with a percentage of recruitment at 8.36% and the other occurs in July with a percentage of recruitment at 16.73%.

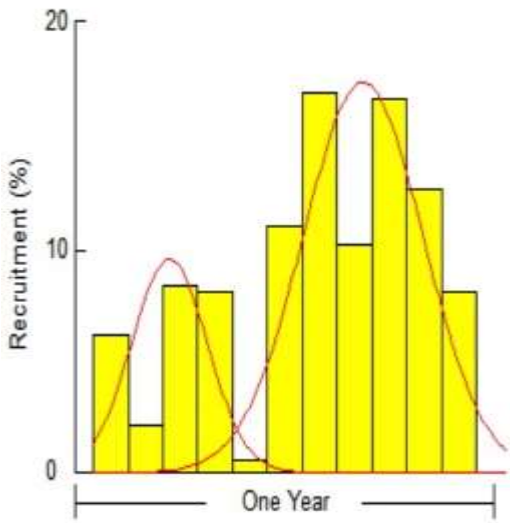

Fig. 6: Recruitment pattern of *C. zillii.*

3.5 Reproduction

From a total number of 545 fish sampled, 201 males and 316 females were detected. A total of 545 fish were analyzed, 302 (55.4%) were males and 243 (44.6%) were females. The overall sex ratio between males and females was found to be 1:0.81 showing the domination of males in the samples and significantly different from the expected ratio of 1:1 (χ^2= 6.39, p= 0.05). The lengths at first maturity (L_{m50}) for males and females were 8.2 and 8.4 cm, respectively caught during February.

The gonad-somatic index (GSI) for both sexes followed nearly the same trend and the GSI values of females were higher than those of males (Fig. 7). However, the highest value of GSI for females (5.35) occurred in April and then gradually dropped to the lowest value (0.04) in July, while the highest value for males occurred in July (1.89) and the lower value (0.02) in August.

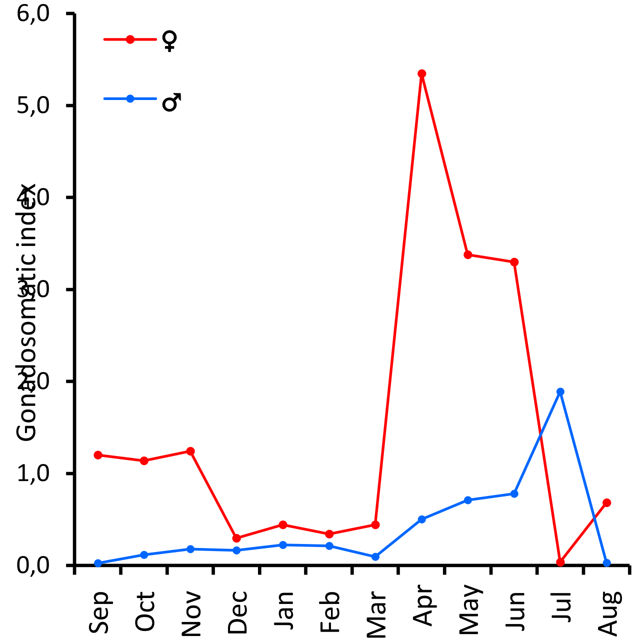

Fig. 7: Monthly variations in the gonad-somatic index of *C. zillii.*

3.6 Biological target reference points

The relative yield-per-recruit (*Y*'/*R*) and biomass-per-recruit (B'/R) models displayed that their values were 0.017 and 0.227, respectively. The results of this analysis produced the following estimated values of $E_{0.1}$, $E_{0.5}$ and E_{max} 0.753, 0.374 and 0.939, respectively (Fig. 8). The present exploitation rate

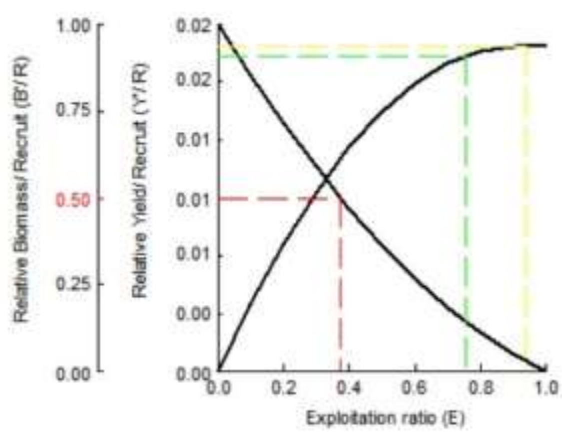

Fig. 8: The biological target reference points of *C. zillii.*

($E_{present}$) was (0.60) below the biological target reference points ($E_{0.1}$ and E_{max}) indicating the stock of *C. zillii* was under an exploitation state.

3.7 Virtual population analysis

The outputs of the length-structured virtual population analysis of *C. zillii* are given in Table 1. Most harvests of the species occurred in mid-lengths of 14-18 cm and attained a maximum value of steady-state biomass (t) of 0.01 t at a total length range of 9-18 cm. The recruitment of the species to the fishery was assessed as 3957 then after the population decrease with increased length groups. The fishing mortality rate increased steadily during the mid-lengths (13-20 cm) for the species, with a maximum fishing mortality rate (1.764/y) at 20 cm. The average value of fishing mortality of the species was 0.576, which was lower than the value estimated by the catch-curve (1.13/y).

Table 1. The outputs from the virtual population analysis of *C. zillii*.

Mid-Length	Catch (in numbers)	Population (N)	Fishing mortality (F)	Steady-state Biomass (tons)
7	1	3956.56	0.0015	0
8	9	3448.84	0.0144	0
9	25	2977.1	0.0442	0.01
10	34	2533.38	0.0672	0.01
11	32	2124.74	0.0713	0.01
12	26	1760.82	0.0659	0.01
13	48	1442.98	0.1409	0.01
14	76	1142.9	0.2684	0.01
15	129	857.38	0.5945	0.01
16	114	567.8	0.759	0.01
17	90	342.65	0.9542	0.01
18	66	182.85	1.2939	0.01
19	33	79.11	1.4261	0
20	15	28.98	1.7637	0
21	2	7.69	0.6222	0
22	2	3.31	1.13	0
Average			0.576	

Figure 9 illustrates the yields of the virtual population analysis (VPA) of *C. zillii* in the present study about natural losses, survivability and fishing mortality. The natural losses and survivability of the individuals in the stock exhibited declining trends with rising fishing pressure on the species. While, the fishing mortality value of the species increased steadily to the maximum value of 1.764 within the length range of 20 cm, after which there was a decline at lengths 21 and 22 cm.

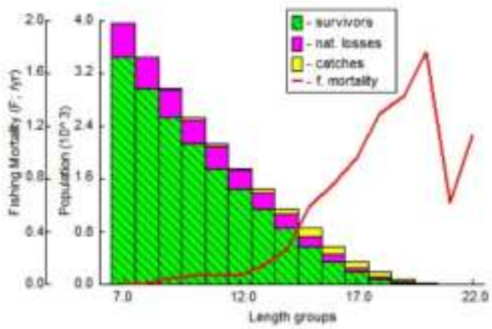

Fig. 9: Length-structured virtual population analysis of *C. zillii*.

4 Discussion

In the present study, the growth of *C. zillii* demonstrated a positive allometric growth according to the value of the growth coefficient (b) of the length-weight relationship of the species. Riedel et al. [39] stated when b value is approximately 3, the fish will follow an isometric growth pattern, when b value is significantly different from 3, the fish will follow allometric growth, but if b>3, the fish will follow the positive allometric, and the fish will often become shorter and fatter and if b<3, fish will follow the negative allometric growth, and will become elongated during the growth process. Our results are in agreement with the growth of the species in the Umhfein Lake, Libya [40] and in the Gbedikere Lake, Nigeria [41]. A negative allometric growth pattern has been reported in *C. zillii* the Lake Zwai, Ethiopia by Negassa and Getahun [42] and in some Egyptian waters [43; 44; 20]. On the other hand, other studies about this species reported isometric growth in other Egyptian waters [18; 19]. Sex, gonad maturity, the health of the fish, degree of stomach fullness, environment, season and number and sizes of specimens examined were the main factors that can be affected by the length-weight relationship in fish [45; 46; 47].

The stock assessment information on growth and mortality estimates for *C. zilli* in the current study with those reported by the various authors in different regions are illustrated in Table 2. The asymptotic length ($L\infty$) for *C. zillii* in the current study was lower than those recorded for the species in some Egyptian waters, for instance, Wadi EL-Raiyan Lakes and Nozha Hydrodrome [18; 21] and in Lake Volta, Ghana [24], whereas compared favorably with estimates from other waters. The growth rate (K) for the species estimated for the study was lower than estimates from other studies, except that in the Nozha Hydrodrome, Egypt [21]. Moreover, the growth performance index (**ø**) from the study (i.e., 2.29) was lower than those recorded for the species in Wadi EL-Raiyan Lakes, Egypt [18] and in Lake Volta, Ghana [24], whereas compared favorably with assessments from other waters. The length of the species at first capture (L_c) in the present study was relatively higher than estimates from other studies. Factors such as variations in the ecological parameters of the

Table 2. Stock assessment information on growth and mortality estimates for *C. zillii* in different ecosystems

Location		L∞	K	t_o	ø	L_c	Z	M	F	E	Author
Wadi EL-Raiyan Lakes, Egypt		33.5	0.49	-0.15	2.74	11.5	1.10	0.20	0.90	0.82	[18]
Rosetta branch, Nile River, Egypt		16.5	0.50	-0.15	2.13	7.5	2.41	1.09	1.32	0.55	[19]
Lake Timsah, Egypt	♂	22.1	0.32	-1.41	2.19	-	2.66	0.46	2.19	0.83	[20]
	♀	17.8	0.68	-0.30	2.34	-	1.88	0.38	1.50	0.78	
Nozha Hydrodrome, Egypt		33.4	0.20	-0.35	2.36	13.0	0.83	0.53	0.30	0.37	[21]
Cross River Basin, Nigeria		27.8	0.46	-	-	11.9	3.16	1.14	2.02	0.64	[23]
Aswan, Nile River, Egypt		19.4	1.4	-	-	13.4	5.60	2.38	3.22	0.57	[22]
Shatt Al-Arab River		25.5	0.32	-0.79	2.32	13.0	1.51	0.84	0.68	0.45	[25]
Lake Volta, Ghana		30.4	0.57	0.38	2.73		4.58	0.89	3.65	0.81	[24]
Garmat Ali river		27.0	0.27	-1.15	2.29	14.9	1.86	0.74	1.13	0.60	This study

habitats, the metabolic activity, availability of feed items, reproductive activity, the genetic constitution of the individuals, fishing pressure and sample size retrieved for analysis [48; 49; 50; 51] could be the reason for the variation in growth parameters in different geographic locations.

The comparison of the rates of total mortality (Z), natural mortality (E), fishing mortality (F) and present exploitation rate ($E_{present}$) of *C. zillii* obtained in this study with those stated by the various authors in different regions are shown in Table 2. The values of Z, M, F and E_{cur} of the species obtained in the present study were within the ranges of these parameters detected in different geographic locations of the species. Mahmoud et al. [21] documented the lowest value of Z (0.83) for the species in Nozha Hydrodrome, Egypt, while the highest value (5.60) was found in Aswan, Nile River, Egypt [22]. The natural mortality (M) extended from 0.20 in Wadi EL-Raiyan Lakes, Egypt [18] to 2.38 in Aswan, Nile River, Egypt [22], while the fishing mortality rate for the species ranged from 0.30 in Nozha Hydrodrome, Egypt [21] to 3.65 in Lake Volta, Ghana [24]. Moreover, the exploitation rate (E) of the species varied from 0.37 for Nozha Hydrodrome, Egypt [21] to 0.83 for the males of the species from Lake Timsah, Egypt [20].

The results revealed that the estimated length at first capture (L_c) for *C. zillii* in the present study was 14.9 cm and was higher than those stated for the species in other geographic locations. Mahmoud and Mazrouh [19] documented the lowest value of L_c (7.5 cm) for the species in the Rosetta branch, Nile River, Egypt. Moreover, the lengths at first maturity (L_{m50}) for males and females of the species in the current study were 8.2 and 8.4 cm, respectively. El-Sayed and Moharram [52] stated that L_{m50} for females and males of *C. zillii* in Abu Qir Bay, Egypt was attained at the length of 8.7 cm and 9.7 cm, respectively. Mahomoud et al. [20] found that the smallest mature male in Lake Timsah, Egypt was 8.4 cm and the female was 7.5 cm. The length at first sexual maturity was 9.8 cm for males and 11.0 cm for females of the species in Cross River, Nigeria [53]. These differences may be attributed to differences in genetic and environmental conditions such as food supply, population density and changes in temperature and salinity [20]. Ghazwan [54] pointed out that the phenomenon of early sexual maturity of *C. zillii* might be influenced by such factors during the early stages of its life and it acquires different levels of masculine or feminine hormones such as androgen and estrogen that affect the genes and genetic control in bodies of this species. Therefore, it can be concluded that the estimated length at first capture (L_c) in this study was higher than the length at first maturity (L_{m50}), which means that the species catch did not meet the criteria for good management ($L_{c50} < L_{m50}$), i.e. they may be vulnerable to capture by the available fishing gear before they mature so that every individual would get at least one chance to breed in their lifetime, which would help renew the stock over the long term [55; 51].

The recruitment pattern of *C. zillii* in the present study reveals that the significant pulse occurs in July and the minor one in March. The two unequal recruitment pulses were also obtained by Kwarfo-Apegyah and Ofori-Danson [56] in the Bontanga Reservoir, Ghana, Abdul and Omoniyi [57] in the Ogun estuary, Nigeria and Uneke and Nwani [23] in the mid-Cross River basin, Nigeria. However, Mohamed and Abood [58] found one seasonal pulse for *C. zillii* in the Shatt Al-Arab River, Iraq, extended from February to May, which accounts for 63.9% of the recruits. The recruitment pattern is associated with the spawning time [59]. Monthly variations in the gonad-somatic index (GSI) for both sexes of *C. zillii* revealed that the spawning season in the study river extended from April to June. State of gonad maturation and gonad-somatic index (GSI) values showed that *C. zillii* in Lake Zwai breeds all year round with peak activities between April and September [42]. Mahomoud et al. [20] found that the period from January to August represented the spawning period of *C. zillii* in Lake Timsah, Egypt. Uneke and Nwani [53] point out that GSI of *C. zillii* in Cross River, Nigeria showed higher values during the period from May to September with a peak in June, while the lower ones occurred during the period from October to February. Variations in the timing of spawning may be linked to age, size, condition and other factors such as geographic distribution, climatic conditions, and nutritional status of fish [60; 61].

The biological reference points are the performance indicator of the fish stock, it often takes various stock dynamics parameters, such as growth, recruitment and mortality, and reflects them to a single index [62; 63]. The present exploitation rate ($E_{present}$) was below the biological target reference points ($E_{0.1}$ and E_{max}) indicating the stock of *C. zillii* was under exploitation state [36]. This agrees with the findings of other authors on *C. zillii* stock in some waters, such as in the Rosetta branch of the Nile River, Egypt [19], in Ogun estuary, Nigeria [57], in Nozha Hydrodrome, Alexandria, Egypt [21], in the River Nile, Aswan region, Egypt [22], in the mid-Cross River basin, Nigeria [23]. Conversely, other studies found that the species was overexploited, such as in Wadi El-Raiyan Lakes, Egypt [18], in Lake Timsah, Egypt [20] and Lake Volta, Ghana [24]. Also, the estimated length at first capture (L_c) in this study was higher than the length at first maturity (L_{m50}). Moreover, the outputs of the virtual population analysis (VPA) revealed that most harvests of the species occurred in mid-lengths of 14-18 cm, with a maximum fishing mortality rate at a length of 20 cm.

King [63] stated that the overall purpose of fisheries science is to provide decision-makers with advice on the relative merits of alternative management, and this advice may include predictions of the reaction of stock and fishers to varying levels of fishing effort and conventionally, including an estimate of the level of fishing effort required to obtain the maximum yield that may be taken from stock on a sustainable basis. Simoes Vitule et al. [] (2009) indicated that invasive freshwater species are often the culprits driving biodiversity loss, either directly through biotic interactions or indirectly by affecting the availability of essential resources, facilitating the spread of infectious disease, or through hybridization with native taxa. The impacts of cichlids introduced on native fish and their habitats were well documented [3]. Tabasian et al. [8] stated that *C. zillii* may compete for food and space with the native fish species and remove macrophytes and phytoplankton, which leads to ecosystem-level changes in the wetland. Also, the cichlids are little desired by the Iraqis compared to exotic and indigenous cyprinids. Therefore, for management purposes, the study suggests that more harvests can be obtained by increasing the fishing activities of this invaded species, such as increasing the number of fishing boats (fishing efforts) and decreasing the mesh size for use as animal forage or for export and therefore decline its abundance in the long term.

5 Conclusions

The results of this study revealed that *C. zillii* mature early, the length at the first capture was much greater than the length at the first maturity, most catches of the species happened in mid-lengths of 14-18 cm, and the stock was under exploitation. So, more harvest could be obtained by a reasonable decrease in the size of the first capture and increase the fishing activities through increasing the fishing efforts by the fishermen to decline its abundance in the long term.

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Conflict of Interest
The author has declared that no competing interests exist.

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