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Stock predictions and virtual population analysis of three invasive fish species in the Shatt Al-Arab River, Iraq

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A B S T R A C T

Carassius auratus, *Oreochromis aureus* and *Coptodon zillii* are invaded fish in the Iraqi waters and are well established and considered one of the dominant species in different natural waters of the country. The stock predictions and virtual population analysis of these species in the Shatt Al-Arab River were studied from November 2015 to October 2016 using the FiSAT II software. A total of 1,511 individuals of C. auratus, 1,353 O. aureus and 1,285 C. zillii were measured to analyze the length-frequencies. The growth was positive allometric for all species. The asymptotic length ($L\infty$) was computed as 21.2, 27.0 and 29.3 cm for C. auratus, O. aureus and C. zillii, respectively. The rates of total mortality (Z), fishing (F), natural (M) and exploitation (E) for C. auratus were 2.69, 1.09, 1.60 and 0.59, O. aureus 2.49, 1.08, 1.41 and 0.57 and C. zillii 1.51, 0.84, 0.68 and 0.45, respectively. The present exploitation rates (E) for O. aureus and C. zillii are lower than the biological target reference points for both species expressing a case of under-exploitation of both species, while C. auratus was operating nearby the exploited situation. Virtual population analysis (VPA) showed that the maximum fishing mortality for the three species occurred in the mid-lengths, with maximum values at the length of 16 cm for C. auratus and O. aureus and 15 cm for C. zillii. Therefore, the present study proposes that more yields can get through increasing the fishing activities on these invasive species, such as increasing the number of fishing boats and decreasing the mesh size to decline their abundances in the long term.

1. INTRODUCTION

1.1. Research Background

The virtual population analysis (VPA) is a modelling technique commonly used in fisheries science for reconstructing the historical fish numbers at age or length using the information on the deaths of individuals in each year, and the deaths are usually partitioned into catch by fisheries and natural mortality, to calculate the population that must have been in the water to produce this catch [1,2]. Ref. [3] stated that the assessment of fish population is essential to meet one of the main objectives of fishery science, that of maximizing yield to fisheries while safeguarding the long-term viability of populations and ecosystems.

Ref. [4] indicated that the 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. During the last decades, thirteen exotic fish have been brought into Iraqi waters as biological control agents (i.e., Gambusia holbrooki; Heteropneustes fossilis; Ctenophryngodon idella) or for aquaculture (i.e., Cyprinus carpio; Hypophthalmichthys molitrix; Hypophthalmichthy nobilis). Others which are majorities, such as Carassius auratus, Carasobarbus sublimes, Hemiculter leucisculus, Oreochromis aureus, Coptodon zilli, O. niloticus and Poecilia latipinna have been invaded Iraqi waters in different ways [5,6,7].

The Shatt Al-Arab River was subjected to multiple impacts due to suffering from the drastic reduction in water quantity and quality related to the decline in rates of the flows from the Tigris and the Euphrates Rivers [8] and diverted off the Karun River into Iranian terrene [9], as well the huge amount of agricultural runoff wastes and untreated wastewater [10]. Under these conditions, the saltwater intrusion further upstream up to 100 km into the Shatt Al-Arab River during dry years and the deterioration of water quality. Ref. [11] reviewed the exotic fish in the river and found all these thirteen species in this river..

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1.2. Literature Review

Crucian carp C. auratus (Linnaeus, 1758) is a member of the family Cyprinidae of the order Cypriniformes. It is native to Eastern Asia which inhabit rivers, lakes, ponds and ditches with stagnant or slow-flowing water and has successfully established populations throughout Europe, North and South America, New Zealand and Australia [12]. The crucian carp is an invasive species to inland waters of Iraq in a way that is not been known. Now, C. auratus is well established, easily became one of the dominant species and is widespread throughout the different natural waters of the country [13-17,7,18]. The contribution of C. auratus in the inland fisheries of the Basrah province during 2017-2019 was 3.9% [19].

The blue tilapia, O. aureus (Steindachner, 1864) and redbelly tilapia Coptodon zillii are members of the Cichlidae. The family is native to Africa and the south-western Middle East and can be found today in other waters inhabiting a variety of fresh and less commonly brackish water habitats, from shallow streams and ponds through the rivers, lakes and estuaries [20]. Tilapia species are invasive fish in Iraqi waters in ways that are not been known, and early records show that C. zillii was caught from the Euphrates River near Musaib city, middle of Iraq [21]. Currently, these two species are well established and dominate the fish populations in various Iraqi waters [16,22,7,23-27]. Tilapias species constituted 15.4% of the inland fisheries of the Basrah province during 2017-2019 [19].

The virtual population analysis of cichlids has been studied by some investigators in some reservoirs in the world using FiSAT II (FAO-ICLARM Stock Assessment Tools) software, such as [28] in the Kaptai Reservoir, Bangladesh, [29] in two reservoirs of the Walawe river basin, Sri Lanka and [30] in Minneriya, Udawalawe and Victoria Reservoirs, Sri Lanka. Ref. [31] evaluated the population characteristics and virtual population analysis (VPA) of O. niloticus and O. aureus from the Garmat Ali River, Iraq.

1.3. Research Objective

There is no study on the virtual population analysis of C. auratus and C. zillii in Iraqi waters. Therefore, the present work described the growth, stock predictions and virtual population analysis of three invasive species (C. auratus, O. aureus and C. zillii) in the Shatt Al-Arab River to manage these fish stocks in this river.

2. MATERIALS AND METHODS

2.1. 2.1. Study area

The Shatt Al-Arab River is formed from the confluence of the Tigris and Euphrates rivers at Al-Qurna town northern Basra Governorate and flows in the southeastern direction towards the Arabian Gulf (Fig. 1). It is about 204 km and varies in width from 250 m at Al-Qurna to more than 1,500 m at the estuary. The river is affected by the tidal current of the Gulf. Data were obtained from three sites on the Shatt Al-Arab River (Fig. 1), near Al-Dair Bridge, Abu Al-Khasib district and north Fao town [7] from November 2015 to October 2016.

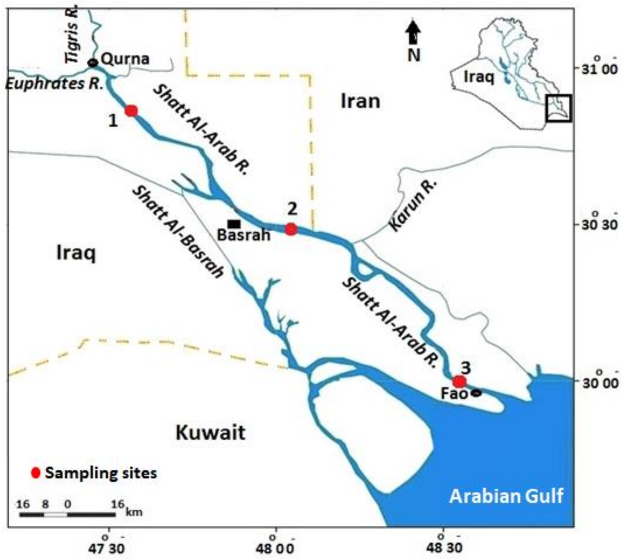

Fig. 1. Map of the Shatt Al-Arab River with locations of sampling sites.

2.2. Fish sampling

A total of 1,511 individuals of *C. auratus*, 1,353 *O. aureus* and 1,285 *C. zillii* were collected monthly from the three sites in the river. The fish was caught using gill nets, cast nets and electro-fishing [7]. After capture, the fish samples were immediately iced and transported to the laboratory for measuring the length (to the nearest 0.1 cm) and weight (to the nearest 0.5 g) of each fish.

2.2. 2.3. Data analysis

The monthly samples of length measurements for all species were grouped into 1-cm intervals, sequentially arranged according to a time series of 12 months. The data were analyzed using FiSAT II software (FAO-ICLARM Stock Assessment Tools, ver. 1.2.2)[32].

The length-weight relationships for each species were established using the exponential regression equation $W = a \times L^b$, where W was the body weight in g, L was the total length in cm, "a" is the intercept and "b" is the regression coefficient [33]. The value of "b" was tested to see if it was statistically different from 3.

Asymptotic length ($L\infty$) and growth rate (K) were computed by using the ELEFAN-I routine of the FiSAT II software, which allows the fitted curve through the maximum number of peaks of the length-frequency distribution. With the help of the goodness of fit value (R_n), growth constant (K) and asymptotic length ($L\infty$) were assessed [33,11].

For the estimation of total mortality rates, the linearized length converted catch curve method (Pauly, 1983) was applied as described in the FiSAT software using the input parameters $L\infty$ and K. The natural mortality coefficient (M) was estimated using Ref. [34] empirical formula as follows:

$$\log_{10} M = -0.0066 - 0.279 \log_{10} L\infty + 0.6543 \log_{10} K + 0.463 \log_{10} T$$

The mean annual water temperature was 24.6 °C [7]. Thus, the fishing mortality rate (F) was calculated from the relation F= (Z-M).

The relative yield-per-recruit (Y'/R) and relative per recruit (B'/R) were estimated by the knife-edge analysis of Ref. [35] as a modified model by Ref. [36] fitted in the FiSAT II routine using $L_c/L\infty$ and M/K as input parameters to estimate the biological target reference points ($E_{0.1}$ and E_{max}), where $E_{0.1}$ is the exploitation rate at which the marginal increase of relative yield-per-recruit is $1/10^{th}$ of its value at E=0 and E_{max} is the exploitation rate which produces maximum yield [37].

The virtual population analysis (VPA) is a routine modified from Ref. [38] and incorporated in the FiSAT package. The input for VPA included "a" and "b" constants from the length-weight relationship, fishing mortality (F), natural mortality (M), asymptotic length ($L\infty$) and growth rate (K) for each species. The routine allows the reconstruction of the population from total catch data by length to determine the array of (F) for each length class.

The initial step is to estimate the terminal population (N_t) given the inputs, from:

$$N_t = C_t \cdot (M + F_t)/F_t,$$

where C_t is the terminal catch (i.e., the catch taken from the largest length class).

Then, starting from N_t, successive values of F are estimated, by iteratively solving:

$$C_i = N_{i+\Delta t} \cdot (F_i/Z_i) \cdot (\exp(Z_i \cdot \Delta t_i)-1),$$

where $\Delta t_i = (t_i+1 - t_i)$, and $t_i = t_o - (1/K) \cdot \ln(1-(L_i/L\infty))$, and where population sizes (N_i) are computed from:

$$N_i = N_{i+\Delta t} \cdot \exp(Z_i)$$

The last two equations are used alternatively, until the population sizes and fishing mortality for all length groups have been computed [32]. An F-array representing the fishing mortality for each length group, the reconstructed population (in numbers), and the mean stock biomass by length class were made using FiSAT II. The results of the VPA analysis were the biomass (tons), the yield (tons), total and fishing mortality and exploitation ratios.

3. RESULTS AND DISCUSSION

3.1. Growth

Table 1 summarizes the sample size, length and weight ranges, length-weight relationship constants (a and b), and correlation coefficient (r^2) for each species. The length and weight of *C. auratus* was 4.6 to 26.8 cm and 1.3 to 371.7 g, respectively, for *O. aureus* ranged between 4.5 and 25.0 cm and their weight varied between 1.9 to 312.0 g, and for *C. zillii* was 2.9-24.0 cm and 0.4-312.0 g. The t-test revealed that the regression slopes (b) in the length-weight relationships for the species were significantly different from value 3 (t= 5.875, $p<0.05$ for *C. auratus*, 2.24, $p<0.05$ for *O. aureus* and t= 9.56, $p<0.05$ for *C. zillii*) indicated positive allometric growth for the three species.

The results of the length-weight relationships in the present study exhibited a positive allometric pattern for *C. auratus*, *O. aureus* and *C. zillii*. Ref. [39] indicated that the positive allometric growth indicates that the fish becomes relatively stouter or deeper-bodied as it increases in length and is designated by a b >3.0. Some studies demonstrated similar findings for these species in some waters [40-42,17,18,43], while some authors reported negative allometric growth for this species in other waters [44-53]. The difference in growth patterns is affected by several factors, including differences in geographical location, fish sizes, season, sex, stage of fish maturity, food availability, stomach fullness, health, stress and sampling methodology [33,54-56].

Table 1. Descriptive statistics and estimated parameters of the length-weight relationships for the three species.

Species	N	Length range (cm)	Weight range (g)	Length-weight relationship		
				a	b	r^2
C. auratus	567	4.6-26.8	1.3-371.7	0.015	3.065	0.993
O. aureus	1082	4.5-25.0	1.9-312.0	0.015	3.058	0.929
C. zillii	852	2.9-24.0	0.4-275.8	0.013	3.159	0.977

The results of growth estimation from the ELEFAN I routine and the mortality rates from the length-converted catch curve analysis for the three species in the studied river are summarized in Table 2. The growth curves of the species superimposed over the restructured length-frequency distributions through the ELEFAN I routine are illustrated in Figure 2. The values of $L\infty$ and K were 30 cm and 0.83, for *C. auratus*, 30 cm and 0.83, for *O. aureus*, and 30 cm and 0.83, respectively for *C. zillii* $L\infty$ = 19.43 cm and K= 1.4 (Table 2). The asymptotic lengths ($L\infty$) for the three species in the present study were better than those recorded for these species in some waters [57,40,46,47,50,58,59], while were lower than those found in other waters [49,51,60,17,43]. The growth of the species in different locations could be affected by several factors, such as ecological conditions, habitat, availability of food, metabolic activity, reproductive activity, sizes of fish, the genetic constitution of the individual, method of sampling and fishing pressure [1,61,62].

3.2. Stock predictions

The total mortality (Z), natural mortality (M) and fishing mortality (F) rates for *C. auratus* were 2.69, 1.09 and 1.60, respectively, while for *O. aureus* were 2.49, 1.08 and 1.41, respectively, and for *C. zillii* were 1.51, 0.84 and 0.68 (Table 2). Moreover, the estimated values of the biological target reference points ($E_{0.1}$ and E_{max}) for *C. auratus* were 0.503 and 0.591, respectively, for *O. aureus* were 0.668 and 0.791, respectively, while for *C. zillii* were 0.751 and 0.938, respectively. The present exploitation rates (E) for *O. aureus* and *C. zillii* are lower than the biological target reference points for both species, whereas the stock of *C. auratus* in the Shatt Al-Arab River was considered as in a status of nearby overfishing. The rates of fishing mortality (F) and the exploitation (E) for *C. auratus* were higher than those observed for *O. aureus* and *C. zillii* in this study. The exploitation (E) values for *C. auratus* and *O. aureus* over the optimum exploitation, tends to be over-exploited according to [63]. However, *C. zillii* was slightly under the optimum level of exploitation, the species is therefore not overexploited in this river. The overexploitation of the three study species in several habitats has been reported by numerous authors [40,47,49,50,60,58,17,43], whereas were unexploited in other waters [57,46,51].

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 [63,37]. In this study, the present

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exploitation rate (E) of *C. auratus* was higher than $E_{0.1}$ and equivalent to E_{max}, thus the stock of this species in the Shatt Al-Arab River was considered as in a status of nearby overfishing. Ref. [17] demonstrated similar findings for the species in the East Hammar marsh, Iraq, where the exploitation rate (E= 0.65) was higher than the values of both $E_{0.1}$ (0.42) and E_{max} (0.52). Conversely, the exploitation rates (E) of *O. aureus* and *C. zillii* in the present study were lower than the biological target reference points ($E_{0.1}$ and E_{max}), which indicates that the stocks are underexploited. Similar findings were observed in *O. aureus* and *C. zillii* stocks in some waters [47,64,51,58,60], while other studies reported that the two species were overexploited [40,49,50].

Table 2. Growth, mortality and exploitation parameters of the three species.

Population parameters	*C. auratus*	*O. aureus*	*C. zillii*
Asymptotic length (L_∞, cm)	29.1	27.8	25.5
Growth coefficient (K)	0.51	0.490	0.32
The goodness of fit (R_n)	0.271	0.214	0.212
Total mortality rate (Z)	2.69	2.49	1.51
Natural mortality rate (M)	1.09	1.08	0.84
Fishing mortality rate (F)	1.60	1.41	0.68
Present exploitation rate ($E_{present}$)	0.59	0.57	0.45
Biological target reference point ($E_{0.1}$)	0.503	0.668	0.751
Biological target reference point (E_{max})	0.591	0.791	0.938

3.3. Virtual population analysis

Table 3 provides the FiSAT II outputs of length-structured virtual population analysis of *C. auratus*, *O. aureus* and *C. zillii*. There were greater harvests (catch and biomass) for mid-length ranging from 11-16 cm for *C. auratus*, from 13-16 cm for *O. aureus* and 12-15 cm for *C. zillii*, with the maximum steady-state biomasses (t) of the three stocks in these lengths. The recruitments of the three species into the fishery were estimated at 5248.7, 5590.5 and 12394.0, respectively, then the populations decreased with the increased length classes. Fishing mortality rates increased steadily between 13-20 cm mid-lengths for *C. auratus*, with maximum fishing mortality rate (2.987/y) at 16 cm mid-length, while for *O. aureus* and *C. zillii* between 14-19 cm with the highest fishing mortality rate (2.249/y) at 16 cm for *O. aureus* and 0.875/y for *C. zillii*. The average values of fishing mortality of the three species were 0.924, 0.812 and 0.255/y, respectively, which were lower than the values estimated by catch-curves, 1.60, 1.41 and 0.68/y, respectively.

The results of the virtual population analysis (VPA) of *C. auratus, O. aureus* and *C. zillii* in the Shatt Al-Arab River about the natural losses, survivability and fishing mortality are demonstrated in figure 3. The natural losses and the survivability of the three fish stocks were declined as they increased in length and fishing mortality. The fishing mortality values for all species were not stable, the highest values 2.99 for *C. auratus* at length 16 cm, 2.25 for *O. aureus* at length 16 cm, and 0.88 for *C. zillii* at length 15 cm, after which a gradual decline, with some fluctuations in fishing mortality values for all species.

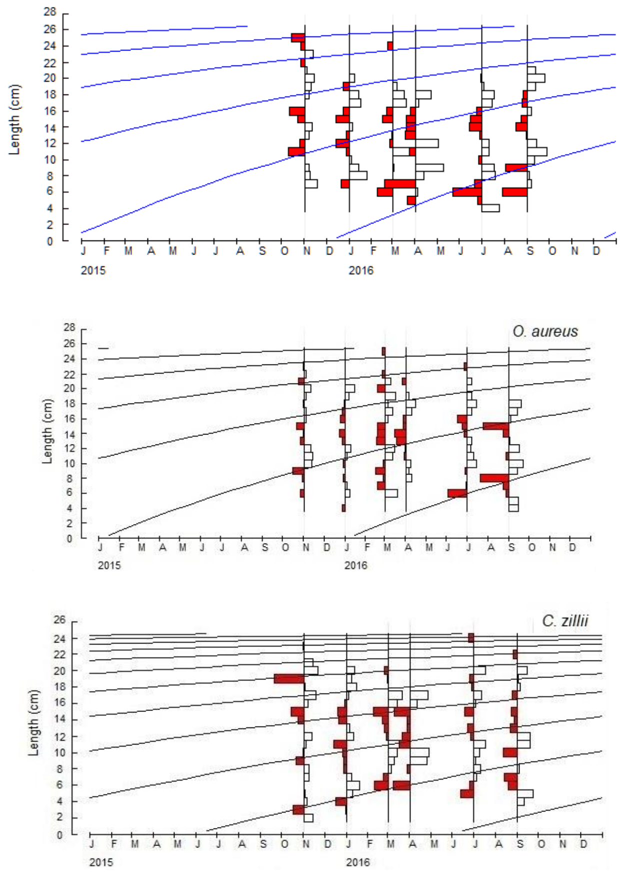

Fig. 2. Growth curves of the three species, by ELEFAN I superimposed on the length-frequency distribution data.

Ref. [64] stated that the virtual population analysis (VPA) is virtual in the sense that the population size is not observed or measured directly but is inferred or back-calculated to have been a certain size in the past to support the observed fish catches and an assumed death rate owing to non-fishery related causes. Virtual population analysis (VPA) showed that the maximum fishing mortality for the three species occurred in the mid-lengths, with maximum values at the length of 16 cm for *C. auratus* and *O. aureus* and 15 cm for *C. zillii*. Further, the estimated values for the length at first capture (L_{50}) of *C. auratus*, *O. aureus* and *C. zillii* in the same river were 10.0, 13.3 and 13.0 cm, respectively [65,59]. There are some studies about the lengths at first maturity (L_m) for these species in nearby waters, the L_m of *C. auratus* in the East Hammar marsh was 12.5 cm [66], while of *O. aureus* and *C. zillii* were 6.6-9.2 and 8.2-8.4 cm in the Garmat Ali River [67,43]. Such a situation suggests that individuals of the species get the chance to join the stock before becoming vulnerable to capture by the available fishing gear. These would enable more females to participate in reproductive activity and allow the young recruits to grow and reproduce to ensure resource availability and sustainability [68].

Table 3. The outputs from the virtual population analysis of the studied species.

Length class (cm)	Catch (numbers)			Population (N)			Fishing mortality (F)			Biomass (tons)		
	C. auratus	*O. aureus*	*C. zillii*	*C. auratus*	*O. aureus*	*C. zillii*	*C. auratus*	*O. aureus*	*C. zillii*	*C. auratus*	*O. aureus*	*C. zillii*
2.0			1.0			12394.0			0.001			0.00
3.0			7.0			11083.0			0.005			0.00
4.0	1.0	2.0	7.0	5248.7	5590.5	9855.8	0.003	0.004	0.005	0.00	0.00	0.00
5.0	23.0	2.0	8.0	4819.3	5094.1	8716.2	0.061	0.005	0.006	0.00	0.00	0.00
6.0	38.0	19.0	23.0	4388.3	4622.7	7660.9	0.107	0.046	0.020	0.00	0.00	0.00
7.0	37.0	37.0	33.0	3964.1	4160.0	6674.4	0.111	0.096	0.032	0.00	0.00	0.01
8.0	17.0	55.0	39.0	3563.4	3706.6	5760.5	0.054	0.153	0.041	0.00	0.00	0.01
9.0	31.0	57.0	56.0	3204.0	3264.1	4921.8	0.105	0.172	0.065	0.00	0.00	0.01
10.0	55.0	38.0	65.0	2851.3	2849.2	4146.0	0.201	0.125	0.085	0.00	0.01	0.01
11.0	107.0	54.0	97.0	2497.4	2481.6	3440.3	0.429	0.193	0.145	0.01	0.01	0.02
12.0	153.0	68.0	116.0	2118.4	2125.9	2781.9	0.696	0.270	0.203	0.01	0.01	0.02
13.0	194.0	188.0	178.0	1726.0	1785.6	2185.1	1.048	0.871	0.378	0.01	0.01	0.02
14.0	218.0	235.0	192.0	1330.2	1364.4	1611.4	1.484	1.390	0.525	0.01	0.01	0.02
15.0	262.0	255.0	227.0	952.1	946.8	1111.9	2.515	2.163	0.875	0.01	0.01	0.02
16.0	193.0	167.0	99.0	576.6	564.4	667.1	2.987	2.249	0.563	0.00	0.01	0.01
17.0	85.0	79.0	52.0	313.1	317.2	420.3	2.153	1.692	0.420	0.00	0.00	0.01
18.0	48.0	45.0	35.0	185.1	187.8	264.3	1.887	1.484	0.407	0.00	0.00	0.01
19.0	25.0	22.0	36.0	109.4	110.1	157.1	1.497	1.097	0.670	0.00	0.00	0.01
20.0	11.0	9.0	6.0	66.2	66.4	75.9	0.953	0.643	0.183	0.00	0.00	0.00
21.0	3.0	10.0	3.0	42.6	42.3	42.4	0.344	1.068	0.140	0.00	0.00	0.00
22.0	2.0	5.0	3.0	30.1	22.2	21.4	0.289	0.887	0.244	0.00	0.00	0.00
23.0	1.0	5.0	1.0	20.5	11.1	8.1	0.184	1.855	0.174	0.00	0.00	0.00
24.0	3.0	0.0	1.0	13.6	3.2	2.2	0.805	0.000	0.680	0.00	0.00	0.00
25.0	3.0	1.0		6.6	1.8		1.742	1.410		0.00	0.00	
26.0	1.0			1.7			1.600			0.00		
Mean							0.924	0.812	0.255			

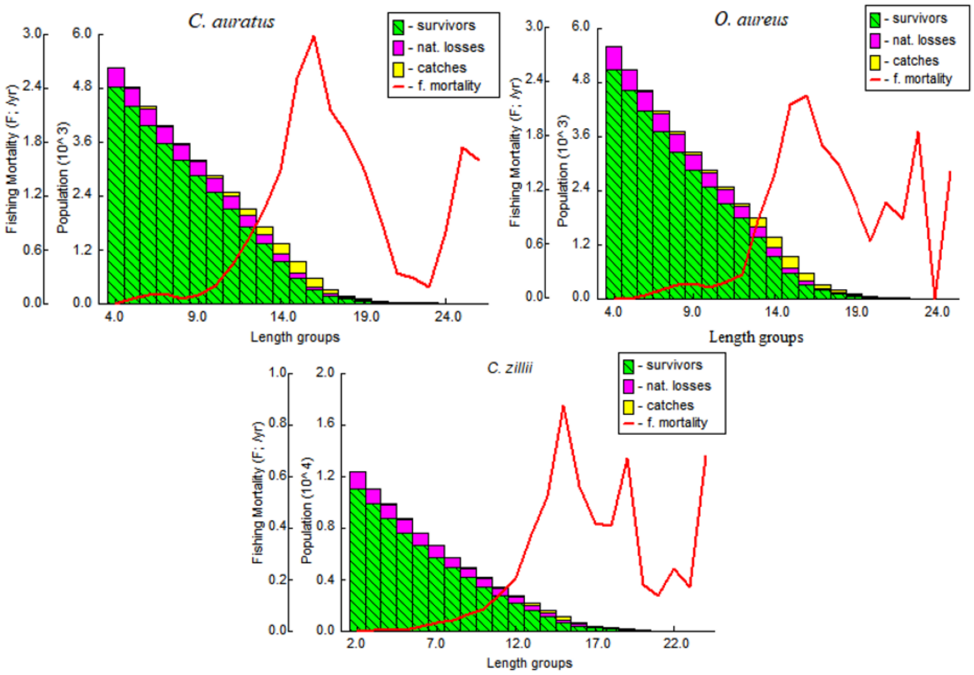

Fig. 3. Length-structured virtual population analysis of the studied species.

Ref. [69] stated that the **o**verall 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, include an estimate of the level of fishing effort required to obtain the maximum weight or yield that

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may be taken from stock on a sustainable basis. The impacts of cyprinids and cichlids introduced upon native fish and their habitats were well documented in several countries [70-73]. As the three fish species are invaders to Iraqi waters and these species are not popular table fish in Iraq, maybe due to their novelty in Iraq or their relatively unimportant sizes compared to exotic and indigenous cyprinids, therefore conservation measures to protect these species, such as the closed season, controls of fish size caught, control of fishing effort and stock enhancement, are not recommended.

4. CONCLUSION

Accordingly, the present study proposes that the officials in fishery management can get more yields through increasing the fishing activities on these invasive species, such as increasing the number of fishing boats and decreasing the mesh size to decline their abundances in the long term.

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REFERENCE

[1] Sparre, P. and Venema, S.C. Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fisheries Technical Paper. No. 306. 1, Rev. 2. FAO, Rome, Italy. 1998.

[2] Baharti, V. Virtual population analysis. In A. Gopalakrishnan (Ed.) Advanced Methods for Fish Stock Assessment and Fisheries Management. ICAR-Central Marine Fisheries Research Institute, Kochi, India 2017. p.232-237.

[3] [3] Jenning, S., Kasier, M. and Reynold, J. Marine Fisheries Ecology. Blackwell Science, Oxford. 2000.

[4] [4] Simoes Vitule, J.R., Freire, C.A. and Simberloff, D. Introduction of non-native freshwater fish can certainly be bad. Fish and Fisheries, 2009. 10: 98-108. DOI:10.1111/J.1467-2979. 2008.00312.X.

[5] Jawad, L. A. Impact of environmental change on the freshwater fish fauna of Iraq. International Journal of Environmental Studies, 2003. 60: 581-593. DOI: 10.1080/ 0020723032000087934.

[6] Coad, W.B. Freshwater Fishes of Iraq. Pensoft Publishers, Sofia, Bulgaria. 2010.

[7] Mohamed, A.R.M. and Abood, A.N. Compositional change in fish assemblage structure in Shatt Al-Arab River, Iraq. Asian Journal of Applied Sciences, 2017. 5(5): 944-958. DOI: 10.24203/ AJAS.V5I5.4983.

[8] Al-Mahmood, H.K.H, Hassan, W.F., Alhello, A.Z.A., Hammood, A.I. and Muhson, N.K. Impact of low discharge and drought of the water quality of the Shatt Al-Arab and Al-Basrah Rivers (south of Iraq). Journal of International Academic Research for Multidisciplinary, 2015. 3(1): 285-296.

[9] Hameed, A.H. and Aljorany, Y.S. Investigation on nutrient behavior along Shatt Al-Arab River River, Basrah, Iraq. Journal of Applied Sciences Research, 2011. 7: 1340-1345.

[10] Eassa, A.M., Jassim W.F., Al-Maliki J.H., Al-Saad T.R., and Mehson N.K. Assessment of eutrophication and organic pollution status of Shatt Al- Arab River by using diatom indices. Mesopotamia Environmental Journal, 2015. 1(3): 44-56.

[11] Mohamed A.R.M. and Abood, A. N. Dispersal of the exotic fish in the Shatt Al-Arab River, Iraq. Journal of Agriculture and Veterinary Science, 2017. 10(8): 50 -57. DOI: 10.9790/2380-1008025057.

[12] Lorenzoni, M., Ghetti, L., Pedicillo, G. and Carosi, A. Analysis of the biological features of the goldfish Carassius auratus auratus in Lake Trasimeno (Umbria, Italy) with a view to drawing up plans for population control. Folia Zoologica, 2010. 59 (2): 142-156. DOI: 10.25225/fozo.v59.i2.a9.2010.

[13] AI-Rudainy, A.J., Mohamed, A.R.M. and Abbas, L.M. Ecology and biodiversity of fish community in Euphrates River at Al-Mussaib Power Station, middle of Iraq. Proceeding of Euro-Arab 2006 Environmental Conference and Exhibition, 27-29th N0vember 2006, Kuwait. pp 624-634.

[14] Mohamed, A.R.M., Hussain, N.A., Al-Noor, S.S, Mutlak, F.M., I. M. Al-Sudani, A. M. Mojer and A. J. Toman. Fish assemblage of restored Al-Hawizeh marsh, Southern Iraq. Ecohydrology and Hydrobiology, 2008. 8(2-4): 375-384. DOI:10.2478/V10104-009-0029-5

[15] Hussain, N.A., Mohamed, A.R.M., Al-Noor, S.S, Mutlak, F.M., Abed, I. M. and Coad, B.W. Structure and ecological indices of fish assemblages in the recently restored Al-Hammar Marsh, Southern Iraq. Bio Risk, 2009. 3: 173-186. DOI: 10.3897/biorisk.3.11.

[16] Mohamed, A. R. M., Hussein, S. A and Lazem, L. F. Spatiotemporal variability of fish assemblage in the Shatt Al-Arab River, Iraq. Basrah Journal of Agricultural Sciences, 2013. 26 (1): 43-59.

[17] Mohamed, A.R.M., Hussein, S.A. and Mutlak F.M. Stock Assessment of four fish species in East Hammar marsh, Iraq. Asian Journal of Applied Sciences, 2016. 4(3): 620-627.

[18] Mohamed, A.R.M. and Al-Jubouri M.O.A. Growth, reproduction and food habit of an invasive species of Carassius auratus in the Al-Diwaniya River, Middle of Iraq. Journal of Applied and Natural Science, 2019. 11(3): 704-711. DOI:10.31018/jans.v11i3.2163.

[19] Mohamed, A.R.M. and Abood, A.N. The current status of inland fisheries in Basrah province, Iraq. International Journal of Fisheries and Aquatic Studies, 2020. 8(5): 120-127. DOI:10.22271/FISH.2020.V8.I5B.2313

[20] Uneke, B.I. Condition Factor of Tilapia Species in Ebonyi River, Southeastern Nigeria. International Journal of Biological Sciences and Applications , 2015. 2(4): 33-36.

[21] Saleh, K.I. First recorded of Tilapia zillii (Gervais, 1848), in natural water of Iraq (Tigris River). The First Scientific Conference of Agricultures College, University of Basra, 2007.p26-27.

[22] Shakir, H.F. and Wahab, N.K. Structure of Fish Community For South East Al-Tharthar Lake in Salah Alddin Province/Iraq. Tikrit Journal for Agricultural Sciences, 2015. 15(2): 111-124.

[23] Mohamed, A.R.M. and Al-Jubouri, M.O.A. Fish assemblage structure in Al-Diwaniya River, middle of Iraq. Asian Journal of Natural and Applied Sciences, 2017. 6(4): 10-20.

[24] Mohamed, A.R.M., Younis, K.H. and Hameed, E.K. The ecological condition of the Garmat Ali River, Iraq. Global Journal of Biology, Agriculture & Health Sciences, 2017. 6(3):13-21. DOI:10.24105/GJBAHS.6.3.1703.

[25] Abdullah, A.H.J., Abdullah, S.A. and Al-Robayii, O.A. Spatial and temporal pattern of sympatric fish assemblage in the Al-Sweib River South of Iraq. Proceedings of the

3rd Agricultural Scientific Conference 5-6 March 2018. The University of Kerbala, 2018. 1-17p.
[26] Abdullah, S.A., Abdullah, A.H.J. and Ouda, Y.W. Diversity and status of fish fauna in the Al-Kahlaa River, in Missan Province-Iraq, with notes on environmental variables. EurAsian Journal of BioSciences, 2019. 13: 1817-1824.
[27] Mohamed, A.R.M. and Salman, A.N. Population dynamics and management of invasive blue tilapia (Oreochromis aureus) in Garmat Ali River, Basrah, Iraq. Asian Journal of Fisheries and Aquatic Research, 2020. 10(2): 44-54. DOI: 10.9734/ajfar/2020/v10i230180.
[28] Ahmed, K.K.U., Amin, S.M.N., Haldar, G.C. and Dewan, S. Population dynamics and stock assessment of Oreochromis niloticus (Linnaeus) in the Kaptai Reservoir, Bangladesh. Indian Journal of Fisheries, 2003. 50(1): 47-52
[29] Athukorala D.A. and Amarasinghe U.S. Population dynamics of commercially important fish species in two reservoirs of the Walawe river basin, Sri Lanka. Asian Fisheries Science, 2010. 23(1): 71-90.
[30] Amarasinghe U.S., Prabath, R.P., Jayasinghe, K. and Moreau, J. Length-based stock assessment of Oreochromis mossambicus and Oreochromis niloticus (Actinopterygii: Perciformes: Cichlidae) in multi-mesh gillnet fisheries in reservoirs of Sri Lanka. Acta Ichthyologica Et Piscatoria, 2017. 47(3): 265-277. DOI:10.3750/AIEP/02147.
[31] Mohamed, A.R.M. Assessment of two cichlids stocks with virtual population analysis in Garmat Ali River, Basrah, Iraq. World Journal of Advanced Research and Reviews, 2022. 13(2): 163-172. DOI: 10.30574/wjarr.2022.13.2.0134.
[32] Gayanilo, F.C.Jr, Sparre, P. and Pauly, D. FAO-ICLARM Stock Assessment Tools II (FiSAT II). Revised version. User's guide. FAO Computerized Information Series (Fisheries), 2005. 8: 1-168.
[33] Pauly, D. Some simple methods for assessment of tropical fish stocks. FAO Fisheries Technical Paper, 1983. 234: 52.
[34] Pauly, D. On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. ICES Journal of Marine Science, 1980. 39(3): 175-192. DOI:10.1093/ICESJMS/39.2.175.
[35] Beverton, R.J.H. and Holt, S.J. Manual of methods for fish stock assessment. Part II. FAO Fisheries Technical Paper, 1966. No. 38, 67p.
[36] Pauly D. and Soriano M.L. Some practical extensions to Beverton and Holt's relative yield-per-recruit model. In J.L. Maclean, L.B. and L.V. Dizon Hosillo (Eds.) The First Asian Fisheries Forum 1986.p.491-496.
[37] Cadima, E.L. Fish stock assessment manual. FAO Fisheries Technical Paper. No. 393. 2003. 161p.
[38] Jones, R. and van Zalinge, N.P. Estimations of mortality rate and population size for shrimp in Kuwait waters. Kuwait Bulletin of Marine Science, 1981. 2: 273-288.
[39] Riedel, R., Caskey, L.M. and Hurlbert, S.H. Length-weight relations and growth rates of dominant fishes of the Salton Sea: implications for predation by fish-eating birds. Lake and Reservoir Management, 2007. 23: 528-535. DOI:10.1080/07438140709354036.
[40] [40] Mehanna, S.F. Population dynamics of two Cichlids, Oreochromis aureus and Tilapia zillii from Wadi El-Raiyn, Lakes, Egypt. Agricultural and Marine Sciences, 2004. 9(1): 9-16. DOI:10.24200/JAMS.VOL9ISS1PP9-16.
[41] [41] Hadi, A.A. Some observations on the age and growth of Tilapia zillii (GERVAIS, 1848) in Umhfein Lake (Libya). Journal of Science and Its Applications, 2008. 2: 12-21.
[42] Adeyemi, S.O. and Akombo, P.M. A growth and mortality rate of dominant cichlids in Gbedikere Lake, Kogi State, Nigeria. Animal Research International, 2012. 9(1): 1497-1501.
[43] Mohamed, A.R.M. and Al-Wan S.A. Biological aspects of an invasive species of Oreochromis niloticus in the Garmat Ali River, Basrah, Iraq. Journal of Agriculture and Veterinary Science, 2020. 13(2): 15-26. DOI: 10.9790/2380-1302011526.
[44] Negassa, A. and Getahun, A. Breeding season, length-weight relationship and condition factor introduced fish, Tilapia zillii Gerv. 1848 (Pisces: Cichlidae) Lake Zwai, Ethiopia. Ethiopian Journal of Science, 2003. 26(2): 115-122. DOI:10.4314/SINET.V26I2.18207.
[45] Jiménez, B.L. Age-growth models for Tilapia Oreochromis aureus (Perciformes, Cichlidae) of the Infiernillo reservoir, Mexico and reproductive behaviour. Revista De Biologia Tropical, 2006. 54(2): 577-588. DOI: 10.15517/rbt.v54i2.13923.
[46] Abbas, L.M., Al-Rudainy, L.J., Mohamed, A.R.M. and Hussain, T.S. Some biological aspects of the gold fish Carassius auratus (L. 1758) in the Euphrates River, middle of Iraq. Iraqi Journal of Agriculture, 2008. 13: 61-70.
[47] Mahmoud, M.H. and Mazrouh, M.M. Biology and fisheries management of Tilapia species in Rosetta branch of the Nile River, Egypt. Egyptian Journal of Aquatic Research, 2008. 34(3): 272-285. DOI:10.21608/EJABF.2014.2217.
[48] Shalloof, K.A. Some observations on fisheries biology of Tilapia zillii (Gervais, 1848) and Solea vulgaris (Quensel, 1806) in Lake Qarun, Egypt. World Journal of Fish and Marine Sciences, 2009. 1(1): 20-28.
[49] Messina, E.P., Varela, R.T., Abunader, J.I.V., Mendoza, A.A.O. and Arce J.M. Growth, mortality and reproduction of the blue tilapia Oreochromis aureus (Perciformes: Cichlidae) in the Aguamilpa Reservoir, Mexico. Revista De Biologia Tropical, 2010. 58(4): 1577-1586. DOI: 10.15517/rbt.v58i4.5432.
[50] Mahomoud, W.F., Amal, M.M.A., Kamal, F.E.A., Mohamed, R. and Magdy, M.K.O. Reproductive biology and some observation on the age, growth, and management of Tilapia zillii (Gerv, 1848) from Lake Timsah, Egypt. International Journal of Fisheries and Aquaculture, 2011. 3(2): 15-25. DOI:10.5897/IJFA.9000028.
[51] Mahmoud, M.H., Ezzat, A.A., Ali, T.E. and El Samman, A. Fisheries management of cichlid fishes in Nozha Hydrodrome, Alexandria, Egypt. Egyptian Journal of Aquatic Research, 2013. 39(4): 283–289. DOI: 10.1016/j.ejar.2013.12.006.
[52] Birecikligil, S.S., Çiçek, E., Öztürk, S., Seçer, B. and Celepoğlu, Y. Length-length, length-weight relationship and condition factor of fishes in Nevşehir Province, Kızılırmak River Basin (Turkey). Acta Biologica Turcica, 2016. 29(3): 72-77.
[53] Efitre, J., Murie, D.J. and Chapman, L.J. Age validation, growth and mortality of introduced Tilapia zillii in Crater Lake Nkuruba, Uganda. Fisheries Management and Ecology, 2016. 23: 66-75. DOI:10.1111/FME.12163.
[54] Froese, R. Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. Journal of Applied Ichthyology, 2006. 22(4): 241-253. DOI:10.1111/J.1439-0426.2006.00805.X.

[55] Cuadrado, J.T., Lim, D.S., Alcontin, R.M.S, Calang, J.L. and Jumawan, J.C. Species composition and length-weight relationship of twelve fish species in the two lakes of Esperanza, Agusan del Sur, Philippines. FishTaxa, 2019. 4(1): 1-8. DOI:10.1111/J.1439-0426.2010.01516.X.

[56] Pachla, L.A., Hartmann, P.B., Massaro, M.V., dos Santos, T., Antonetti, D.A. and Reynalte-Tataje, D.A. The length-weight relationship of four fish species captured in the Ibicuí River, southern Brazil. Journal of Applied Ichthyology, 2020. 36: 383-385. DOI:10.1111/jai.14017.

[57] Zhonghua, D., Jianyi, S., Jianbo, C., Yang, X., Decqing, T. and Zhiguo, M. The growth and stock assessment of Carassius auratus L. in Wanghu Lake. Journal of Lake Sciences, 1994. 6(3): 257-266. DOI: 10.18307/1994.0309.

[58] El-Bokhty, E.E.B. and El-Far, A.M. Evaluation of Oreochromis niloticus and Tilapia zillii fisheries at Aswan region, River Nile, Egypt. Egyptian journal of aquatic biology and fisheries, 2014. 18(3): 79-89. DOI:10.21608/EJABF.2014.2220.

[59] Mohamed, A.R.M. and Abood, A.N. Population dynamics and management of two cichlid species in the Shatt Al-Arab River, Iraq. Journal of Applied and Natural Science, 2020. 12(2): 261-269. DOI:10.31018/jans.vi.2293.

[60] Uneke, B.I. and Nwani, C.D. Reproductive dynamics and virtual population analysis (VPA) of Tilapia zillii (Perciformes: Cichlidae) in a tropical flood river basin. Nigerian Journal of Fisheries, 2014. 10(1 & 2): 642-652. DOI:10.5897/IJFA.9000028.

[61] Wootton, R.J. Growth: environmental effects. In A.P. Farrell (Ed.) Encyclopedia of fish physiology: from genome to environment. Elsevier Science Publishing Co. Inc, United States 2011.p.1629-1635.

[62] Panda, D., Mohanty, S.K., Pattnaik, A.K., Das, S. and Karna, S.K. Growth, mortality and stock status of mullets (Mugilidae) in Chilika Lake, India. Lakes & Reservoirs, 2018: 1-13. DOI:10.1111/LRE.12205.

[63] Collie, J.S. and Gislason, H. Biological reference points for fish stocks in a multispecies context. Canadian Journal of Fisheries and Aquatic Sciences, 2001. 58: 2167-2176. DOI: 10.1139/cjfas-58-11-2167.

[64] Abdul, W.O. and Omoniyi, I.T. Recruitment pattern, probability of capture and predicted yields of Tilapia zillii in Ogun estuary, Nigeria. Journal of Agricultural Science and Environment, 2011. 11(2): 90-102.

[65] Abood, A.N. and Mohamed, A.R.M. The current status of inland fisheries in Basrah province, Iraq. International Journal of Fisheries and Aquatic Studies, 2020. 8(5): 120-127. DOI: 10.22271/FISH.2020.V8.I5B.2313.

[66] Al-Noor, S.S. Population status of gold fish Carassius auratus in restored East Hammar Marsh, Southern Iraq. JKAU: Journal of Marine Sciences, 2010. 21(1): 65-83.

[67] Al-Wan, S.M. and Mohamed, A.R.M. Analysis of the biological features of the blue tilapia, Oreochromis aureus in the Garmat Ali River, Basrah, Iraq. Asian Journal of Applied Sciences, 2019. 7(6): 776-787. DOI:10.24203/AJAS.V7I6.6037.

[68] Udoh, J. P. and Ukpatu, J. E. First estimates of growth, recruitment pattern and length-at-first-capture of Nematopalaemon hastatus (Aurivillius, 1898) in Okoro River estuary, southeast Nigeria. AACL Bioflux, 2017. 10(5):1074-1084.

[69] King, M.M. Fisheries Biology, Assessment and Management. 2nd ed. Blackwell Publishing Ltd. 2007.

[70] Canonico, G. C., Artihington, A., McCrary, J. K., and Thieme, M.L. The effects of introduced tilapias on native biodiversity. Aquatic Conservation: Marine and Freshwater Ecosystems, 2005. 15: 463-483. DOI: 10.1002/aqc.699.

[71] Leunda, P.M. Impacts of non-native fishes on Iberian freshwater ichthyofauna: current knowledge and gaps. Aquatic Invasions, 2010. 5(3): 239-262. DOI:10.3391/AI.2010.5.3.03.

[72] Innal, D. 2011. Distribution and impacts of Carassius species (Cyprinidae) in Turkey: a review. Management of Biological Invasions, 2011. 2: 57-68. DOI: http://dx.doi.org/10.3391/ mbi.2011.2.1.06

[73] Morgan, D.L., Gill, H.S., Mark G. Maddern, M.G. and Beatty, S.J. Distribution and impacts of introduced freshwater fishes in Western Australia. New Zealand Journal of Marine and Freshwater Research, 2014. 38(3): 511-523. DOI: 10.1080/00288330.2004.9517257.