Original Research Article

Stock assessment and virtual population analysis of *Carassius auratus*(Linnaeus, 1758) in the Al-Diwaniya River, Middle of Iraq

ABSTRACT

A total of 1128 individuals of *C. auratus* were collected from the Diwaniyah River, Iraq. Samples were collected between November 2016 and October 2017 using different fishing gearsaiming to assess the stock assessment and virtual population analysis.Fish length ranged from 8.0 to 33.0 cm,with a length-weight relationship exhibiting positive allometric growth.Asymptotic length (L_∞) was estimated at 33.0 cm, the growth coefficient (K) was 0.16, and the growth performance index (Ǿ) was 2.241. The values of total (Z), natural (M) and fishing (F) mortality rates were 0.89, 0.47, and 0.42, respectively.The exploitation rate (E) was 0.48. Length with a 50% probability of capture (L_{C50}) was estimated at 18.7 cm and was higher than the length at first maturity (L_{m50}).The recruitment consisted of one seasonal pulse from April to July. The exploitation rate (E) was below the biological target reference points ($E_{0.1}$ and E_{max}), indicating the stock was under exploitation state.The result of the virtual population analysis revealed that most of the fishing mortality happened in mid-lengths (18-26 cm) with a maximum rate at a length of 25 cm.Natural losses were highest among individuals within the length range of 8.0 to 15 cm and then decreased gradually to the length group of 30.For management purposes, this study suggests that more yields can be obtained by increasing the fishing activities on this invasive species, such as increasing the number of fishing boats and decreasing the mesh size to decline its abundance in the long term.

Keywords: Carassius auratus, growth andmortality,yield-per-recruit, VPA, Diwaniya River, Iraq.

1. INTRODUCTION

The fish species, *Carassius auratus* (Linnaeus, 1758) belongs to the family Cyprinidae of order Cypriniformes. This family represented 289 genera and 1791 valid species [1]. This species is indigenous to Eastern Asia and inhabits 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 [2].

C. auratus is an invasive species in Iraqi waters. Al-Nasiri and Shamsul Hoda [3] listed the freshwater fish species of Iraq and referred to the presence of *C. auratus* for the first time in Iraqi waters, this species is considered as an unofficially introduced exotic fish to Iraq. It has invaded the country in a way that is not yet known, though, Coad [4] mentioned that this species has been introduced throughout Iranian waters including Khuzestan waters in the southwest of Iran, bordering Iraq, these fish can easily have crossed the border into Iraqi waters. *C. auratus* taxonomy is probably confused in Iraq, where the checklist of fish species often identified *C. auratus* in the literature as *C. carassius*[4].
Now, *C. auratus* is well established, easily become one of the dominant species and widespread throughout the different natural waters of the country. The species constituted

10.8% of the fish population in Euphrates River at Al-Mussaib Power Station [5], 15.3% of fish in Al-Huwaizah marsh [6], 23.6% of fish in East Hammar marsh [7], 20.0% of fish in Chybayish marsh[8], 20.3% of fish in Shatt Al-Arab river [9], 21.2%, of fish in Garmat Ali River [10], 35.2% of fish in Euphrates River at Al-Hindyah Barrier[11], 13.1% of fish in the East Hammar marsh [12], 13.2% of fish in the Shatt Al-Arab River [13] and 14.6% in fish in the Diwaniya River, middle of Iraq [14].

Moreover, it is known that *C. auratus* is considered a hazardous species for native fish communities through the flow of nutrients in the entire ecosystem, competition for food and other resources and may decline in fish abundance as a result of increased water turbidity [2, 15].

A study of fish population dynamics provides insight into the status, including age and growth, mortality, exploitation rates, recruitment, vulnerability to capture, relative yield and relative biomass per recruit needed to formulate management strategies that successfully conserve the stocks and maximize sustainable gains [16, 17]. Relatively few studies have been done about stock assessment on *C. auratus* have been carried out, despite its wide distribution throughout the world.Zhonghua*et al.*[18] studied the growth and stock assessment of *C. auratus* in Wanghu Lake, China. Abbas *et al*. [19] described some population aspects of *C. auratus* in the Euphrates River, middle of Iraq. Al-Noor [20] studied the population status of *C. auratus* in the East Hammar marsh, Iraq. Mohamed *et al*. [12] assessed the stock of *C. auratus* in the East Hammar marsh. Hashemi *et al.*[21] described the growth parameters, mortality rates and exploitation rate of *C. auratus* in the Shadegan Wetland, Iran. Yin*et al*. [22] considered the growth characteristics and resource evaluation of crucian carp (*C. auratus*) in the Yellow River, China. Abood and Mohamed [23] studied the population dynamics of *C. auratus*in the Shatt Al-Arab River, Iraq.

This study provides new data on growth, mortality and exploitation rates, length at first capture, recruitment pattern, reproduction, biological target reference points and virtual population analysis of the *C. auratus*population in the Diwaniyah River, middle Euphrates, Iraq, to provide information for proper management of this species.

2. MATERIALS AND METHODS

2.1 Study area

Monthly sampling was conducted from two sites on the Diwaniyah River, an extension of the Hilla River, a Euphrates River branch at the Hindiyah Barrier in central Iraq (Fig. 1) between November 2016 and October 2016. 2017. The Diwaniyah River is 123 km long, 25-30 m wide and 3-5 m depth. The surface water temperature values during the time of this study varied from 10.2 to 32.8°C with a mean value of 21.7°C and the predominant vegetation on both banks of this locality were reed,*Phragmites australis* and cattail,*Typha domingensis,* whereas hornwort,*Ceratophyllumdemersum*was dominant in the deeper areas.The fish fauna comprises 27 species and is dominated by cyprinids, including *Carassiucarassius*, *Carasobarbusluteus* ,*Leuciscusvorax*, *A. grypus*, *Luciobarbusxanthopterus* and *Mesopotamichthyssharpeyi*; other common species are *Planilizaabu* (Mugilidae) and *Oreochromis aureus* (Cichlidae) [24].

2.2 Fish sampling

Samples were caught with seine nets (3m long and 2.5m deep with a 20mm mesh size), gill nets (25m long with 20x20, 30x30 and 50x50mm mesh sizes) and cast nets (9m diameter with 15x15mm mesh

Fig. 1. Map of Al-Qadisiyah Province showing the sampling sites in Al-Diwaniya River.

size), and by electrofishing equipment (provides 150-300V) between November 2016 and October 2017. Fish were immediately preserved in an icebox for subsequent analysis[14].

2.3 Data analysis

At the laboratory, the total length of the fish was individually measured to the nearest mm using a graduated wooden measuring board and to the nearest gram of 0.1 g using the digital balance.To establish the length-weight relationship, the commonly used relationship $W = a\ L^b$was applied [25], where W is the weight (g), L is the total length (cm), and a and b are constants, using data from all fish collected[14]. The hypothesis of isometric growth was tested with a Student's t-test [26].

The monthly samples of length measurements for the species were pooled in bimonthly periods and then grouped into 1-cm intervals to construct the length-frequency distributionsto assess the stock assessment and virtual population analysis of the species in the river. The data were analyzed using FiSAT II software (FAO-ICLARM Stock Assessment Tools, ver. 1.2.2) [27].

The von Bertalanffy growth function (VBGF) parameters (asymptotic length ($L\infty$) and growth coefficient (K)) were estimated with the ELEFAN Iroutine of the FiSAT II software. The estimates of L and K were then used to estimate the growth performance index ($\acute{Ø}$) using the equation[28]: $\acute{Ø} = log_{10}K + 2\ log_{10}L\infty$.

The total mortality rate (Z) was estimated by the length-converted catch curve analysis method of Pauly [29] incorporated in the FiSAT package using the input parameters L∞ and K, and selecting the best points on the straight line of the right arm of the curve. The natural mortality rate (M) was estimated using Pauly's [30] empirical equation relating L∞, K and mean water temperature (T= 21.7°C) as:

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

The fishing mortality (F) was obtained by the subtraction of M from Z and the current exploitation rate ($E_{current}$) was calculated from the relationship: E= F/Z [31]. The linearized catch curve used for estimating Z was extrapolated backwards to the points of the descending part of the length-converted catch curve, a method incorporated into the FiSAT software package. The inbuilt logits method was used to derive values of the lengths at capture at probabilities of 0.25% (L_{25}), 0.5% (L_{50}) and 0.75% (L_{75}).

A one-year recruitment pattern was obtained by projecting the length frequency data backwards onto the time axis described in the FiSAT routine. This routine reconstructs the recruitment pulse from a time series of length-frequency data to determine the number of pulses per year and the relative strength of each pulse. Input parameters were L∞ and K [32].

The model of Beverton and Holt [33], as modified by Pauly and Soriano [34] was followed to predict the relative yield per recruit (Y´/R) and the relative biomass-per-recruit (B'/R) using the knife-edge selection curve incorporated in FiSAT software. The input parameters of Lc/L∞ and M/K values were used to estimate the biological target reference points, maximum economic yield ($E_{0.1}$), optimum sustainable yield ($E_{0.5}$) and maximum sustainable yield (E_{max}). These reference points were compared with the current rate of exploitation ($E_{current}$) following Cadima [35].

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 the length-structured virtual population analysis, VPA[36] incorporated in the FiSAT package. The input parameters in the VPA analysis were L∞, K, M, F and 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 rates.

3. Results

3.1 Growth

The length-weight relationship for 314 specimens of *C. auratus* ranging from 8.0 to 30.0 cm in total length and between 10.7 to 700.0 g in weight in this studywas $W = 0.013L^{3.129}$, r= 0.957. The t-test revealed that the regression slope (b) was significantly different from value 3 (t= 3.424, P>0.05), which indicates positive allometric growth.

Overall, 1128 specimens of *C. auratus* were involved in the stock assessment and virtual population analysis of the species in the river. The minimum and maximum lengths of the specieswere 8.0 cm and 30.0 cm, respectively. The best value of the VBGF growth constant (K) was estimated as 0.16 by using the direct fit of length-frequency data in the ELEFAN I routine (Fig. 2). The response surface (R_n) was calculated as 0.202, which selected the best combination of growth parameters L∞= 33.0 cm andK= 0.160. The optimized growth curve was superimposed on the restructured length-frequency histograms (Fig. 3). The growth performance index (Ǿ) was 2.241.

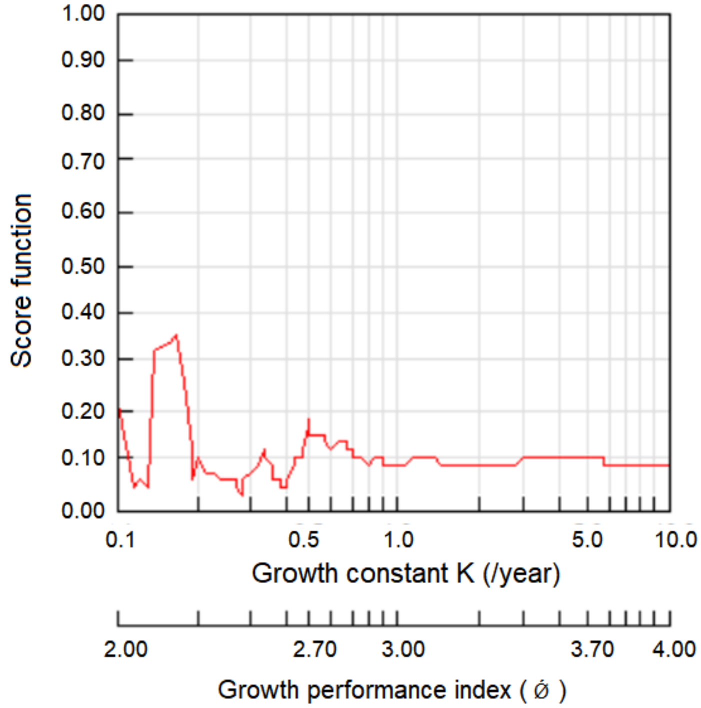

Fig. 2. K-scan routines of *C. auratus*

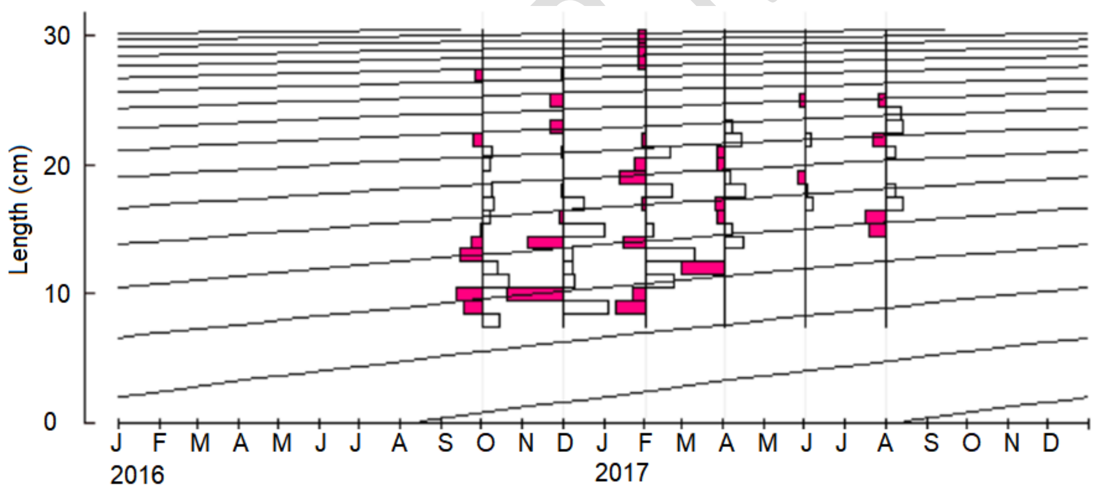

Fig. 3. Restructured length-frequency distribution using ELEFAN-1 for *C. auratus*

3.2 Mortality and exploitation rates

The total mortality rate (Z) of *C. auratus* was estimated at 0.89 yr-1 using length converted catch curve (Fig.4). The darkened quadrilaterals represent the points used in calculating *Z* through least squares lines regression. The yellow 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 natural and fishing mortality rates were estimated at M= 0.47yr-1 and F= 0.42yr-1,respectively. The current exploitation rate ($E_{current}$) was obtained at 0.48.18.73

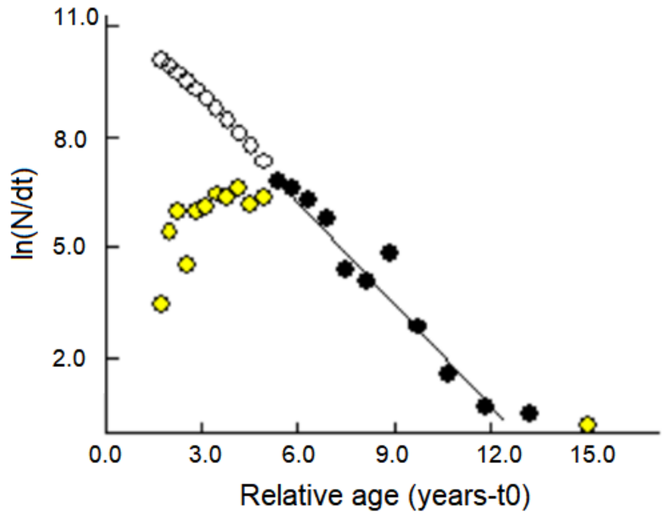

Fig. 4.Length converted catch curve for estimation of Z for *C. auratus*

3.3 Probability of capture

Figure 5 shows the logistic of the probability of the capture routine of *C. auratus*of each size class obtained by backward extrapolation of the straight portion of the right descending part of the catch curve in FiSAT software. The length at which 50% of the stock biomass is vulnerable to capture is estimated at L_{50}= 18.7 cm. The L_{25} was calculated as 16.6 cm while L_{75} was found to be 20.8 cm.

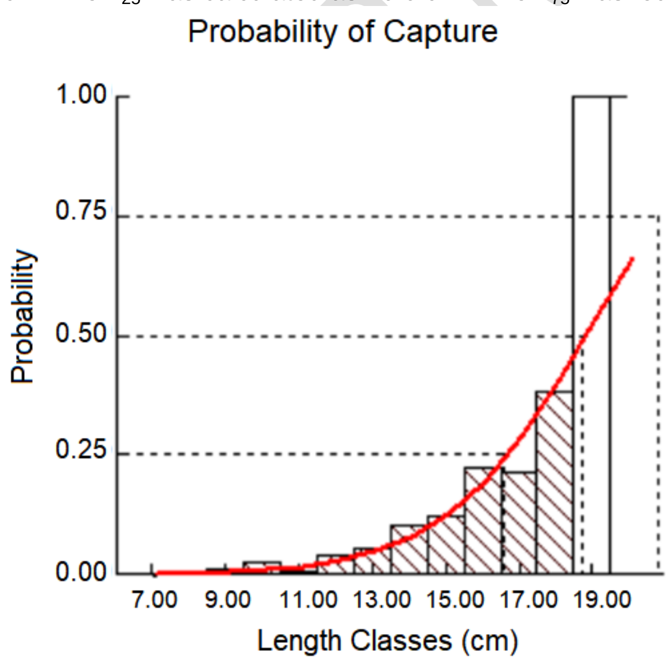

Fig. 5. Probability of capture for *C. auratus*

3.4 Recruitment

Figure 6 shows the annual recruitment pattern of *C. auratus* in the river. The recruitment consists of one seasonal pulse from April to July, with the highest values in May (14.81%) and July (14.40%) of total recruitment throughout the year.

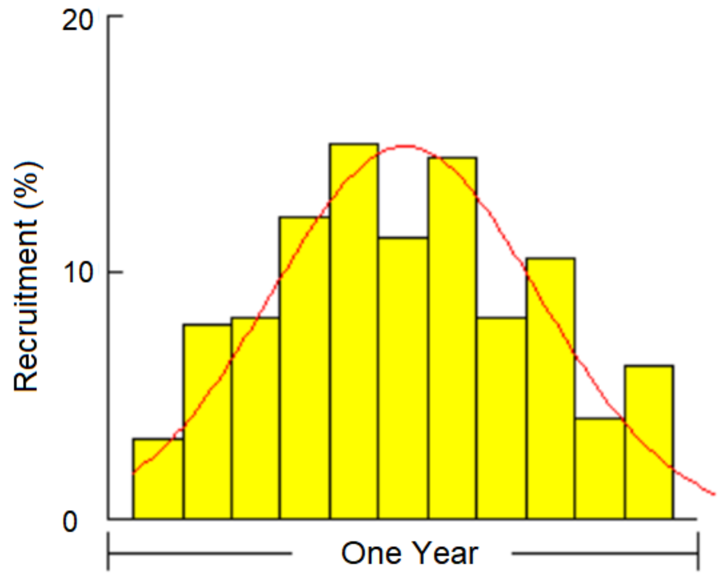

Fig. 6. Recruitment pattern of *C. auratus*

3.5 Yield per Recruit (Y'/R) and Biomass per Recruit (B'/R)

The Beverton-Holt relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) estimated for the species demonstrated that their values were 0.012 and 0.430, respectively.Moreover, the analysis revealed that the values of $E_{0.1,}$ $E_{0.5}$and E_{max} were 0.802, 0.373 and 0.948, respectively (Fig. 7). The current exploitation rate ($E_{current}$)was (0.48) below the biological target reference points ($E_{0.1}$ and E_{max}),indicating the stock of *C. auratus* in the study river was under exploitation state.

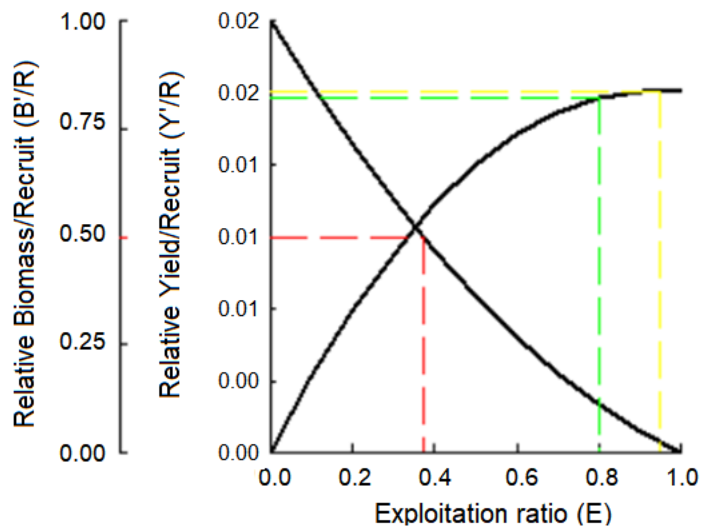

Fig. 7. Relative yield per recruit (Y'/R) and biomass per recruit (B'/R) analyses for*C. auratus*

3.6 Virtual population analysis

The result of the length-structured virtual population analysis, VPA, is presented in Table 1. The table shows the length classes, catch in number, C, population, N, fishing mortalities based on length classes, and steady-state biomass. The most catches of the species occurred in lengths of 19 to 21

Table 1. FiSAT II output of virtual population analysis of *C. auratus*.

Mid-Length	Catch (in numbers)	Population (N)	Fishing mortality (F)	Steady-state Biomass (tons)
8	3	8586.85	0.0015	0.02
9	22	7631.97	0.0118	0.02
10	40	6731.95	0.0234	0.03
11	10	5887.19	0.0064	0.04
12	45	5141.87	0.0316	0.04
13	53	4428.61	0.0414	0.05
14	78	3774.36	0.0685	0.06
15	73	3161.47	0.0729	0.06
16	101	2618.14	0.1166	0.07
17	71	2110.1	0.096	0.07
18	90	1691.43	0.1447	0.07
19	147	1309.11	0.2969	0.06
20	131	929.44	0.355	0.06
21	107	625	0.4095	0.05
22	72	395.2	0.4069	0.04
23	20	240.04	0.1612	0.03
24	16	161.73	0.1767	0.02
25	38	103.17	0.7246	0.02
26	6	40.52	0.222	0.01
27	2	21.82	0.1174	0.01
28	1	11.82	0.0941	0
29	1	5.82	0.1737	0
30	1	2.12	0.42	0
Average			0.18143	

Figure 8 further shows that natural losses and survivability of the fish population decreased with an increase in length and fishing mortality. Natural losses were highest among individuals within the length range of 8.0 to 15 cm and then decreased gradually to the length group of 30. cm.Moreover, the fishing mortality value of the species was not consistent, in which two distinguished peaks were at lengths of 21 and 22 cm and then to the maximum value (0.725) at 25 cm.

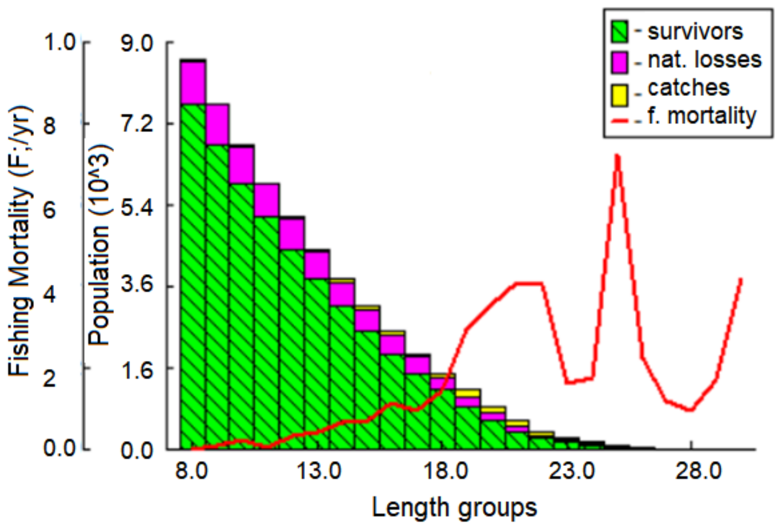

Fig. 8. Length-structured virtual population analysis of *C. auratus*

4. DISCUSSION AND CONCLUSION

The assessment of fish population is essential to meet one of the main objectives of fishery science: maximizing yield to fisheries while safeguarding the long-term viability of populations and ecosystems [37]. The basic purpose of stock assessment is to provide decision-makers with the information necessary to make rational choices on the optimum level of exploitation of aquatic living resources such as fish [38]. The weight-length relationship is regarded as an important tool for studying the biology of fish, fish physiology, fish ecology, and stock assessment [39]. According to the result of the length-weight relationshipof *C. auratus*in the present study, the growth of the species exhibited a positive allometric growth (b>3), i.e. this type of growth indicates that the fish becomes relatively stouter or deeper-bodied as it increases in length[40]. This growth shape was found to be similar to those recorded by several authors in various waters [18, 41, 21, 22, 23]. Conversely, some authors stated a negative allometric growth for this species in other waters [19, 20, 42]. However, some authors found that the species' growth demonstrated an isometric growth pattern [43, 2, 12]. The growth pattern of the species can be affected by several influences, including the environmental conditions between different geographical locations, seasons, sex, stage of maturity, stomach fullness, diseases, and sampling methodology [26, 44-46].

Growth parameters and mortality rates of fish are crucial inputs for stock assessments. This is because they provide valuable information on the variation of fish size over time and the decline in population biomass due to fishing and natural causes[47]. The stock assessment information about the growth and mortality of *C. auratus* in this study compared with those reported by the various authors in different regions is demonstrated in Table 2. The growth parameters of fish population dynamics (asymptotic length L∞ and growth coefficient (K) are critical for stock assessment and fisheries management. Some studies reported that L∞ for *C. auratus* in Wanghu Lake[18], Euphrates River, Iraq[19], Yellow River, China [22], and Shatt Al-Arab River, Iraq [23] were shorter than the present findings, while was lower than those recorded for the species inthe Lake Trasimeno, Italy[2], East Hammar marsh, Iraq [12] and Shadegan Wetland, Iran [21]. However, an L∞ of 33.0 cm obtained in this study agreed with the value previously estimated for the Shadegan Wetland, Iran by Hashemi *et al*. [21] through (34.6 cm). The growth rate (K) and the growth performance index (Ǿ) for the species estimated in the present study were lower than estimates from other studies in Table 2.Abood and Mohamed [23] recorded the highest value of K in the Shatt Al-Arab River, Iraq, while the maximum value of Ǿ was observed by Mohamed *et al*. [12] in the East Hammar Marsh, Iraq (Table 2). The variations in the growth parameters of the same species in different locations observed would be due to the population density, availability of food, differences in ecosystem temperatures, reproductive activity, environmental pollution, fisheries degradation and fishing pressure [16, 48-51].

Table 2. Comparison of growth and mortality parameters of *C. auratus* in different regions

Location	L∞ (cm)	K	Ǿ	Z	M	F	E	Source
Wanghu Lake, China	28.6	0.26	-	0.96	0.61	0.35	0.36	Zhonghua*et al.* [18]
Euphrates River, Iraq	27.9	0.36	-	1.20	0.75	0.4	0.38	Abbas *et al.* [19]
East Hammar Marsh, Iraq	-	-	-	0.92	0.62	0.30	0.33	Al-Noor [20]
Lake Trasimeno, Italy	43.0	0.27	2.70	-	-	-	-	Lorenzoni *et al.* [2]
East Hammar Marsh, Iraq	42.3	0.27	2.97	1.87	0.65	1.22	0.65	Mohamed *et al.* [12]
Shadegan Wetland, Iran	34.6	0.36	-	1.52	0.75	0.77	0.51	Hashemi *et al*. [21]
Yellow River, China	27.8	0.38	-	1.06	0.44	0.62	0.58	Yin, *et al*. [22]
Shatt Al-Arab River, Iraq	29.1	0.51	2.64	2.69	1.09	1.60	0.59	Abood and Mohamed [23]
Al-Diwaniya River, Iraq	33.0	0.16	2.24	0.89	0.47	0.42	0.48	Present Study

The rates of the total mortality (Z), natural mortality (M), fishing mortality (F) and the current exploitation ($E_{current}$) of *C. auratus* in this study were compared with those reported by the various authors in different regions. It is clear from Table 2 that all rates (Z, M, F and E) estimated in this study were not in agreement with the rates found for *C. auratus* in other waters. The highest values of Z, M and F rates of the species in these waters were obtained by Abood and Mohamed [23] in the Shatt Al-Arab River, Iraq.However, the lowest value of Z was observed in the present study, while M in the Yellow River, China [22] and F in the East Hammar Marsh, Iraq [20]. The low fishing mortality observed in the present study is partly related to the fact that the catch also involves other cyprinids species enjoyed by the community and abundant in catches, such as *Carasobarbus luteus, Arabibarbusgrypus, Mesopotamichthyssharpeyi, Luciobarbusxanthopterus and Leuciscus vorax*in Al-Diwaniya River[14]. The value of the exploitation rate ($E_{current}$) of the species in the present study was within the ranges recorded in other populations of *C. auratus*. Al-Noor [20] documented the lowest value of E (0.31) for the species in East Hammar Marsh, Iraq, while thehighest value (0.65) observed by Mohamed *et al.*[12] in the same habitat.Pauly [30] indicated that the optimum categorization of exploitation rate for healthy fish stocks is taken as 0.5 with values lower or greater than E= 0.5 interpreted as underexploited or overexploited stock, respectively, which means that the *C. auratus* population in the present study was under exploitation.

The estimated length at first capture (L_{c50}) of *C. auratus* in the current study was 18.73 cm. However, the length at first maturity (L_{m50}) of the species in the Euphrates River in the same region was found to be 17.4 cm [19], 12.20 cm in Lake Trasimeno, Italy [2] and 16.3 cm in Shadegan Wetland, Iran [21].

The recruitment pattern suggests that the annual recruitment of the species consists of one seasonal pulse, which occurs from April to July. This period of recruitment could betraced back to this period of active reproductive activity and spawning. Mohamed and Al-Jubouri [14] mentioned that the maximum values of GSI of the species happened during February-March in the same studied river. A similar result was observed for this species by Al-Noor [20] and Mohamed *et al*. [12] in East Hammar Marsh and by Abood and Mohamed [23] in the Shatt Al-Arab River. Lorenzoni *et al.*[2] mentioned that spawning of *C. auratus* in Lake Trasimeno, Italy occurred from March to June and suggested that it is multiple spawned.

The low current exploitation ($E_{current}$) of *C. auratus* in the present study is also supported by the results of relative yield-per-recruit (Y'/R) and relative biomass-per-recruit (B'/R), in which both estimates values of the biological target reference points, $E_{0.1}$ (0.802) and E_{max} (0.948) are lower than the current exploitation rate ($E_{current}$), which denotes that the studied stock underexploited [35]. Conversely, Mohamed *et al*. [12] observed that the current exploitation rate (0.65) was higher than the values of both $E_{0.1}$ (0.42) and E_{max} (0.52) in the Hammar Marsh, Iraq.However, Abood and Mohamed [23] found that the current exploitation rate ($E_{current}$= 0.59) was higher than $E_{0.1}$(0.503) and equivalent to E_{max}(0.591) for the stock of*C. auratus* in the Shatt Al-Arab River, Iraq, and considered as in a status of nearby overfishing.

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 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 [16, 52]. The most excellent harvest of the population of *C. auratus* in the present study was made from individuals of 19 to 21 cm, which was above the length of first maturity (L_{m50}) and the estimated size at first capture (L_{c50}) by the fishing gears [53]. The first sexual maturation is an important point in the animal's life history and must be taken into account for successful fish management [54]. The occurrence of 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. This would enable more females to participate in reproductive activity and allow the young recruits to grow and reproduce to ensure resource availability and sustainability [55]. 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, include an estimate of the level of fishing effort required to obtain the maximum yield that may be taken from stock on a sustainable basis [17, 38].

Therefore, for management purposes, more yields could be obtained by increasing the fishing activities on this species for a substantial harvest, with some precautionary measures to avoid overexploitation.

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