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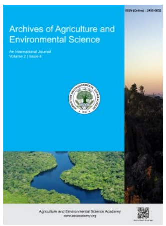

ORIGINAL RESEARCH ARTICLE

CrossMark

Stock assessment and virtual population analysis of River shad, *Tenualosa ilisha* (Bloch & Schneider, 1801) in the Shatt Al-Arab River, Iraq

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ABSTRACT

Historically, the river shad, *Tenualosa ilisha* fishery is the most significant marine fishery from the economic-socio point of view in Basrah province for a long time, but its contribution declined from 90.2% of total landings in 1965-1973 to 5.8% in 2020. The stock and virtual population analysis of the species in the Shatt Al-Arab River, Iraq was assessed using FiSAT II software. Samples were collected from two sites in the river from November 2015 to October 2016. A total of 462 individuals of *T. ilisha* ranging from 7.0 to 42.5 cm were collected. The length-weight relationship was derived, indicating a positive allometric growth for the species. L_∞, K, and Ø were 59.1 cm, 0.27, and 2.975, respectively. Total (Z), natural (M) and fishing (F) mortalities were 1.94, 0.59, and 1.35, respectively. The exploitation rate (E) was 0.70. Length at first capture (L_{c50}) was found to be 24.4 cm. The recruitment pattern of *T. ilisha* was continuous throughout the year with two unequal prominent peaks. The relative yield per recruit analysis revealed that the current exploitation rate (E) of *T. ilisha* was higher than both $E_{0.1}$ and E_{max}. Also, the 40 cm length group was more vulnerable to fishing according to VPA analysis, followed by the 34 cm and 26 cm length groups. For management purposes, it must be introduced an extensive *T. ilisha* management action plan by protecting brood species during the breeding season by imposing a ban on fishing in the Shatt Al-Arab River during the main spawning migration and conserving the small *T. ilisha* (Milat <23.0 cm) from catching.

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INTRODUCTION

The river shad, *Tenualosa ilisha*, belongs to the subfamily Alosinae of the family Clupeidae. Clupeidae represented 506 available species and only 192 valid species in the world (Fricke *et al*., 2022). Fischer and Bianchi (1984) revised the scientific name of *Hilsa ilisha* to *Tenualosa ilisha*. Dutta and Hazra (2017) stated that the genus *Tenualosa* has five species viz., *T. ilisha* (Hamilton), *T. toil* (Valenciennes), *T. macrura* (Bleeker), *T. reevesii* (Richardson), and *T. thibaudeaui* (Durand). The geographical distribution of *T. ilisha* extends from the Arabian Gulf, along the coast of Pakistan, India, Bangladesh, and Burma to South Vietnam (Kuronuma and Abe, 1986). *T. ilisha* is locally known as 'Sbour' in Iraq and other countries of the Arabian Gulf and is an important migratory fish in the Indo-West Pacific region, and the normal habitats for the species are in the lower regions of the estuaries and the foreshore areas, but during the breeding season, they ascend the rivers and then return to the original habitat after spawning, where they remain until the next breeding season (Almukhtar *et al.* (2016). In Iraq, *T. ilisha* is by far the largest single marine species fishery, ascending from the marine waters of the Arabian Gulf to the upper reaches of the Shatt Al-Arab River to reproduction during the period March to September, coincided with the spring flooding of the Tigris and Euphrates Rivers, and most of their catches are made by dhow boats, speedboats and small boats using drifting gillnets (Mohamed and Abood, 2020). Unfortunately, the contribution of *T. ilisha* catches has dropped to lower levels over the recent years, in contrast with the contributions of other species, such as threadfin bream, mullets, emperor, spotted leatherskin, tigertooth croaker, and sea breams which have improved considerably, where the total catches have increased steadily from about 3,755 t in 2011 to 19,877 t in 2020 (Mohamed and Abood, 2022). Several authors referred that *T. ilisha* had dominated the Iraqi marine fisheries for a long time and was responsible for determining the general trend of this fishery from 1965 to 2000 (Khayat, 1978; Ali *et al.*, 1998; Mohamed *et al.*, 2002). More, the total landing of marine fish in Iraq reached 19,877 t in 2020, and *T. ilisha* was 1,154 t constituting only 5.8% of the total catches this year (Mohamed and Abood, 2022).

The stock assessment of *T. ilisha* has been studied widely by different authors in its distribution areas, especially in the Indian subcontinent (Rahaman *et al.*, 2000; Nurul Amin *et al.*, 2002, 2004; Halder and Nurul Amin, 2005; Ahmed *et al.*, 2008; Nurul Amin *et al.*, 2008; Rahman and Cowx, 2008; Milton, 2010; Dutta *et al.*, 2012; Panhwar and Liu, 2013; BOBLME, 2015; Rahman *et al.*, 2018; Dutta *et al.*, 2019, 2021), in Kuwait (Al-Baz and Grove, 1995) and Iran (Hashemi *et al.*, 2010; Roomian and Jamili, 2011). Few works have been done on stock assessment of *T. ilisha* in Iraqi waters. Mohamed *et al.* (2001) and Mohamed and Qasim (2014) studied the stock assessment of the species in the Iraqi marine waters, northwest Arabian Gulf, while Mohamed *et al.* (2016) assessed the stock of *T. ilisha* in the East Hammar marsh, Basrah using the FiSAT II software.

This study carried out the stock assessment of *T. ilisha* in the Shatt Al-Arab River, such as growth parameters, mortality rates, probability of capture, recruitment pattern, yield per recruit, and virtual population analysis of *T. ilisha* from 2016 to 2017 by FiSAT II software to derive requisite information for the sustainable management of the species.

MATERIALS AND METHODS

Study area

The Shatt Al-Arab River originates from the confluence of the Tigris and Euphrates rivers at Qurna, north of Basrah province, Iraq, and flows in the southeastern direction towards the Arabian Gulf (Figure 1). The river is about 204 km long, whereas the width varies from 250 m at the mouth to more than 1,500 m at the estuary. The tidal pattern in the Shatt Al-Arab River likes that of the upper part of the Gulf, and the dominant tide is of a semi-diurnal type with two high and two low waters occurring daily (Al-Ramadhanm and Pastour, 1987; Asadi and Alhello, 2019). The catchment land of the river is used for agriculture, palm forests, and human settlements. Hydro-ecological conditions of the Shatt Al-Arab River have undergone conspicuous changes due to a series of anthropogenic activities such as agricultural runoff wastes and untreated wastewater, invasion of fish species, and seawater intrusion as a result of drastically reduced water quantity and quality related to the decline in rates of the flow from the Tigris, Euphrates and Karun Rivers (Brandimarte *et al.*, 2015; Yaseen, *et al.*, 2016). The surface water temperature values during the time of this study varied from 13.3 to 34.7 °C with a mean value of 24.6 °C, salinity ranging from 1.0 to 9.7 ‰, and the discharge rate in the north of the river fluctuated from 40.9 to 59.8 m^3/s (Mohamed and Abood, 2017).

Fish sampling

Data were obtained from two sites on the Shatt Al-Arab River (Figure 1), Abu Al-Khasib district, and north Fao town (Mohamed and Abood, 2017) from November 2015 to October 2016. The sampling was performed with the help of local fishermen from each site by using gill nets (200-500 m length with 15-35 mm mesh size), cast net (9 m diameter with 15x15 mm mesh size), and electro-fishing by generator engine (provides 300-400V and 10A).

During this study, a total length of 984 specimens of *T. ilisha* was measured in the field to the estimation of growth and population parameters. Subsamples of fish were kept in a cooler box and immediately transported to the laboratory. At the laboratory, the total length of fish was individually measured to the nearest 0.1 cm using the measuring board and weighed using the electronic weighing balance to the nearest 0.1g. The monthly samples of length measurements for the species were pooled in bimonthly periods from the two sites and then grouped into 2-cm intervals to construct the length-frequency distributions. The data were analyzed using FiSAT II software (FAO-ICLARM Stock Assessment Tools, ver. 1.2.2) (Gayanilo *et al.*, 2005).

The formula of $W= a L^b$, was used to estimate the relationship between the weight (W) and total length (L) of the fish. The linear regression of the log-transformed equation used in this analysis was as follows: Log W= Log a + b Log L, where a= intercept and b= slope of the length-weight relationship. Furthermore, the b-value for the species was tested by t-test to verify if it was significantly different from isometric growth (Ricker, 1975).

The von Bertalanffy growth function and length frequency distribution was plotted based on the ELEFAN I routine of the FiSAT II software, which is used to understand the seasonal oscillation along with the estimation of the L_∞, K, and R_n. The predicted maximum length from extreme values was computed. The estimate of theoretical age at length zero (t_0) was obtained by using the empirical equation of Pauly (1983).

$$\log_{10}(-t_0) = -0.3922 - 0.275 \log_{10}L_\infty - 1.0381 \log_{10}K$$

The growth performance index (ǿ) for the species was computed based on the length data using the following equation (Pauly and Munro, 1984).

$$Ø' = \log_{10}K + 2 \log_{10}L_\infty$$

Mortality rates

The length-converted catch curve method incorporated in the FiSAT package estimated the instantaneous total mortality (Z), and the natural mortality (M) for the species calculated using Pauly's (1980) empirical equation relating M, t_0, L_∞, and K, and mean water temperature (T) where T= 24.6°C (Mohamed and Abood, 2017).

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

Fishing mortality (F) was derived from the difference between Z and M, and the exploitation ratio (E) from fishing mortality/total mortality. Estimation of probabilities of capture by detailed analysis of the left ascending part of the catch curve using the estimation of $L\infty$ and K through the logistic curve in the FiSAT package.

Recruitment pattern

ELEFAN I routine of FiSAT routine was used to obtain recruitment patterns by backward projection onto the time axis of the available length-frequency data through growth parameters ($L\infty$ and K). The peaks and troughs of the graph obtained reflect the seasonality of recruitment.

Stock assessment

The model of Beverton and Holt (1966), as modified by Pauly and Soriano (1986) was followed to predict the relative yield per recruit (Y′/R) of the species, using the knife-edge analysis incorporated in FiSAT software. The data of $L_c/L\infty$ and M/K values were used to estimate $E_{0.1}$ (exploitation point at which the related increase in yield per recruit reached 1/10 of the related increase computed at a very devalued value of E), $E_{0.5}$ (the exploitation rate corresponding to 50% of the unexploited relative biomass per recruit (B′′/R)) and E_{max} (exploitation point that gives maximum relative yield-per-recruit). The current exploitation rate (E) and the biological target reference points ($E_{0.1}$ and E_{max}) were used to indicate the stock status (Cadima, 2003).

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 (1981) 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 (Gayanilo *et al.* 2005). The input parameters used were $L\infty$, K, M and F and constants of length-weight relationship (a and b) were used as inputs to VPA analysis for the species.

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 (Gayanilo *et al.*, 2005). 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.

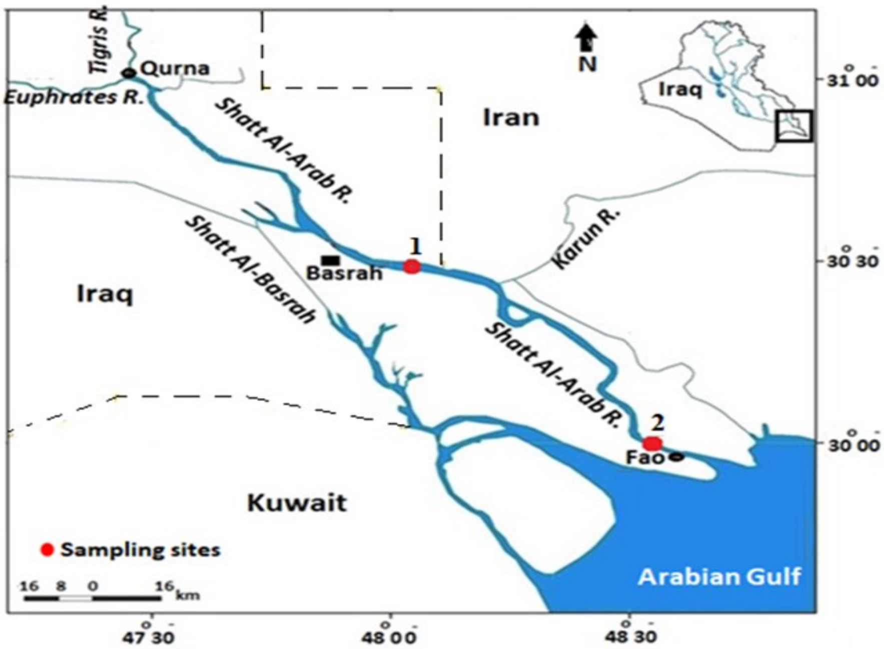

Figure 1. *Map of Shatt Al-Arab with locations of study sites.*

RESULTS AND DISCUSSION

Growth

The overall length-frequency distribution of 984 individuals of *T. ilisha* in the studied river is explained in Figure 2. Length frequency was assembled in length groups with one cm intervals, ranging in total length from 6.0 to 42.5 cm. Fish lengths 17 to 29 cm formed 68.8 % of the species' catch. More importantly, the length group of 26 cm composed about 9.0% of the total catch.

Table 1 illustrates the size range of *T. ilisha* obtained in this study with those obtained by the various authors in different geographic localities. The upper size of *T. ilisha* in the present study (42.5cm) was similar to the size documented for the species by Dutta *et al.* (2012) on the West Bengal coast, India, whereas was higher than those reported by Nurul Amin *et al.* (2005) about the male's individuals in Bangladesh waters, and Hashemi *et al.* (2010) in north Arabian Gulf, Iran. However, the upper size of *T. ilisha* in this study was lower than those stated by other studies in Table 1. These differences may be associated with several factors such as water condition, food supply, population density, fishing pressure and possibly using different fishing gears (Riedel *et al*., 2007). The size structure of *T. ilisha* in the present study indicates that over 63% of the catch was between 21 and 42 cm. These fish may be on their way to breeding grounds or back to the sea after spawning with their progenies. The spawning migration of *T. ilisha* to Shatt Al-Arab River, east Hammar marsh, and rivers in south Iran was well documented by several authors (Hussein *et al.*, 1991; Al-Hassan, 1999; Roomiani and Jamili, 2011).

The total length and weight of the species were 7.0 to 42.5 cm and 2.3 to 879.2 g, respectively. The length-weight relationship equation obtained for 462 individuals of *T. ilisha* is $W= 0.004L^{3.271}$, $r^2= 0.995$. The high coefficient of determination ($r^2= 0.995$, $p<0.05$) exhibited good quality weight prediction for the analyzed fish species. The t-test revealed that the regression slope was significantly different from the theoretical value ($t= 25.32$, $p<0.05$) and exhibited positive allometric growth. Riedel *et al.* (2007) stated that the positive allometric growth indicates that the fish becomes relatively stouter or deeper-bodied as it increases in length and is indicated by a b >3.0. Values of growth coefficient (b) of *T. ilisha* recorded in various geographic localities are presented in Table 1 and exhibited different growth types. Some studies showed positive allometric patterns (Nurul Amin *et al.*, 2005; Bhaumik *et al.*, 2011; Mohamed and Qasim, 2014), while other studies demonstrated isometric growth patterns. However, Dutta *et al.* (2021) stated that the growth pattern of *T. ilisha* in the northern Bay of Bengal, India exhibited a negative allometric growth. The variations in the growth type of the same species in different geographical localities may be due to various factors like the number and size of specimens examined, stomach fullness, sex variation, disease and parasite loads, stage of maturity, the method of sampling, and the variations in the environmental conditions among different localities (Gokce *et. al.*, 2007; Riedel *et al.*, 2007; Mili *et al.*, 2017; Cuadrado *et al.*, 2019).

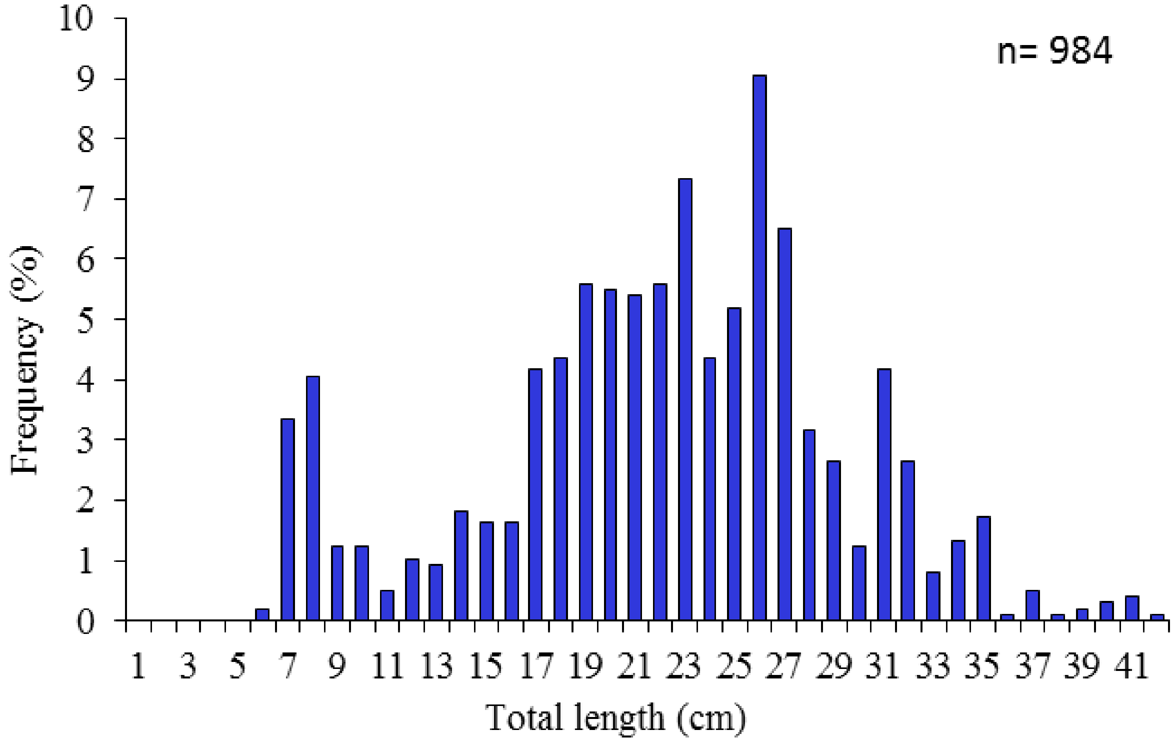

Figure 2. *The annual length-frequency distribution of T. ilisha.*

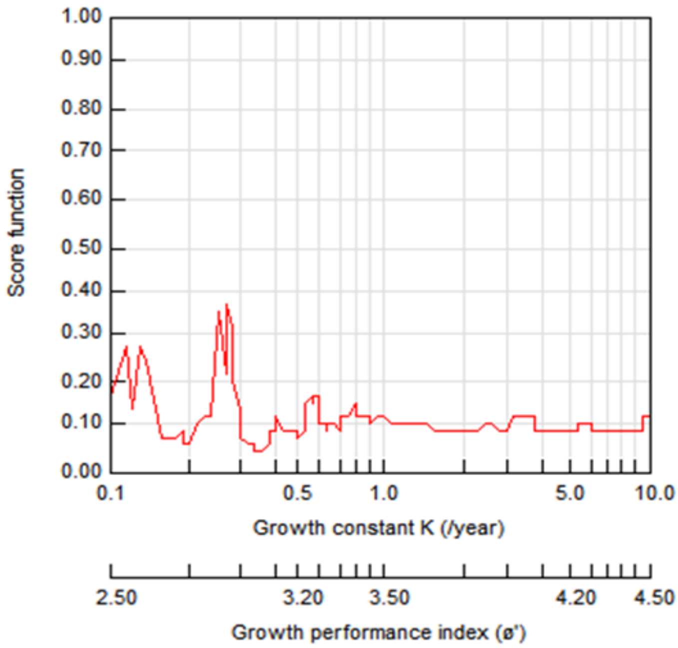

Figure 3. *K-scan routines of T. ilisha.*

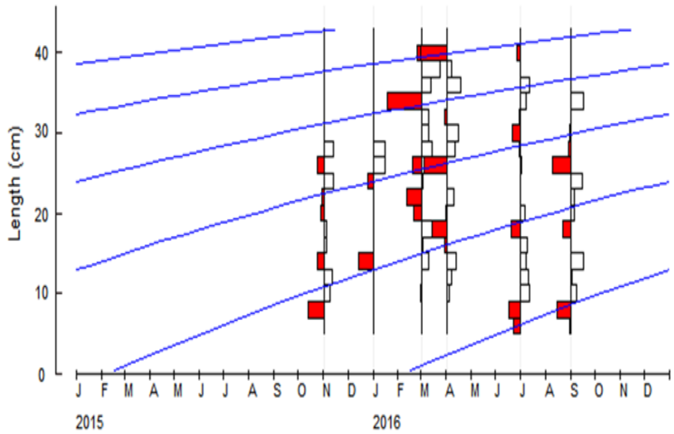

Figure 4. *Restructured length-frequency distribution using ELEFAN-1 for T. ilisha.*

Table 1. Comparative data for the sizes and growth coefficient (b) of *T. ilisha* from different regions.

Region	Length range (cm)	(b)	Authors
Northwest Arabian Gulf, Kuwait	14.0-57.0	2.983♂ 3.104♀	Al-Baz and Grove (1995)
Bangladesh waters	3.0-61.0	2.820-3.077	Nurul Amin *et al.* (2004)
Bangladesh waters	21.0-49.0 21.0-37.0	3.381	Nurul Amin *et al.* (2005)
Bangladesh waters	20.0-46.0 20.0-52.0	2.983♂ 3.072♀	Haldar and Nurul Amin (2005)
North Arabian Gulf, Iran	20.0-39.0	-	Hashemi *et al.* (2010)
North Arabian Gulf, Iran	-	2.968	Roomian and Jamili (2011)
Hooghly estuary, India	20.6-52.5	3.11	Bhaumik *et al.* (2011)
West Bengal Coast, India	15.5-41.2	-	Dutta *et al.* (2012)
Northwest Arabian Gulf, Iraq	12.2-47.0	3.268	Mohamed and Qasim (2014)
Meghna River, Bangladesh	20.9-47.8	3.040♂ 3.078♀	Flura *et al.* (2015)
East Hammar marsh, Iraq	2.3-47.7	3.006	Mohamed *et al.* (2016)
Northern Bay of Bengal, India	20.8-48.8	2.860	Dutta *et al.* (2021)
Shatt Al-Arab River, Iraq	7.0-42.5	3.271	Present study

Growth parameters of the von Bertalanffy growth formula for *T. ilisha* from the K-scan routine (Figure 3) were observed by using the direct fit of length-frequency data in ELEFAN I and the response surface (R_n) for the curve (Figure 4). Growth parameters for *T. ilisha* were L∞= 59.1 cm, K= 0.27 and R_n= 0.179. From these results, the t_o value for *T. ilisha* was -0.699, whereas the value of the growth performance index (Ø) obtained for the species was 2.975. Therefore, the von Bertalanffy growth equation for *T. ilisha* can be expressed as:

$$L_t = 59.1\,(1\text{-}e^{-0.27\,(t\,+0.699)})$$

Table 2 compares the growth parameters (L∞ and K) for *T. ilisha* obtained in this study with that obtained from other studies by applying the ELEFAN I module implemented in the FiSAT II software. The values of growth parameters are different among various geographic localities for the same species. The asymptotic length (L∞) for *T. ilisha* in the present study was better than those recorded for the species in some waters (Al-Baz and Grove, 1995; Haldar and Nurul Amin, 2005 (males); Ahmed *et al.*, 2008; Hashemi, *et al.*, 2010; Roomiani and Jamili, 2011; Dutta *et al.*, 2012; Panhwar and Liu, 2013; Mohamed *et al.*, 2016; Dutta *et al.*, 2021), whereas was lower than those found in other waters (Nurul Amin *et al.*, 2004; Haldar and Nurul Amin, 2005 (females); Al-Sabbagh and Dashti, 2009). On the other hand, the L∞ value of *T. ilisha* in this study was almost similar to those obtained by Mohamed *et al* (2001) and Mohamed and Qasim (2014) for the species in Iraqi marine waters, Northwest

Table 2. Comparison of population parameters of *T. ilisha* from different areas of the world.

Region	L∞ (cm)	K	Z	F	M	E	Source
North Arabian Gulf, Kuwait	52.5	0.36	1.20	0.80	0.40	0.67	Al-Baz and Grove (1995)
Northwest Arabian Gulf, Iraq	60.5	0.32	1.28	0.66	0.62	0.52	Mohamed *et al* (2001)
Bangladesh waters	62.5	0.77	3.50	1.27	2.23	0.61	Nurul Amin *et al.* (2004)
Bangladesh waters ♂	51.5	0.53	3.08	2.07	1.01	0.67	Haldar and Nurul Amin (2005)
♀	65.6	0.51	2.87	1.95	0.92	0.68	
Bangladesh waters	58.5	0.71	2.61	1.39	1.22	0.53	Ahmed *et al.* (2008)
North Arabian Gulf, Kuwait	63.0	0.40	2.16	1.44	0.72	0.67	Al-Sabbagh and Dashti (2009)
Northwest Arabian Gulf, Iran	43.3	0.78	4.53	3.24	1.29	0.72	Hashemi *et al.* (2010)
Northwest Arabian Gulf, Iran	42.7	0.77	2.55	1.80	0.75	0.70	Roomian and Jamili (2011)
Bay of Bengal, India	47.8	1.90	1.98	0.73	1.25	0.37	Dutta *et al.* (2012)
Indus River, Pakistan	31.5	1.5	2.89	2.21	0.67	0.23	Panhwar and Liu (2013)
Northwest Arabian Gulf, Iraq	61.5	0.28	1.38	0.93	0.45	0.67	Mohamed and Qasim (2014)
East Hammar marsh, Iraq	57.1	0.33	1.55	0.87	0.68	0.56	Mohamed *et al.* (2016)
Northern Bay of Bengal, India	53.3	0.83	3.15	0.71	2.44	0.78	Dutta *et al.* (2021)
Shatt Al-Arab River, Iraq	59.1	0.27	1.94	1.35	0.59	0.70	Present study

Arabian Gulf. This variability in the growth of the same species in different locations could be attributed to several factors, such as different environmental conditions, availability of food, metabolic activity, reproductive activity, sizes of fish, method of sampling, and fishing pressure (Panda *et al.* 2018). Wootton (2011) stated that the growth of an individual fish achieves depends on three constraints, the genetic constitution of the individual, the abiotic environment experienced by the fish will set constraints on growth, and the biotic environment.

Mortality and exploitation rates

Figure 5 represents the length-converted catch curve used to estimate the total mortality rate (Z) of *T. ilisha.* The darkened circles represent the points used in the estimate (Z) which was 1.94 with 95% of the confidence interval (1.48-2.41; r^2= 0.930). Values of natural mortality rate (M) and fishing mortality (F) were 0.59 and 1.35, respectively. Therefore the current exploitation rate ($E_{current}$) is computed as 0.70.

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, how a population arrived at its current state and how it might change in the future (Pope *et al.*, 2010; Kebtieneh *et al.*, 2016). Total mortality (Z), natural mortality (M), fishing mortality (F), and the actual exploitation (E) rates of *T. ilisha* are documented in various geographic localities and presented in Table 2. In general, all the rates are within the ranges recorded in other populations of the species. However, Hashemi *et al.* (2010) recorded the highest values of Z (4.53) and F (3.24) for the species in north-western Arabian Gulf, Iran, whereas the highest values of M (2.44) and E (0.78) were found in the northern Bay of Bengal, India (Dutta *et al.*, 2021). According to Gulland (1971)'s criteria, most of the *T. ilisha* stocks are under heavy exploitation, except the stocks of the species in the Bay of Bengal, India (Dutta *et al.*, 2012) and the Indus River, Pakistan (Panhwar and Liu, 2013).

Probability of capture

Figure 6 shows the probabilities of the capture of each size class obtained by backward extrapolation of the straight portion of the right descending part of the catch curve in FiSAT software. Values of L_{25}, L_{50} and L_{75} for *T. ilisha* were 19.46, 24.37 and 29.28 cm, respectively. Therefore, the length at first capture (L_c) was 24.37 cm.

Recruitment

As shown in figure 7, the annual recruitment pattern of *T. ilisha* indicated that recruitment occurred throughout the year with two unequal prominent peaks. The major one contributed 82.0% of the total recruits and extended from January to May with a peak in March (26.1%), while the minor one formed 18% and occurred from June to November with a July peak (7.1%).

The recruitment pattern of *T. ilisha* in the present study reveals a bimodal recruitment form, the major peak occurring from January to May with a peak in March, and the minor one extended from June to November with a peak in July. The bimodal recruitment pattern was also observed for the same species in the Shatt Al-Arab River by Jabir (1995), in Iraqi marine waters, northwest Arabian Gulf by Mohamed *et al.* (2001) and Mohamed and Qasim (2014) and in Bangladesh waters by Rahman and Cowx (2008). Some works found prolonged recruitment with one major peak pattern for the recruitment of *T. ilisha* in some waters, such as between July-November on the northeast coast of India (Reuben *et al.*, 1992), June-September on the West Bengal coast, Bangladesh (Nurul Amin *et al.*, 2004), June-October in Northern Bay of Bengal, India (Dutta *et al.*, 2012), June-August in Sundarban Estuary in the Bay of Bengal, India (Dutta *et al.*, 2019) and May-September in the northern Bay of Bengal, India (Dutta *et al.*, 2021).

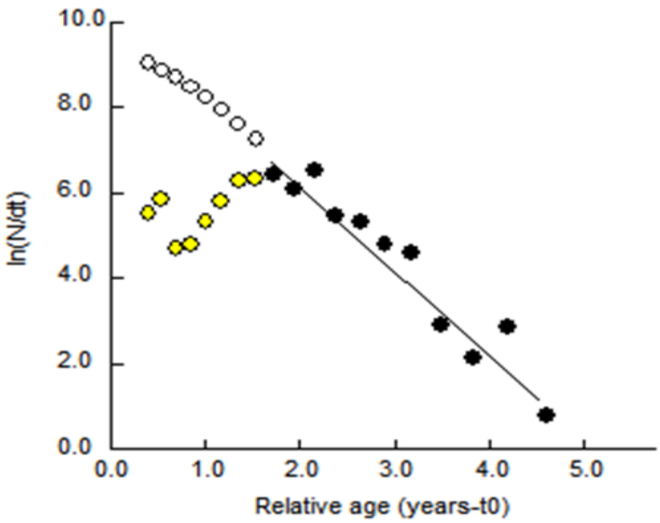

Figure 5. *Length converted catch curve for estimation of Z for T. ilisha.*

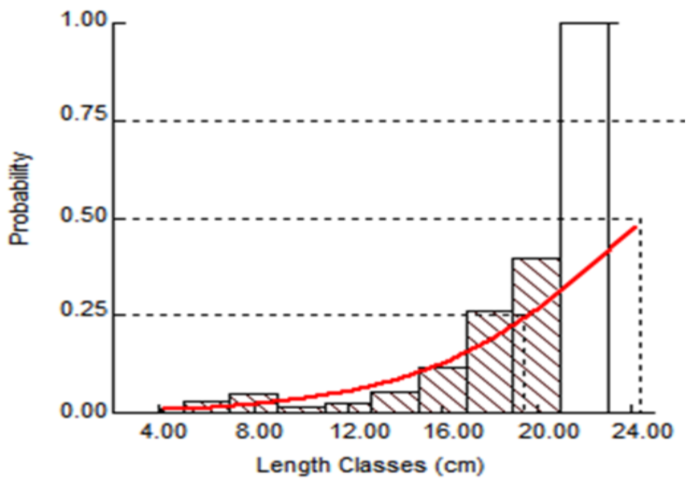

Figure 6. *Probability of capture for T. ilisha.*

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

Figure 8 shows the values of yield per recruit and the biomass per recruit, which are analyzed by the knife-edge selection routine in the Beverton and Holt Y/R model incorporated in FiSAT software as a function of M/K (2.185) and $L_c/L\infty$ (0.410), which derived from the previous analyses. Consequently, $E_{0.1}$ and E_{max} were estimated. The obtained values of the biological target reference points, $E_{0.1}$ and E_{max} were 0.570 and 0.675, respectively, and this revealed that the current exploitation rate ($E_{current}$= 0.70) was higher than both biological target reference points.

Jennings *et al.* (2000) 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. The large exploitation of *T. ilisha* 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 $E_{0.1}$ (0.570) and E_{max} (0.675) are lower than the actual exploitation rate (E). Similar findings have been observed in the stocks of *T. ilisha* in Kuwait waters, northwest Arabian Gulf (AL-Baz and Grove, 1995), in the northern Bay of Bengal, India (Dutta *et al.*, 2012; 2021), in Bangladesh waters (Rahman *et al.*, 2000; Nurul Amin *et al.*, 2002; Halder *et al.*, 2005), in coastal waters of Arabian Gulf, Iran (Hashemi *et al.*, 2010; Roomian and Jamili, 2011) and Iraqi marine waters, northwest Arabian Gulf (Mohamed and Qasim, 2014). These results indicate that the stocks of *T. ilisha* are a target species and are suffering from a high rate of exploitation in the Arabian Gulf and the Bay of Bengal.

Virtual population analysis

Table 3 provides the FiSAT II outputs of the length-structured virtual population analysis of *T. ilisha*. The catches ranged from 17 at length class 10cm to 153 at length class 26cm. The recruitment of *T. ilisha* into the fishery was estimated at 3494 then after the population declined with the increased length groups. Most harvests of the species happened in mid-lengths of 18-26 cm. However, the 40 cm length group was more vulnerable to fishing, which has more harvested according to VPA

Table 3. FiSAT II output of virtual population analysis of *T. ilisha* from Iraqi marine waters.

Mid-Length	Catch (in numbers)	Population (N)	Fishing mortality (F)	Steady-state Biomass (tons)
6.0	35.00	2509.81	0.1049	0.00
8.0	52.00	2277.92	0.1662	0.00
10.0	17.00	2041.37	0.0579	0.00
12.0	19.00	1851.24	0.0687	0.01
14.0	34.00	1669.04	0.1315	0.01
16.0	57.00	1482.50	0.2400	0.02
18.0	98.00	1285.38	0.4644	0.02
20.0	107.00	1062.88	0.5930	0.03
22.0	127.00	849.42	0.8625	0.03
24.0	94.00	635.55	0.8092	0.03
26.0	153.00	473.01	1.8813	0.03
28.0	57.00	272.03	1.0641	0.02
30.0	53.00	183.42	1.4558	0.02
32.0	34.00	108.94	1.4979	0.02
34.0	30.00	61.55	2.5244	0.01
36.0	6.00	24.54	0.9684	0.01
38.0	3.00	14.88	0.7153	0.00
40.0	7.00	9.41	4.2507	0.00
42.0	1.00	1.44	1.3500	0.00
Mean			1.01	

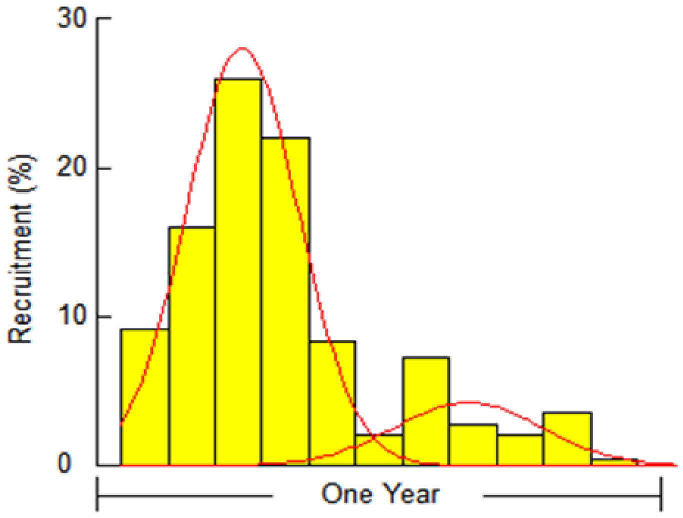

Figure 7. *Recruitment pattern of T. ilisha.*

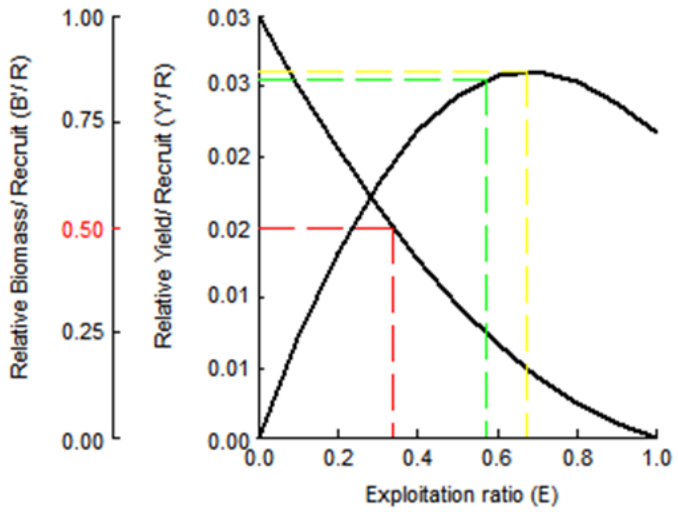

Figure 8. *Relative yield per recruit (Y'/R) and biomass per recruit (B'/R) analyses for T. ilisha.*

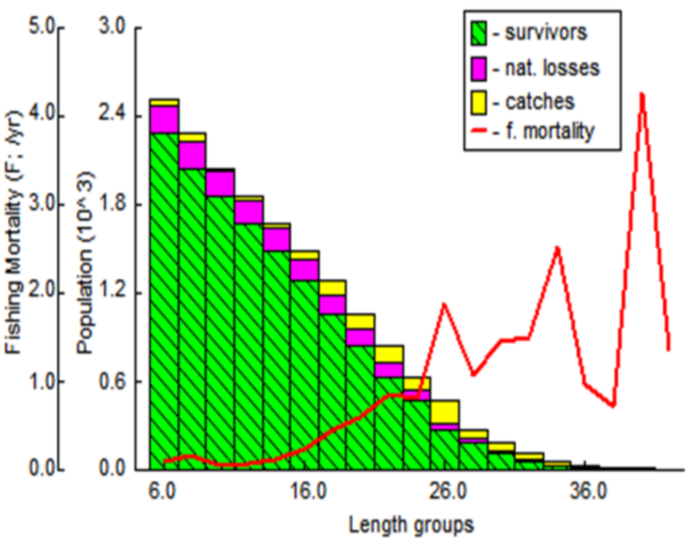

Figure 9. *Length-structured virtual population analysis of T. ilisha from Iraqi marine waters*

analysis, followed by the 34 cm and 26 cm length groups. The average fishing mortality value of *T. ilisha* was 1.01/year and was lower than that estimated by the catch-curve method (1.35/ year). The maximum steady-state biomass (t) of this species (0.03 t) occurred in the length groups 20-26 cm, then fell to 0.01 ton for mid-length 36 cm.

Figure 9 explains the outputs of the virtual population analysis (VPA) of *T. ilisha* in the present study about the natural losses, survivability, and fishing mortality. The natural losses and survivability of the fish population decreased with an increase in length and fishing mortality. Also, the fishing mortality value of the species was not consistent, in which three distinguished peaks were at lengths of 26, 34, and 40 cm.

Shepherd and Pope (2002) 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. According to the virtual population analysis (VPA), most catches of *T. ilisha* in this study occurred in mid-lengths of 18-26 cm. Further, Almeidaa *et al.* (2018) stated that the first sexual maturation is an important point in the animal's life history and must be considered for successful fish management. In the present study, there was a difference between the length at the first capture of *T. ilisha* (L_{c50}= 20.6 cm) and the length at first maturity (L_{m50}). The length at first maturity (L_{m50}) of the species in the region varied from 22.5 to 23.9 cm (Hussein *et al.*,1991) and 27.3 cm (Koochaknejad *et al.*, 2018). These results mean that the species' catches have not met 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 to ensure resource availability and sustainability (Udoh and Ukpatu, 2017; Panda *et al.*, 2018).

Conclusion

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. Historically, the *T. ilisha* fishery is the most significant marine fishery from the economic-socio point of view in the Basrah province. So, proper management leading to sustainable utilization of this resource is extremely essential.

The Iraqi Government must be introduced an extensive shad management action plan by protecting brood shad during breeding seasons by imposing a ban on fishing, restricted mesh size, etc. in the Shatt Al-Arab River during the main spawning migration, and conserving the small *T. ilisha* (Milat <23.0 cm).

REFERENCES

Ahmed, M. S., Sharif, A. S. M. & Latifia, G. A. (2008). Age, growth and mortality of Hilsa shad, *Tenualosa ilisha* in the River Meghna, Bangladesh. *Asian Journal of Biological Sciences*, *1*(2), 69-76.

AL-Baz, A. F. & Grove, D. J. (1995). Population biology of sbour *Tenualosa ilisha* (Hamilton-Buchanan) in Kuwait. *Asian Fisheries Science*, *8*, 239-254.

Al-Hassan, L. A. L. (1999). Shad of the Shatt Al-Arab River in Iraq. *Shad Journal*, *4*(2), 1-4.

Al-Sabbagh, T. & Dashti, J. (2009). Post-invasion status of Kuwait's fin-fish and shrimp fisheries (1991-1992). *World Journal of Fish and Marine Sciences*, *1*(2), 94-96.

Almukhtar, M. A., Jasim, W. & Mutlak, F. (2016). Reproductive Biology of Hilsa Shad *Tenualosa ilisha* (Teleostei: Clupeidae) during spawning migration in the Shatt Al-Arab River and southern Al-Hammar Marsh, Basra, Iraq. *Journal of Fisheries and Aquatic Science*, 11, 43-55, https://doi.org/10.3923/jfas.2016.43.55

Ali, T. S., Mohamed, A. R. M. & Hussain, N. A. (1998). The Status of Iraqi Marine Fisheries during 1990-1994. *Marina Mesopotamica*, *13*, 129-147.

Almeidaa, Z. S., Carvalhob, I. F. S., Dinizb, A. L. C., Netaa, R. N. F. C., Torresc, C. L. & Serra, I. M. R. S. (2018). Models of sexual maturation as a tool for the conservation of commercial fish in a RAMSAR site of Brazil. Conference Paper in AIP Conference Proceedings· November 2018). https://doi.org/10.1063/1.5079159

Al-Ramadhanm, B. M. & Pastour, M. (1987). Tidal characteristics of Shatt Al-Arab River. *Marina Mesopotamica*, *2*(1), 15-28.

Asadi S. A. R. & Alhello A. A. (2019). General assessment of Shatt Al-Arab River, Iraq. *International Journal of Water*, *13*(4), 360-375.

Bhaumik, U., Naskar, M. & Sharma, A. P. (2011). Size distribution, length-weight relationship and sex ratio of the Hilsa (*Tenualosa ilisha*) in the Hooghly estuarine system. *Journal of Inland Fisheries Society of India*, *43*(2), 1-5.

Beverton, R. J. H. & Holt, S. J. (1966). Manual of methods for fish stock assessment. Part II. Fish. Biol. Tech. Pap. 38, 10-67.

BOBLME. (2015). Stock assessment of Hilsa shad, *Tenualosa ilisha* in Myanmar BOBLME-2015-Ecology-22.

Brandimarte, L., Popescu, I. & Neamah, N. K. (2015). Analysis of fresh-saline water interface at the Shatt Al-Arab estuary. *International Journal of River Basin Management*, *13*, 17-25, https://doi.org/10.1080/15715124.2014.945092

Cadima, E. L. (2003). Fish stock assessment manual. FAO Fisheries Technical Paper. No. 393. Rome, FAO. 161pp.

Cuadrado J. T., Lim D. S., Alcontin R. M. S, Calang J. L. & Jumawan J. C. (2019). Species composition and length-weight relationship of twelve fish species in the two lakes of Esperanza, Agusan del Sur, Philippines. *FishTaxa*, *4*(1), 1-8.

Dutta, S., Maity, S., Chanda, A. & Hazra, S. (2012). Population structure, mortality rate and exploitation rate of Hilsa Shad (*Tenualosa ilisha*) in West Bengal coast of northern Bay of Bengal, India. *World Journal of Fish and Marine Sciences*, *4* (1), 54-59.

Dutta, S. & Hazra, S. (2017). From biology to management: A critical review of Hilsa Shad (*Tenualosa ilisha*). *Indian Journal of Geo Marine Sciences*, *46*(8), 1503-1510.

Dutta, S., Chakraborty, K. & Hazra, S. (2019). Life History and Population Dynamics of *Tenualosa ilisha* of Sundarban Estuary in Bay of Bengal, India for Sustainable Fishery Management. *Indian Journal of Geo Marine Sciences*, 48(12), 1870-1880.

Dutta, S., Orlov, A. M. & Hazra, S. (2021). Population biology and exploitation status of four commercially important marine fishes of the northern Bay of Bengal, India. *Iranian Journal of Fisheries Sciences*, *20*(1): 62-83, https://doi.org/10.22092/ijfs.2021.123477

Fischer W. & Bianchi, G. (1984). FAO Species Identification Sheet for Fishery Purposes. Western Indian Ocean (Fishing Area 51). Prepared and Printed with the Support of the Danish International Development Agency (DANIDA). FAO, Rome, Vol. 1-6.

Flura, M., Zaher, B.M.S., Rahman, M. A., Rahman, M. A. & Pramanik, M. M. H. (2015). Length-weight relationship and GSI of hilsa, *Tenualosa ilisha* (Hamilton, 1822) fishes in Meghna river, Bangladesh. *International Journal of Natural and Social Sciences*, *2*(3), 82-88.

Fricke, R., Eschmeyer, W. N. & Fong, J. D. (2022). Eschmeyer's Catalog of Fishes. Species by family/subfamily. http://researcharchive. Cal academy. org/research/ichthyology/ catalog/ SpeciesByFamily.asp). Online Version, Updated 5 April 2022.

Gayanilo, F.C.Jr, Sparre, P. & Pauly, D. (2005). FAO-ICLARM Stock Assessment Tools II (FiSAT II). Revised version. User's guide. FAO Comp. Info. Ser. (Fisheries). 8: 1-168.

Gokce, G., Aydin, I. & Metin, C. (2007). Length-weight relationships of 7 fish species from the North Aegean Sea, Turkey. *International Journal of Natural and Engineering Sciences*, *1*, 51-52.

Gulland, J. A. (1971). Fish resources of the Ocean. Fishing News Books, Surrey, London, England. 255pp.

Halder, G. C. & Nurul Amin, S. M. (2005). Population dynamics of male and female, *Tenualosa ilisha* of Bangladesh. *Pakistan Journal of Biological Sciences*, *8*(2), 307-313.

Hashemi, S., Mohammadi, G. & Eskandary, G. (2010). Population Dynamics and Stock Assessment of Hilsa Shad, (*Tenualosa ilisha* Hamilton Buchanan, 1822) in coastal waters of Iran (Northwest of Persian Gulf). *Australian Journal of Basic and Applied Sciences*, *4*(12), 5780-5786.

Hussein, S. A., Al-Mukhtar, M. A. & Al-Daham, N. K. (1991). Preliminary investigation on fisheries and some biological aspects of sbour, *Hilsa ilisha* from Shatt Al-Arab river, Iraq. *Basrah Journal of Agricultural Sciences*, *4*, 141-151.

Jennings, S., Kasier, M. & Reynold, J. (2000). Marine Fisheries Ecology. Blackwell Science, Oxford. 391pp.

Jones, R. & van Zalinge, N.P. (1981). Estimations of mortality rate and population size for shrimp in Kuwait waters. *Kuwait Bulletin of Marine Sciences*, 2, 273-288.

Khayat, K. M. S. (1978). An economic study of fishing industry in Iraq. Publications of the Arabian Gulf Studies Center. University of Basrah, Iraq. 196 pp.

Kebtieneh, N., Alemu, Y. & Tesfa, M. (2016). Stock assessment and estimation of maximum sustainable yield for tilapia stock (*Oreochromis niloticus*) in Lake Hawassa, Ethiopia. *Agriculture, Forestry and Fisheries*, 5(4), 97-107, https://doi.org/10.11648 /j.aff.20160504.12

Koochaknejad E., Savari A., Safahieh A. & Eskandari G. (2018). Age, growth and maturity of Hilsa shad (*Tenualosa ilisha*) in northwestern part of the Persian (Arabian) Gulf. *Journal of Marine Science and Technology*, 17(1), 47-58, http://hdl.handle.net/1834/13424

Kuronuma, K. & Abe, Y. (1986). Fishes of the Arabian Gulf. Kuwait Institute of Sciences Research, Kuwait. 356pp.

Mili, S., Ennouri, R., Chhibi, M., Laouar, H., Romdhane, N. & Missaoui, H. (2017). Length-weight relationships (LWRs) of endemic and introduced freshwater fish species in 13 Tunisian reservoirs. *Journal of New Sciences, Agriculture and Biotechnology*, *41*(8), 2253-2259.

Milton, D. A. (2010). Status of hilsa (*Tenualosa ilisha*) management in the Bay of Bengal. Report to FAO Bay of Bengal Large Marine Ecosystem Project 15 February 2010, 70pp.

Mohamed, A. R. M. & Qasim, A. M. H. (2014). Stock Assessment and Management of Hilsa Shad (*Tenualosa ilisha*) in Iraqi Marine Waters, Northwest Arabian Gulf. *World Journal of Fish and Marine Sciences*, *6*(2), 201-208.

Mohamed A. R. M. (2018). Assessment and management of Iraqi marine artisanal fisheries, northwest of the Arabian Gulf. *Journal of Agriculture and Veterinary Science*, 11(9): 85-92, https://doi.org/10.9790/2380-110901859210.9790/2380-1109018592

Mohamed, A. R. M., Ali, T. S. & Hussain, N. A. (2002). The assessment of Iraqi marine fisheries during 1995-1999. *Iraqi Agricultural Journal*, *17*(1), 127-136.

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

Mohamed, A. R. M. & Abood, A. N. (2017). Compositional change in fish assemblage structure in Shatt Al-Arab River, Iraq. *Asian Journal of Applied Sciences*, *5*(5), 944-958.

Mohamed, A. R. M. & Abood, A. N. (2020). Current status of Iraqi artisanal marine fisheries in northwest of the Arabian Gulf of Iraq. *Archives of Agriculture and Environmental Science*, 5(4), 457-464, https://doi.org/10.26832/24566632.2020.050404

Mohamed, A. R. M. & Abood, A. N. (2022). Characterization of Iraqi artisanal marine fisheries, northwest of the Arabian Gulf. *Ocean and Coastal Research*, (in press).

Mohamed, A. R. M., Ali, T. S. & Hussain, N. A. (2001). Stock assessment of. Hilsa shad *Tenualosa ilisha* in the Iraqi waters, Northwest Arabian Gulf. *Marina Mesopotamica*, *16*(1), 1-9.

Nurul Amin, S. M., Rahaman, M. A., Haldar, G. C., Mazid, M. A. & Milton, D. A. (2002). Population Dynamics and Stock Assessment of Hilsa Shad, *Tenualosa ilisha* in Bangladesh. *Asian Fisheries Sciences*, *15*, 123-128.

Nurul Amin, S. M., Rahaman, M. A., Haldar, G. C., Mazid, M. A., Milton, D. A. & Blaber, S. J. M. (2004). Stock assessment and management of *Tenualosa ilisha* in Bangladesh. *Asian Fisheries Science*, *17*, 51-59.

Nurul Amin, S. M., Arshad, A., Haldar, G. C., Shohaimi, S. & Ara, R. (2005). Estimation of size frequency distribution, sex ratio and length-weight relationship of Hilsa (*Tenualosa ilisha*) in the Bangladesh water. *Research Journal of Agriculture and Biological Sciences*, 1(1), 61-66.

Nurul Amin, S. M., Rahaman, M. A., Haldar, G. C., Mazid, M. A. & Milton, D. A. (2008). Catch Per Unit Effort, Exploitation Level and Production of Hilsa Shad in Bangladesh Waters. *Asian Fisheries Science*, *21*, 175-187.

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

Panhwar, S. K. & Liu, Q. (2013). Population statistics of the migratory hilsa shad, *Tenualosa ilisha*, in Sindh, Pakistan. *Journal of Applied Ichthyology*, 29, 1091-1096, https://doi.org/10.1111/JAI.12134

Pauly, D. (1983). Some simple methods for assessment of tropical fish stocks. FAO Fishery Technical Paper, 234, 52.

Pauly, D. & Munro, J. L. (1984). Once more on the comparison of growth in fish and invertebrates. *ICLARM Fishbyte*, 2(1): 21.

Pauly, D. & Soriano, M.L. (1986). Some practical extensions to Beverton and Holt's relative yield-per-recruit model, in: Maclean, J.L., Dizon, L.B., Hosillo, L.V. (Eds.), The First Asian Fisheries Forum, pp. 491-496.

Pope, K. L., Lochmann, S. E. & Young, M. K. (2010). Methods for assessing fish populations. Chapter 11. Pp: 325-351. University of Nebraska, Nebraska Cooperative Fish & Wildlife Research Unit. Publications paper 73.

Rahman, M. J. & Cowx, I. G., (2008). Population dynamics of Hilsa Shad (*Tenualosa ilisha*, Clupeidae) in Bangladesh waters. *Asian Fisheries Science*, 21, 85-100.

Rahman, M. A., Nurul Amin, S. M., Haldar, G. C. & Mazid, M. A. (2000). Population Dynamics of *Tenualosa ilisha* of Bangladesh Water. *Pakistan Journal of Biological Sciences*, *3*(4), 564-567.

Rahman, M. J., Abdul Wahab, M., Nurul Amin, S. M., Nahiduzzaman M. & Romano N. (2018). Catch trend and stock assessment of Hilsa *Tenualosa ilisha* using digital image measured length-frequency data. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*, *10*, 386-401, https://doi.org/10.1002/mcf2.10034

Roomian, L. & Jamili, S. (2011). Population dynamics and stock assessment of Hilsa shad, *Tenualosa ilisha* in Iran (Khuzestan province). *Journal of Fisheries and Aquaculture Sciences*, 6, 151-160, https://doi.org/10.3923/JFAS.2011.151.160

Reuben, S., Dan, S. S., Somaraju, M. V., Philipose, V. & Sathianandan, T. V. (1992). The resources of hilsa shad, Hilsa ilisha (Hamilton), along the northeast coast of India. *Indian Journal of Fisheries*, *39*, 169-181.

Ricker, W. E. (1975). Computation and interpretation of biological statistics of fish populations. *Bulletin of Fishery Research Board of Canada*, *191*, 1-382.

Riedel, R., Caskey, L. M. & Hurlbert, S. H. (2007). Length-weight relations and growth rates of dominant fishes of the Salton Sea: implications for predation by fish-eating birds. *Lake and Reservoir Management*, 23, 528-535, https://doi.org/10.1080/07438140709354036

Shepherd, J. G. & Pope, J. G. (2002). Dynamic pool models I: Interpreting the past using virtual population analysis, in: Hart, P.J.B., Reynolds, J.D. (Eds.), Handbook of Fish Biology and Fisheries. Vol. 2. Fisheries. Oxford, UK, pp. 127-136.

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

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

Yaseen, B. R., Al-Asaady, K. A., Kazem, A. A. & Chaichan, M. T. (2016). Environmental Impacts of Salt Tide in Shatt Al-Arab-Basra/Iraq. *Journal of Environmental Science, Toxicology and Food Technology*, 10, 35-43.