Bangladesh J. Zool. **48**(2): 231-241, 2020 ISSN: 0304-9027
eISSN: 2408-8455

POPULATION DYNAMICS AND STOCK ASSESSMENT OF HILSA SHAD, *TENUALOSA ILISHA* (HAMILTON, 1822) ALONG THE COAST OF BANGLADESH

Md Khairul Islam[1], Md. Humayun[2], Manmatha Nath Sarker[3]*, Md. Sharifuddin[3] and M. Niamul Naser[1]

Department of Zoology, Faculty of Biological Sciences, University of Dhaka, Dhaka 1000, Bangladesh

Abstract: Stock Assessment of *Tenualosa ilisha* (Hamilton, 1822) were estimated using FiSAT-II software with length-frequency data collected from different landing centers. The Southeast Coast of Bay Of Bengal, Cox's Bazar. The Von Bertalanffy growth parameters $L_\infty$and K for the species were asymptotic length (L_∞) was 51.41 cm, growth rate (K) was 0.75 year^{-1} and t_0 = -0.2 year respectively. The estimated value of total mortality (Z) based on length converted catch curve using these growth parameters was 2.35 year^{-1}.Natural mortality (M) based on growth parameters and mean environmental temperature (T = 27° C) was 1.00 year^{-1} and fishing mortality (F) was 1.35 year^{-1}. Optimum length of hilsa at first capture (L_c=L_{50}) was 28.36 cm TL. Growth performance indices (ϕ') was 3.30. The estimated value of the exploitation rate (E) using the length-converted catch curve was 0.57. The recruitment pattern of this species was continuous and two peaks per year. The present investigation clearly showed the over fishing (E > 0.50) condition for *T. ilisha* in Bangladesh. The estimated length-weight relationship for the combined sex was found to be W = 0.0109 L^3. Virtual population analysis (VPA) showed that the maximum fishing mortality occurring in the length between 30 to 35 cm with a maximum value in the length of 32 cm that repeatedly indicate high fishing mortality in the *T. ilisha*. The generalized length-weight relationship was fitted with the pooled data of all monthly samples were BW = 0.029 $TL^{2.718}$ (R^2= 0.833) respectively. The results revealed that all length-weight relationships were highly correlated (r > 0.993). Maximum sustainable yield (MSY) was estimated as 435,554 t.

Key words: Population Dynamics, Stock assessment, *Tenualosa ilisha*, Cox's Bazar, Bangladesh

INTRODUCTION

Hilsa (*T. ilisha)* is the national fish of Bangladesh. It is an important marine diadromous fish, locally known as "Ilish". This is the largest single species fishery in both the inland and marine waters of Bangladesh especially during

*Author for corresponding: < mn_sarker2001@yahoo.com>, [2]*Center for Development Initiative In Capture Fisheries, Shyamoli, Dhaka, Bangladesh,* [3]*Marine Fisheries Capacity Building Project, Department of Fisheries, Matshya Bhaban Dhaka, Dhaka, Bangladesh.*
 DO: https://doi.org/10.3329/bjz.v48i2.52365

the monsoon in almost all the principal river system, estuaries and the sea of Bangladesh (Amin *et al.* 2004). Bangladesh harvest about 60% of world hilsa catch. Hilsa contributed 12.9% of the country's total fish production in 2017-2018 with an estimated annual production of 517,198 t, which was 1.0% to the GDP to support livelihoods of 1.2 million hilsa fishers of Bangladesh (Sarker *et al.* 2019). Geographical Indication Registration Certificate has been achieved for our national fish hilsa (FRSS 2018). In Bangladesh hilsa may reach up to 60 cm in total length and 3 kg in weight at 4 years of age (Sarker *et al.* 2016). Most commonly found hilsa is 35 to 40 cm in length and less than one kg in weight. Mature hilsa migrate upstream primarily during the southwest monsoon and consequent flooding of the rivers (Rahman 2000, Ahsan *et al.* 2014). The larvae and juveniles make their way downstream to the sea during a period of 5-6 months feeding and growing on the way. Maturity occurs between 6-12 months of age where the survivors undertake their first spawning migration upriver (Rahman *et al* 1998 and Naser, 2018).

MATERIAL AND METHODS

Length-frequency data of *T. ilisha* were collected weekly from the commercial catches from 6 different landing centers of Bangladesh coastal district Cox's Bazar from March, 2018 to February, 2019. The complete length-weight related data was provided by Bangladesh Marine Fisheries Capacity Building Project (BMFCB), Department of Fisheries (DoF), Matshya Bhaban, Ramna, Dhaka, Bangladesh. The data collection procedure was followed by Standard Operating Procedure on Information Collection from Landing Center for Marine Fisheries Stock Assessment (Azad *et al.* 2012). A total of 1702 specimens of hilsa ranging size from 20-51 cm (1±mm) in total length (TL) and 58-1411 g in total body weight (BW) were collected randomly for the analysis. The total length was measured as the distance from snout to the tip of the caudal fin and body weight was taken with an electric digital balance for each fish after the specimens were dried on blotting paper.

To avoid gill net selectivity different landing sites were selected as different mesh size of gill nets are used to catch the hilsa fish on the availability of different size group of fishes. The data from landing sites were then pooled month-wise and subsequently grouped into length classes by 2 cm interval. The data were then pooled monthly from different landing sites and subsequently grouped into classes of 2 centimeter intervals. The data were analyzed using the FiSAT-II (FAO-ICLARM Stock Assessment Tools) as explained in details by Gayanilo Jr. *et al.* (1996). The fitting of the best growth curve was based on the ELEFAN-I programme (Pauly & David 1981), which allows the fitted curve through the maximum number of peaks of the length-frequency distribution. With the aid of the best growth curve, the growth constant (K) and asymptotic length (L_∞) were estimated.

Data processing and analysis: Estimation of Asymptotic length (L_∞), Growth co-efficient (K) and Age at zero (0) length (t_0):Month-wise length-frequency data were used to estimate the total asymptotic length (L_∞) cm and growth co-efficient (K) $year^{-1}$ of the von Bertalanffy growth equation (Bertalanffy 1938; Beverton & Holt 1957). The data collection period started from March, 2018 and continued up to February, 2019. The ELEFAN-I and ELEFAN-II routines incorporated in FiSAT-II (FAO ICLARM Stock Assessment Tools) Software (Gayanilo *et al.*2005) were used to determine L_∞ and K values following the Powell-Wetherall method (Wetherall *et al.* 1987). This method was used to provide an initial estimate of L_∞. This initial estimate of L_∞ was then used as seed value to determine the value of K (Silvestre & Graces 2004). Minor adjustments to L_∞ and K were made to maximize the 'goodness of fit' criterion built in to ELEFAN-I (Pauly 1987). This led to a preliminary estimate of L_∞ and K that were used to obtain "probability of capture" by length class using the routine in FiSAT. These "probability of capture" were used to correct the length- frequency distribution data to account for incomplete selection and recruitment and the final estimate of L_∞ and K were obtained by using the corrected length-frequency data through ELEFAN I (Silvestre & Graces 2004). ELEFAN-I was used to estimate the growth parameters based on the Von Bertalanffy Growth Formula (VBGF) expressed in the form (Pauly & Gaschutz 1979): $L_t = L_\infty [1 - \exp\{- K (t - t_0)\}]$

Where, L_t is the predicted length at time t, L_∞ is the asymptotic length or maximum length of a given stock of a fish, K is the growth constant , also called 'stress factor' by (Pauly 1980) and t_0 is the "age" the fish would have been at zero (0) length. t_0 was estimated by employing the equation of Pauly (1980): $\text{Log} (-t_0) = - 0.3922 - 0.2752 * \text{Log} (L_\infty) - 1.038 * \text{Log} (K)$

Growth Performance (ϕ'): The growth performance of *T. ilisha* population in terms of length was compared using the index of Pauly & Munro (1984), $\phi' = \text{Log}_{10} (K) + 2 \text{Log}_{10} (L_\infty)$

Phi prime (ϕ') is much used as the probability best means of averaging growth parameters of a particular species. ϕ' is calculated for each datum set and averaged. Inserting a value L_∞ for instances the mean of all estimates gives a value of corresponding to the L_∞ inserted, whenever L_∞ and K are estimated from a new set of datum for the same species calculation of ϕ' indicates if the new pair of L_∞ and K is in accordance with previous result. The new ϕ' should be close to the previous estimate, because ϕ' is the constant in the regression of Log K + 2 log L_∞ (Sparre & Venema 1998).

Mortality Estimation: In FiSAT-II software package (Gayanilo *et al.* 2005), ELEFAN-II was used to estimate the total mortality Z (year^{-1}) using the length converted catch curve by means of final estimates L_∞ and K and length-frequency data (Beverton & Holt 1957, 1966) for the species *T. ilisha.* The rate of natural mortality M (year^{-1}) for the species was calculated by using Pauly's empirical equation (Pauly 1983):

$$\text{Ln}(M) = -0.0152 - 0.279\,\text{Ln}(L_\infty) + 0.6543\,\text{Ln}(K) + 0.463\,\text{Ln}(T)$$

Pauly (1983) suggests to account for schooling in above equation by multiplication by 0.8 so that for schooling species the estimate becomes 20% lower: and the above equation will be modified to: $M = 0.8 * \exp[-0.0152 - 0.279\,\text{Ln}(L_\infty) + 0.6543\,\text{Ln}(K) + 0.463\,\text{Ln}(T)]$

This formula was used to obtain the estimate of M, given L_∞ in cm, K the growth constant and T the mean environmental temperature °C. Once Z and M were obtained, then fishing mortality F was derived from the relationship $F = Z - M$ (Silvestre & Graces 2004). The exploitation rate E was obtained by the relationship: $E = F/Z = F / (F + M)$ (Beverton & Holt 1966; Ricker 1975).

Probability of Capture: Probability of capture calculated from the length converted catch curve routine and estimated the final L_{25}, L_{50} and L_{75} (Length at which 25%, 50% and 75% of fish would be vulnerable to the gear (Pauly 1984).

Recruitment Pattern: Recruitment Pattern was obtained by the backward projection of the frequencies on the time axis of a time series of samples along a trajectory defined by the Von Bertalanffy growth equation (Moreau & Cuende 1991). This routine reconstructs the recruitment pulses from time series of length-frequency data to determine the number of pulses per year and the relative strength of each pulse (Gayanilo *et al.* 2005).

Virtual Population Analysis (VPA): The terminal population (N_t) was estimated from $N_t = C_t (M + F_t)/F_t$. Where C_t is the terminal catch, and F_t is the terminal fishing mortality and M is the natural mortality. Starting from N_0 successive value of F was estimated by iteratively solving:

$C_i = N_{i+\Delta t} \cdot (F_i/Z_i) \cdot \{\exp(Z_i \cdot \Delta t_i) - 1\}$ (Gayanilo *et al*, 2005). Where C_i = Catch (in number) for a population during a unit time period i, $\Delta t_i = (t_{i+1} - t_i)$ and $t_i = t_0 - (1/K) \cdot \text{Ln}\{1 - (L_t/L_\infty)\}$.

The population size N_i was computed from $N_i = N_i + \Delta t * \exp(Z_i)$. The last 2 equations were used alternatively until the population sizes and fishing mortality for all length group have been computed (Jones & Van Zalinge 1981; Moreau & Cuende 1991).

Relative Yield-per-Recruit and Relative Biomass-per-Recruit: The Relative Yield-per-Recruit (Y'/R) was computed using the following formula (Gayanilo & Pauly 1997; Beverton & Holt, 1966):

$$Y'/R = E \cdot U^{M/K} \{1 - \frac{3U}{(1+m)} + \frac{3U^2}{(1+2m)} - \frac{3U^3}{(1+3m)}\}$$

Where, $U = 1 - (L_c/L_\infty)$, $m = (1 - E)/ (M/K) = K/Z$, L_c = length of fish at first capture i.e. length at which 50% of the fish are retained by the gear and $E = F/Z$.

Relative Biomass-per- Recruit B'/R was estimated from the relationship $B'/R = (Y'/R)/F$

The value of E_{max}, $E_{0.1}$ and $E_{0.5}$ were estimated by using the first derivative of this function, where, E_{max} = maximum sustainable exploitation rate, $E_{0.1}$ = exploitation rate at which the marginal increase of relative yield-per-recruit is 1 / 10th and $E_{0.5}$ = value of E under which the stock has been reduced to 50% of its unexploited biomass.

Length-Weight Relationships: The total length was measured as the distance from snout to the tip of the caudal fin and body weight was taken with an electric digital balance for each fish after the specimens were dried on blotting paper. The relationship between the total length (TL) and total body weight (BW) of fish was estimated by using the equation: $BW = aTL^b$

Where, BW = Body weight of fish in (g); a = Constant (intercept); TL = Total length of fish in (cm); b = an exponent indicating isometric growth when equal to

Maximum Sustainable Yeild (MSY): The total annual stock size, average standing stock size and MSY of *T. ilisha* were also estimated. For this purpose, at first exploitation rate (U) was estimated using the equation given by (Beverton & Holt 1957 and Ricker 1975) as $U = F/Z\ (1 - e^{-z})$. To estimate the annual catch (Y), the landing data of hilsa were collected from the Fisheries Resources Survey System (FRSS), Department of Fisheries (DoF), Bangladesh. Then by using the values of U, F and Y the total annual stock $(\frac{Y}{U})$ and average standing stock $(\frac{Y}{F})$ were determined. The approximate MSY was then calculated using the relationship proposed by Gulland (1979).

$$MSY = Z_t * 0.5\ B_t$$

Where, Z_t is the instantaneous total mortality in the year t and B_t the standing stock size in the year. The length-weight relationship of *T. ilisha* was estimated using the formula: $W = aL^b$, where 'a' is a constant and 'b' is an exponent.

RESULTS AND DISCUSSION

Growth Parameters: Growth parameters of von Bertalanffy growth parameters for *T. ilisha* were estimated as L_∞ = 51.41 cm and K = 0.75 $year^{-1}$. These values did not show much difference when compared to the L_∞ and K values estimated by other studies for the same species from Bangladesh waters (Ahmed *et al.* 2002; Ahmed *et al.* 2008; Rahman *et al.* 2008) but was slightly lower than studies (Rahman *et al.* 2000; Amin *et al.* 2002; Amin *et al.* 2004) where L_∞varied between 52 and 66 cm and the K varied between 0.66 and 0.83 $year^{-1}$.

For these estimates "K Scan" option of the FiSAT-II was used as recommended by Gayanilo *et al.* (2005). The computed growth curve produced with those parameters are shown over its restructured length distribution in Fig. 2. The t_0 value was taken as -0.2 $year^{-1}$. Another test is the so-called 'Munro's phi prime test' (Munro & Pauly 1983; Pauly & Munro 1984) estimated from length-frequency data (ϕ' =3.30). The data were found to be well within the clupeid fish values, which indicate the reliability of the estimated parameters.

Mortality Parameters: The annual rate of natural (M), fishing (F) and total (Z) mortality were computed as 1.00 $year^{-1}$, 1.35 $year^{-1}$ and 2.35 $year^{-1}$, respectively. Fig. 5 represents the catch curve utilized in the estimation of Z. The dark circles represents the points used in calculating Z through least square linear regression. The blank circles represent points either not fully recruited or nearing to L_∞hence discarded from calculation. Good fit to the descending right hand limits of the catch curve was considered. The estimated mortality rates are quite similar to the mortality rates estimated for same species by many authors (Ahmed *et al.* 2002; Ahmed *et al.* 2008; Rahman *et al.* 2008) but lower than (Rahman *et al.* 2000; Amin *et al.* 2002).

Exploitation Rate: The exploitation rate (E) has been estimated from the Gulland's (1971) equation, E = F/ (F+M). From these range of values of F and Z it can be shown that the rate of exploitation (E) is 0.57 $year^{-1}$ (Fig.9). It appears that the stock of *T. ilisha* of the Cox's bazar area of Bangladesh is under fishing pressure (E_{max}=0.75). This assumption is based on Gulland (1971) who stated that suitable yield is optimized when F = M and when E is more than 0.5, the stock is generally supposed to be over fished. The present exploitation rate (E) is much similar with other exploitation rate (E) estimated by other authors (Amin *et al.* 2004; Rahman *et al.* 2008) and is slightly lower than (Rahman *et al.* 2000; Amin *et al.* 2002; Amin *et al.* 2004) and is slightly greater than (Ahmed *et al.* 2002; Ahmed *et al.* 2008) and maximum exploitation rate (E_{max}) shows similarity with other E_{max} values estimated by other authors (Rahman *et al.* 2000; Amin *et* *al.* 2004 and Rahman *et al.* 2008) and is slightly greater than (Amin *et al.* 2002; Ahmed *et al.* 2002; Amin *et al.* 2004; Rahman *et al.* 2008).

Probability of Capture: The estimated length sizes for 25% (L_{25}), 50% ($L_{50} = L_c$) and 75% (L_{75}) probabilities of capture would be 26.45 cm, 28.36 cm and 29.69 cm, respectively for *T. ilisha* (Fig. 6). The optimum length at first capture of hilsa obtained in this study was 28.36 cm, which was lower than the value obtained by (Amin *et al.* 2004; Rahman *et al.* 2008). This may be an indication that the number of large size fish is decreasing, which ultimately indicates that the fishery is heading towards overexploitation. Therefore, any hilsa smaller than 28.36cm TL must not be captured.

Recruitment Pattern: Two recruitment peaks were found for *T. ilisha* one in May-July and another in October-December (Fig. 7). The 2 pulses most probably associated with the 2 peaks in spawning seasons (Rahman 2001). The offspring born during the peak spawning period, forming the main recruitment pulse. 2 recruitment peaks were found by many authors (Ahmed *et al.* 2002; Rahman *et al.* 2008) although one recruitment peaks were also found by many authors (Rahman *et al.* 2000; Amin *et al.* 2002; Amin *et al.* 2004).

Virtual Population Analysis (VPA): The length-structured VPA is a powerful tools for fish stock assessment by which the size of each cohort is estimated along with the annual mortality caused by fishing. The F at length array showed in (Fig. 8) that the maximum fishing mortality occurring in the length between 30-35 cm with a maximum value in the length of 32 cm that repeatedly indicate high fishing mortality in the *T. ilisha.*

Yield/Recruit (Y'/R) and Biomass/Recruit (B'/R): The relative Yield/recruit (Y'/R) and Biomass/recruit (B'/R) were determined as a function of L_c/L_∞ and M/K were 0.55 and 1.33, respectively. The $E_{0.1}$ and $E_{0.5}$ were found to be 0.605 and 0.379, respectively. Fig. 9 showed that the present exploitation rate E= 0.57 exceeds the optimum exploitation rate E= 0.50. The current relative Yield/recruit (Y'/R) value was greater than other values found by other authors (Rahman *et al.* 2000; Amin *et al.* 2002; Amin *et al.* 2004) and relative Biomass/recruit (B'/R) was lower than other values found by other authors (Rahman *et al.* 2000; Amin *et al.* 2002; Amin *et al.* 2004).

Length-Weight Relationships: For the study of the length-weight relationship, a total of 1702 specimens of *T. ilisha* for the individuals ranging in sizes from 20 to 51 cm in total length and weighing 58 to 1411 g were measured. From these, length-weight relationships were estimated with the form $W = aL^b$, using the logarithmic transformation Log W = Log a + b Log L, where, a and b are constants estimated by linear regression of the log transformation varieties. The regression takes the form Log W = -1.53603 + 2.718 Log TL (r = 0.99), Corresponding to, W = -1.53603 * $TL^{2.718}$.

Which may be used to convert length-frequency data to catch at length data. The length-weight relationship was found to be: W = 0.02910 * TL^{3}

The present length-weight relationship did not show much difference when compared to the length-weight relationship estimated for the same species from Bangladesh waters by other authors (Rahman *et al.* 2000; Amin *et al.* 2005; Ahmed *et al.* 2008 and Flura *et al.* 2015).

Stock Size and Maximum Sustainable Yeild (MSY): The value of total annual catch, total annual stock, standing stock and MSY estimated were 517,000 t, 994,230 t, 382,962 t and 449,980 t respectively. From these results it is evident that the value of Maximum Sustainable Yeild (MSY) is below the annual catch, this indicates high fishing pressure on the stock in Bangladesh, which was also investigated and suggested by Amin *et al.* 2002, 2004. Therefore, immediate necessary step must be undertaken to reduce the fishing pressure on the stock, although the present study showed that the Maximum Sustainable Yeild (MSY) of *T. ilisha* in Bangladesh is increased compared to other studies related to this species in Bangladesh water.

CONCLUSION

The stock assessment is very important for proper exploitation and management of the population of fish species. The length-weight relationship of commercially important marine fish like hilsa helps to manage their stock in the Northern Bay of Bengal. From the present study it is clear that the growth of *T. ilisha* is positive allometric in nature and the length and the weight is significantly correlated. It indicates that the species maintain their shape throughout their life. From the perspective of condition factor the growth of *T. ilisha* is excellent. The results of this study indicated that the stock of *T. ilisha* is heavily exploited. Any increase in the existing fishing level/exploitation will most likely result in a reduction in the yield per recruit and thereby hamper the MSY. It is necessary to immediately impose fishing regulation on the stock and this can be done by gradually increasing the mesh size of the gears or by restricting fishing for certain seasons or declaring fish sanctuaries in certain areas, especially in spawning areas. According to Froese (2004), overfishing can be prevented by following certain rules. All of the mature fish population should be caught, those who have attained optimum length but the mega-spawners should not be targeted at all. In the present study, it is observed that the percentage of mature and optimum length size fishes were caught with maximum number and the percentage of mega-spawner catch were found to be minimum. Due to this reason overfishing of hilsa population could not be established in Cox's bazar coast during this period, but the E value of 0.57 denotes symptoms of max overexploitation in near future. If any population is affected by the 'recruitment overfishing', the population might be seriously hampered to attain the sustainable yield in the long run (Sharp 1983), so the fishing regulation must be strong for Hilsa to make this species sustain for a long time in future. Further long term monitoring is required to establish the Hilsa population dynamics, is it relevant to population dynamics in the Cox's bazar coast.

LITERATURE CITED

AHMED, M.S., MOSTAFA, M.G., SAIFUL, B.R., ARAFAT, M.Y. AND MD ALI, M.S. 2002. Some aspects of population dynamics of hilsa shad *Tenualosa ilisha* in the River Meghna of Bangladesh. *Fisheries Science.* **68**(1): 318-321.

AHMED, M.S., SHARIF, A.S.M. and LATIFA, G.A. 2008. Age, growth and mortality of Hilsa shad, *Tenualosa ilisha* in the River Meghna, Bangladesh. *Asian Journal of Bio Science.* **1**(2): 69-76.

AHSAN, D.A., NASER, M.N., BHAUMIK, U., HAZRA, S. and BHATTACHARYA, S.B. 2014. Migration, spawning patterns and conservation of Hilsa shad (*Tenualosa ilisha*) in Bangladesh and India. *Academic Foundation. New Delhi, India.* 95p.

AMIN, S.M.N., ARSHAD, A., HALDAR, G.C., SHOHAIMI, S. and 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.

AMIN, S.M.N., RAHMAN, M.A., HALDAR, G.C., MAZID, M. A. and MILTON, D.A.2002. Population dynamics and stock assessment of Hilsa Shad in Bangladesh. *Asian Fisheries Science.* **15**: 123-128.

AMIN, S.M.N., RAHMAN, M.A., HALDAR, G.C., MAZID, M.A., MILTON, D.A. and BLABER, S.J.M. 2004. Stock Assessment and Management of *Tenualosa ilisha* in Bangladesh. *Asian Fisheries Society.* **17**: 50-59.

AZAD, S.A., RAJALI, H.B., ISLAM, A.B.M.A., RAHMAN, M.J., SARKER, M.N., ISLAM, M.S. and RAHMAN, M.A. 2012. Standard Operating Procedure on Information Collection form Landing Center for Marine Fisheries Stock Assessment. Bangladesh Marine Fisheries Capacity Building Project, Department of Fisheries, Bangladesh, Dhaka. 32p.

BERTALANFFY, L.V. 1938. A Quantitative Theory of Organic Growth. *Human Biology.* **10**: 181-213.

BEVERTON, R.J.H. and HOLT, S.J. 1957. On the dynamics of exploited fish pupations. *Fish.Invest. London.* **19**(2): 553p.

BEVERTON, R.J.H. and HOLT, S.J. 1966. Manual of Methods for Fish Stock Assessment, Part 2. *In:* Tables of Yield Functions, *Fisheries Technical Paper No. 38. Food and Agriculture Organization of the United Nations,* Rome, Italy. 7-29p.

DoF. 2018. Yearbook of Fisheries Statistics of Bangladesh, 2017-18. Fisheries Resources Survey System (FRSS), Department of Fisheries. Bangladesh: Ministry of Fisheries, 2018. **35**: 129p.

FLURA, ZAHER, M., RAHMAN, B.M.S., RAHMAN, M.A., ALAM, M.A. and 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.

FROESE, R. 2004. Keep it simple: three indicators to deal with overfishing. *Blackwell Publishing Ltd, Fish and Fisheries.***5**: 86-91.

GAYANILO, F.C. and PAULY, D. 1997. The FAO ICLARM Stock Assessment Tools (FiSAT): *Reference Manual. Food and Agriculture Organization of the United Nations, Rome, Italy.* 15-42 p.

GAYANILO, F.C., SORIANO, P. and PAULY, D. 1996. The FAO-ICLARM Stock Assessment Tools (FiSAT) Users Guide. *FAO Computerized Information Series (Fisheries),* Rome, FAO. **8**: 266p.

GAYANILO, F.C., SPARRE, P. and PAULY, D. 2005. FAO-ICLARM Stock Assessment Tools II (FiSAT-II), User's Guide, Computerized Information Series (Fisheries) No. 8, (Revised Version), *Food and Agriculture Organization of the United Nations, Rome, Italy.* 459 p.

GULLAND. J.A. 1971. The Fish Resources of the Oceans, Fishing News, London. 9-52p.

GULLAND, J.A. 1979. Report of FAO/IOP workshop on the fishery resources of the western Indian Ocean South of the Equator. *Rome, FAO, IOFC/DEV/***79/45**: 1-37.

HAMILTON, F. 1822. An account of the fishes found in the river Ganges and its branches. Edinburgh & London. An account of the fishes found in the river Ganges and its branches: i-vii + 1-405, Pls. 1-39.

JONES, R. and van ZALINGE, N.P. 1981. Estimation of mortality rate and population size for shrimp in Kuwait waters. *Kuwait Bulletin of Marine Science.* **2:** 273-288.

MOREAU, J. and CUENDE, F.X. 1991. On improving the resolution of the recruitment patterns of fishes. *Fish byte.* **9**(1): 45-46.

MUNRO, J.L. and PAULY, D. 1983. A simple method for comparing growth of fishes and invertebrates. *ICLARM Fishbyte.***1**: 5-6.

NASER, M.N. 2018. Hilsa Shad (*Tenualosa ilisha*)-the iconic fish of the Bengal Delta. In: Nishat B, Mandal S, Pangare G, editors. Conserving Ilish, Securing livelihoods: Bangladesh-India initiatives. *India: IWA, Academic Foundation. New Delhi, India.* 37-52 p.

PAULY, D. 1980. On the interrelationship between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. *J. Cons. CIEM.***39**(2): 175-192.

PAULY, D. 1983. Fish population dynamics in tropical waters: a manual for use with programmable calculators. *ICLARM Studies Reviews.***8**: 325p.

PAULY, D. 1984. Fish population dynamics in tropical waters: a manual for use with programmable calculators. *ICLARM Fish byte.* **1**(2): 9–13.

PAULY, D. 1987. Review of the ELEFAN System for analysis of length-frequency data in fish and aquatic invertebrates. *In:* Pauly, D. and Morgan, G.R. eds., *Length Based Methods in Fisheries Research, Conference Proceedings, International Center for Living Aquatic Resource Management, Manila, Philippines.* 5-8.

PAULY, D. and DAVID, N. 1981. ELEFAN-I a Basic Program for the Objective Extraction of Growth Parameters from Length Frequency Data. *Meeresforschung/Rep. Mar. Res.* **28**(4): 205-211.

PAULY, D. and GASCHUTZ, G. 1979. A simple method for fitting oscillating length growth data with a programme for pocket calculators. *Cons. Int. Explor. Mer, C.M. G:24.*

PAULY, D. and MUNRO, J.L. 1984. Once more on growth comparison in fish and invertebrates. *Fishbyte.* **2**(1): 21p.

RAHMAN, M.A., AMIN, S.M.N., HALDAR, G.C. and MAZID, M.A. 2000. Population dynamics of *Tenualosa ilisha* of Bangladesh water. *Pakistan Journal of Biological Science.***3**(4): 564-567.

RAHMAN, M.J. 2001. Population biology and management of hilsa shad (*Tenualosa ilisha*) in Bangladesh. Ph D. Thesis, The University of Hull, England.

RAHMAN, M.J. and COWX, I.G. 2008.Population Dynamics of Hilsa Shad (*Tenualosa ilisha,* Clupeidae) in Bangladesh Waters. *Asian Fisheries Science.* **21**: 85-100.

RAHMAN, M.J., MUSTAFA, M.G. and RAHMAN, M.A. 1998. Population dynamics and recruitment of Hilsa, *Tenualosa ilisha* Workshop on Hilsa Fishery Research in Bangladesh, Bangladesh Fisheries Research Institute, Australian Centre for International Agricultural Research/Commonwealth Scientific and Industrial Research Organization, Dhaka, 3-4 March.

RICKER, W.E. 1975. Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Bd. Canada.***191**: 382p.

SARKER, M.N., NASER, M.N., UDDIN, M.S., DAS, N.N. AND HUMAYUN, M.2019. On the management of single fish species of Hilsa shad (*T. ilisha*) resources of Bangladesh. *Bangladesh J. Zool.* **47**(1): 173-183.

SARKER, M.N., RAHMAN, M.J., ISLAM, A.B.M.A. and RAHMAN, A. 2016. Population Dynamics of Marine Fishes of Bangladesh. *In* Consultative workshop on the result obtained from the land based survey. Report-1. *Bangladesh Marine Fisheries Capacity Building Project, DoF.*15 p.

SHARP, G.D. and Y.J. CSIRKE, (Eds.). 1983. Proceedings of the expert consultation to examine changes in abundance and species composition of neritic fish resources. *FAO Fish. Rep l FAO Int. Pesca.***2**(291): 1-553 and **3**: 557-1224.

SILVESTRE, G.T. and GARCES, L.R. 2004. Population parameters and exploitation rate of demersal fishes in Brunei Darussalam. *Fish Research.* **69**: 73-90.

SPARRE, P. and VENEMA, S.C. 1998. Introduction to tropical fish assessment, Part: 1 manual. *FAO Fisheries Technical Paper No.* ***306****/ 1 Rev. 2 Rome.*

WETHERALL. A., POLOVINA, J.J. and RALSTON, S. 1987. Estimating Growth and Mortality in Steady-State Fish Stocks from Length-Frequency Data. *In:* Pauly, D. and Morgan, G.R.(Eds.).Length-Based Methods in Fisheries Research, *Conference Proceedings, International Center for Living Aquatic Resource Management,* Manila, Philippines. 1-22.

(Manuscript received on 14 February, 2020 revised on 4 October, 2020)