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Stock Assessment and Management of hilsa shad tenualosa ilisha in the meghna river of Southeastern Bangladesh considering the emerging Climate change

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STOCK ASSESSMENT AND MANAGEMENT OF HILSA SHAD, *TENUALOSA ILISHA* IN THE MEGHNA RIVER OF SOUTHEASTERN BANGLADESH CONSIDERING THE EMERGING CLIMATE CHANGE

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Dedicated

To My Beloved Family Members

Declaration

I hereby declare that the whole work submitted as a thesis entitled **"STOCK ASSESSMENT AND MANAGEMENT OF HILSA SHAD *TENUALOSA ILISHA* IN THE MEGHNA RIVER OF SOUTHEASTERN BANGLADESH CONSIDERING THE EMERGING CLIMATE CHANGE"** to the Department of Fisheries, Faculty of Agriculture, University of Rajshahi, Rajshahi- 6205, Bangladesh for the degree of Doctor of Philosophy is the result of my own investigation which has been carried out under the supervision of Dr. Md. Yeamin Hossain, Professor, Department of Fisheries, Faculty of Agriculture, University of Rajshahi, Rajshahi-6205, Bangladesh. I further declare that the thesis has not been submitted elsewhere for any other degree.

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This is to certify that the entitled **"STOCK ASSESSMENT AND MANAGEMENT OF HILSA SHAD *TENUALOSA ILISHA* IN THE MEGHNA RIVER OF SOUTHEASTERN BANGLADESH CONSIDERING THE EMERGING CLIMATE CHANGE"** has been prepared by **Akhery Nima**, Unique ID. **1912567504** under my supervision for submission to the Department of Fisheries, Faculty of Agriculture, University of Rajshahi, Rajshahi-6205, Bangladesh for the degree of Doctor of Philosophy (Ph.D.). All the data presented in this thesis are her own observation and no part of this work has been previously published or submitted for any other degree.

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The Authoress

Abstract

The national fish of Bangladesh, Hilsa shad, *Tenualosa ilisha* (Hamilton, 1822) is a marine, brackish and freshwaters fish belonging the family Clupeidae (Riede, 2004). It is locally known as *ilish* or *ilsha*. The overall objective of this study is to assess the stock of *T. ilisha* from the Meghna River, Southeastern Bangladesh. A total of 1433 individuals were collected for the period of July 2018 to December 2020 where its body weight (BW) and total length (TL) were measured with 0.01 g and 0.01 cm accuracy for each specimen. The current study was on morphometric relationships through length-weight and length-length relationships, meristic features, condition factors (Fulton's, K_F; allometric, K_A; Relative, K_R) and form factor of *T. ilisha*. Physiological status was determined using the equation provided as: $\bar{a} = W/L^b$. If $\bar{a}$ was close to the a value (a, LWR parameter) indicated the fish was in ideal condition, whereas $\bar{a} > a$ pointed to fatty fish and $\bar{a} < a$ to lean fish. The prey-predator status estimated through relative weight. Growth parameters were estimated through the von Bertalanffy equation. Data of length–frequency were analyzed with excel based program and FAO-ICLARM Stock Assessment Tool. The TL ranged from 15.3-57.8 cm while the BW was 37.17–2250 g. The overall K_F was 0.7191-1.7098, K_A was 0.0014-0.0151 and K_R was 0.65-1.66 for *T. ilisha* in the Meghna River. The maximum K_R was found in July while the minimum was in January. The K_F was strongly correlated with TL and BW while K_R was with BW in the Meghna River. K_A has no significant relation neither TL nor BW. The maximum fatty fish was found in the months of December (44%) while the minimum was in October. The highest percentage of lean fish was found in the month February (41%) and the lowest was in September (22%). The W_R indicated that the habitat was in stable circumstance for *T. ilisha*. The TL_{50} (the length at which 50% of specimens become matured) was calculated by using four models ((i) TL *vs.* Gonadosomatic index (GSI), Modified gonadosomatic index (MGSI) and Dobriyal index (DI) model, (ii) logistic model (iii) maximum length based model (L_{max}) and from the following three models, mean L_m was 26.10 cm. Based on monthly variation in GSI, MGSI and DI value, *T. ilisha* spawn all over the year with two peaks in October and April in the Meghna River. Macroscopic observations of gonads showed five maturity stages. Based on macroscopic features, Hilsa spawn throughout the year but highest percentages in October. The total fecundity (F_T) ranged from 65999 to 1575850. Fecundity was found to be highly correlated with TL and BW. Suitable temperature considered as 25-26°c for the spawning. Furthermore, mean air temperature is increasing by 0.029 °C y^{-1}, and rainfall is decreasing by 2.96 mm y^{-1}. The growth parameters through von Bertalanffy model of *T. ilisha* was as L_t = 57.62 (1-exp(-1.13(t-0.009))). The estimated L_∞ = 57.62 cm, K = 1.13 y^{-1}, W_∞ = 2024.6 g, t_0 = 0.009, t_{max} = 4.17 year. The overall growth-performance index ($Ø'$) was 3.38. In addition, the age of *T. ilisha* was estimated as 3.10 years. Fishing mortality (F = 0.97 year^{-1}) rate was lower than natural mortality (M =1.57year^{-1}). Further, estimated exploitation rate (E=0.63) was higher than the maximum permissible exploitation rate (E_{max} = 0.47). Consequently, overfishing is the greatest pivotal threat for *T. ilisha* stock in the context of Meghna River, southeastern Bangladesh. The MSY was calculated at 286,327 MT. Scientists and conservationists will be able to establish early management methods and policies based on the findings of this study of *T. ilisha* to ensure long-term survival in the Meghna River and its adjacent ecosystems.

Contents

List of Tables

List of Figures

List of Plates

Chapter

1

General Introduction

GENERAL INTRODUCTION

1.1. Fisheries and Bangladesh

Bangladesh is blessed with a huge amount of open waterbody like canals, rivers, man-made and natural lakes, estuaries, brackish water marshes, freshwater wetlands or floodplains and an extensive coastline of about 710 km. Together with vast water resources; Bangladesh is rich with various fish and other aquatic species. The marine sector is considered the most vital part of Bangladesh for capturing different fish species. Hence, Bangladesh occupies third position in aquatic biodiversity with 475 coastal and marine fish species after China and India in Asia (Hussain and Mazid, 2010). In our country, fish as key-source of animal protein contributes 60% of daily dietary protein requirement (DoF, 2020). Besides, fisheries sector has a significant role in creating employment opportunities and earning of foreign exchange (Alam and Thomson, 2001). In 2018-19, Bangladesh exported 68.31 thousand MT of fisheries products and earned BDT 42876.40 million. Furthermore, 17 million people directly depend on fisheries sector including 1.4 million women for their livelihoods (DoF, 2020). The involvement of fisheries sector to national GDP is 3.50% and total agricultural sector is 25.72% (DoF, 2020). On the other hand, climate change has a negative impact on both fresh and marine fisheries in Bangladesh (Allison et al., 2009).

At present, improved biological management is the main priority in the development policy that will limit the declination of fisheries resources and enhance production. In order to conserve our threatened fishes, it is immensely essential to identify critical aspects of the life histories including age, growth, reproductive biology and longevity. The knowledge of reproductive biology is the key to frame effective and sustainable fisheries management policy. Formulation of management baseline data and population dynamics of any fish species can be easily understood from the reproductive biology (King, 2007). Effective management practice depends on knowledge of the regenerative capability of fish populations including reproductive behavior (Tracey et al., 2007). Fish growth largely depends on sex, availability of feed, water quality parameters and other ecological factors (Hasan et al., 20210. Maximum sustainable yield of any fish stock is notably affected by its growth and recruitment.

The national fish of Bangladesh, *Tenualosa ilisha* is considered as a major food fish item. The hilsa shad is important socially, culturally and religiously to Bengali people living in Bangladesh, West Bengal and many other areas like Orissa, Bihar and Assam of India (Sharma et al. 2012). The Hilsa is called in Bengali as *Macher raja ilish*, *i,e.,* is the king of fish. About 76% of global hilsa production is supported from Bangladesh while Myanmar, India and other country (Including Thailand, Iran, Malaysia, Iraq, Kuwait, Indonesia, and Pakistan) cover 15%, 4% and 5%, respectively (Islam et al., 2016). *T. ilisha* is the country's most important aquatic resource and affords the largest solitary species fishery in Bangladesh especially throughout the wet season practically in the major river, estuaries and the Bay of Bengal. The contribution of hilsa in total fish production of the country is about 22-25% (Rahman *et al*. 1998). In 2018-19 FY hilsa production was about 532795 MT (DoF, 2020). The hilsa is important to Bangladesh's economy (Milton, 2010) and earns a huge foreign currency (US$12.5 million per year) by exporting this species (DoF, 2014). In addition, Hilsa is the main exporting item after shrimp and has a significant role in the national economy of Bangladesh. Hilsa fishing employs an estimated 0.50 million people, and 2.0-2.5 million people depend on hilsa fisheries for their livelihoods, either directly or indirectly (Roy and Habib 2013).

The Meghna is one of the country's longest rivers in Bangladesh. This River is one of the waterways that carry the melt- and monsoon-waters through Bangladesh into the Bay of Bengal during periods of high water levels. A huge amount of commercially important fishes and prawns species are harvested through large and small scale fishers in this river all over the year. The Meghna River ecosystem is major spawning grounds of hilsa from where found 18% of the total country hilsa production (Hossain et al., 2018). However, the stocks including Hilsa have seriously declined in rivers and streams of Bangladesh by a number of natural and man-made factors that need to be considered within an ecosystem context.

Hilsa fish from Bangladeshi waters has never been the subject of any sound scientific evidence (except Islam et al., 1987; Rahman et al., 1998; Amin et al., 2000; Haldar et al., 2001; Amin et al., 2004; Ahmed et al., 2008; Amin et al., 2008; Nima et al., 2020, 2021). Subsequently, absence of sufficient knowledge on the population structure, growth, longevity, stock's status and its spawning season and grounds of this species remained an impairment to the origination of comprehensive management policies for Hilsa fishery. In addition, in order to manage this commercially important hilsa fishery effectively, it is necessary to identify the exact reason for decline and a severe perception of the biology and ecology of this target species. This is urgent to recognize the limitations of fisheries management at the population level and establish sustainable conservation and management of this fishery based on the integration of population-level and ecosystem-based approaches. Therefore, this study has been set out to address the stock' status of *T. ilisha* and its sustainable management policy implications in Bangladesh with consideration of emerging climate change.

1.2. Short Profile of *Tenualosa ilisha*

Tenualosa ilisha **(**Hamilton, 1822) is a freshwater, brackish and marine fish belonging to the family Clupeidae (Riede, 2004). It is locally known as *ilish* or *ilsha* while the juvenile known as *Jatka* (Shafi and Quddus, 1982). It is a very important commercially table food item in Bangladesh and South Asia and the entire demand is met from the wild stock capture. As a result, overfishing is a major threat for the abundance of wild stock of *T. ilisha*.

<u>Systematic position</u>

Phylum: Chordata
Class: Actinopterygii
Order: Clupeiformes
Family: Clupeidae
Genus: *Tenualosa*
Species: *Tenualosa ilisha*

Plate 1. Photo of *Tenualosa ilisha*

1.2.1. Common names

Tenualosa ilisha is locally known as *ilish* or *ilsha* while the juvenile is known as *Jatka* in Bangladesh (Shafi and Quddus, 1982).

Table 1. Common names of *Tenualosa ilisha*

Common name	Used in	Lnguage
Ilish, jatka	Bangladesh	Bengali
Ilisha, Ilishmach	India	Bengali, Assamese
Chakshi, Chaksi, Chaski, Palla	India	Gujurarti
Mullasu, Palasa, Palia, Polasa, Paliya	India	Kannada
Paliyah, Valava, Paluva	Inida	Malayalam
Chaksi, pala, palla, palva	India	Marathi
Dolum, Karuva-ullam, Oolum, Sevva, Ullam	India, Sri Lanka	Tamil
Palasa, palasah, Palia	India	Telegu
Palla, ilish, Jatka	Pakistan	Punjabi
Palo, Pulla	Pakistan	Urdu
Pepe	Madagascar	Malagasy
Sabur	Global	Arabic
Brk, Mahi Khor Kuchiku, Soboor, Sobur, Zabur, Zomur	Iran	Persian
Shour	Iraq	Arabic
Suboor	Kuwait	Arabic
Nga-tha-lauk, Nga-thalank	Myanmar	Burmese
Hilsa, Placka iliša, Sleď palasah	Czechia	Czech
Hilsa-stamsild	Denmark	Danish
Hilsa herrinf	UK	English
Hilsa shad	Global	English
India salealoosa	Estonia	Estonian
Alose hilsa	France	French
Hilza indyjska	poland	polish
Pala	Portugal	Portuguese
Sábalo hilsa	Spain	Spanish
Indisk staksill	Sweden	Swedish
Cá Cháy	Viet Nam	Vietnamese

(Froese and Pauly, 2021)

1.2.2. Synonyms

Table 2. Synonyms of *Tenualosa ilisha*

Synonym	Status	Validity	Combination
Tenualosa ilisha (Hamilton, 1822)	Accepted	Yes	New
Clupanodon ilisha (Hamilton, 1822)	Synonym (Senior)	No	Original
Clupea ilisha (Hamilton, 1822)	Synonym (Senior)	No	New
Hilsa ilisha (Hamilton, 1822)	Synonym (Senior)	No	New
Macrura ilisha (Hamilton, 1822)	Synonym (Senior)	No	New
Tenualosa illisha (Hamilton, 1822)	Synonym (Senior	No	New
Tenualosa ilsha (Hamilton, 1822)	Synonym (Senior	No	New
Clupea palasah (Cuvier, 1829)	Synonym (Senior)	No	Original

(Froese and Pauly, 2021)

1.2.3. Distribution

T. ilisha is distributed in Asian region together with Bangladesh, Nepal, Sri Lanka, India, Pakistan, China, United Arab Emirates and also in Myanmar, Iraq, Iran, Malaysia, Oman, Kuwait, Qatar, Saudi Arabia, Thailand and Viet Nam (Freyhof, 2014). It is abundant in the Meghna River, Padma River, Rupsha River, Sibsha River, Biskhali River, Tetulia River, Pyra River, Arial Kha River, and a small number of other river systems covering coastal area of Bangladesh (Rahman, 2007).

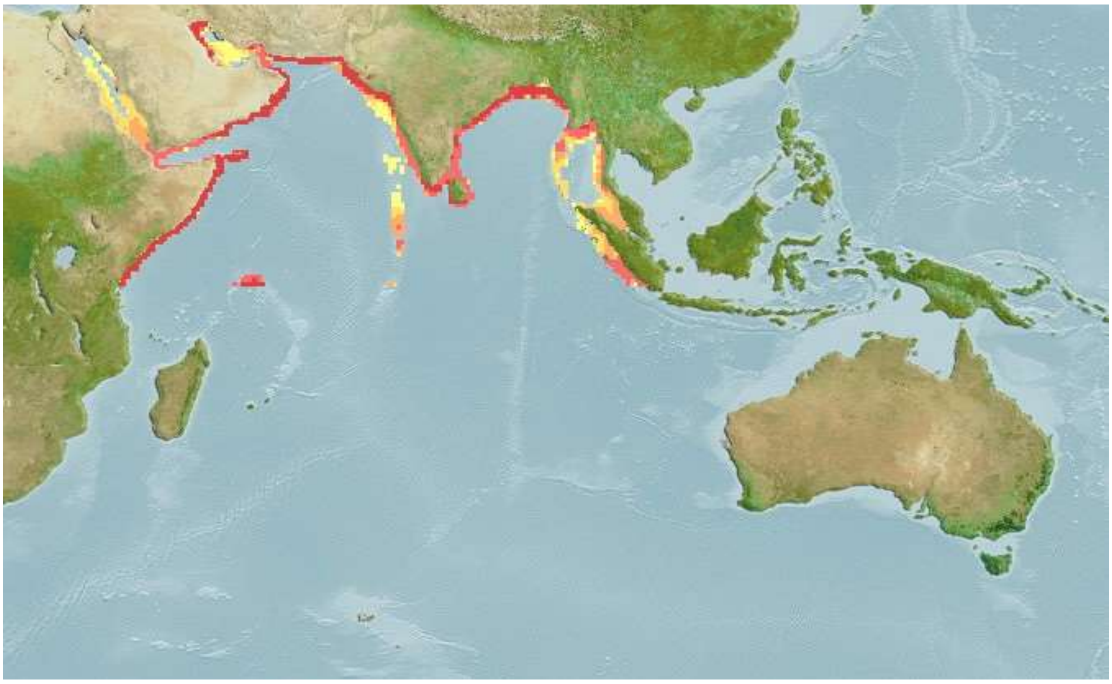


Plate 2. Worldwide distribution of *Tenualosa ilisha* (Source: Froese and Pauly, 2021 Accessed on: 16 July 2021)

1.2.4. Habitat

T. ilisha mainly inhibits estuaries and shallow marine waters while juveniles and young occur in river, coastal area and mangrove swamps (Talwar and Jhingran, 1991).

1.2.5. Morphology

The body shape of *T. ilisha* is fusiform, fairly deep and compressed. Body colour of this fish is silvery shot with gold and purple. Mouth position of the species is terminal and upper jaw with a distinct median notch when seen from above. A total of 43-46 lateral line scales and 29-31 belly scutes were observed (This study).

1.2.6. Fin Formula

D. 15-19 (2-4/13-17); P. 14-16 (1/13-15); P_v. 6-10 (1-2/5-8); A. 18-21 (1-2/16-20); C. 20-22 (2/18-20) (This study).

1.3. Objectives

The specific objectives are-

- To estimate the morphometric relationships and condition factors of *Tenualosa ilisha* in the Meghna River, southeastern Bangladesh
- To determine the physiological and prey-predator status for *T. ilisha* in the Meghna River, southeastern Bangladesh
- To estimate the reproductive biology of *T. ilisha* in the Meghna River, southeastern Bangladesh
- To calculate the growth parameters and longevity of *T. ilisha* through multiple model-inferences in the Meghna River, southeastern Bangladesh
- To assess the stocks of *T. ilisha* in the Meghna River, southeastern Bangladesh

Finally, the study provides a management strategy of *T. ilisha* in the Meghna River, Southeastern Bangladesh.

Chapter 2

Review of Literature

REVIEW OF LITERATURE

It is urgent to review the former research studies for conducting a planned research experiment. There are few published reports on *T. ilisha* for planning appropriate management strategies of this commercially important target fish species. However, some related literatures are described below-

Sabbir et al. (2021a) observed the reproductive biology of *Panna heterolepis* from the Bay of Bengal, Bangladesh with special consideration of climate change. Altogether 569 fishes (female only) were collected during January - December in 2019. Total lengths at which 50% fish become sexually matured were 15.0 cm. The spawning occurred from January to July and was accelerated with temperature. The peak spawning is observed in February.

Sarmin et al. (2021) studied on *Salmostoma bacaila* from the Mahananda river, Bangladesh with emphasizes on population structure, growth pattern and parameters (asymptotic weight & length, age at zero length, growth coefficient), age and length of sexual maturity (L_m), life-span(t_{max}), growth performance index (φ), conditions factor (Fulton's, Allometric, and Relative), prey-predator status, mortality, exploitation rate (E) and maximum sustainable yield. Growth parameters were W_∞ = 11.36 g, L_∞ = 12.66 cm, K = 0.60 year^{-1}, t_0 = 0.048, t_{max} = 5.00 year^{-1} and φ' = 1.98. The L_m was 7.34 cm in TL. The Z, M, and F were calculated 1.57, 0.92 and0.65 year^{-1}, individually. The E was 0.41 and MSY (E_{max}) was estimated as 0.35 y^{-1}.

Akter et al. (2020) studied the growth, reproduction, mortality and exploitation of *Upeneus sulphureus* from the Bay of Bengal, Bangladesh. The gonadosoatic index indicated that the fish spawn two times in a year. One is in January- May and the other in August-October. Further, the growth parameters were L_∞ = 21.80 cm, K = 0.54 y^{-1}, C = 0.05, WP = 0.1 and Rn = 0.300, respectively through von Bertalanffy equation. The instantaneous natural mortality and fishing mortality were 1.31 and 2.86, correspondingly. It's worth noting that the exploitation rate (E = 0.69) was near to the maximum (E_{max} = 0.75). Therefore, wild stock in coastal water may reduce if fishing pressure increases.

Sajina et al. (2020) assessed the management consequences of overfishing *Tenualosa ilisha* in the Hooghly-Bhagirathi River, India.Growth overfishing causes substantial economic loss, therefore practical approaches are important to maximize the benefits. The surveillance and fishery management enforcement measures are often expensive and lead to poor implementation of the measures. The study specified that it would be cost effective and worth the efforts to enforce stringent management measures for hilsa fishery.

Dutta et al. (2019) studied life history of *Tenualosa ilisha* from the Sundarban estuary of Bay of Bengal, India during June 2011 to March 2012. The exploitation rate was 0.78 and the MSY was 11700.18 tons while the yearly catch was 18126.00 tons. The relative yield per recruitment designated mortality as a result of fishing pressure stood high. Extensive fishing of juvenile and growing Hilsa (< 500 g) deteriorated the Hilsa population significantly dropping the economic advantage.

Khatun et al. (2019) observed the reproductive biology of *Eutropiichthys vacha* from Ganges River, Bangladesh with special consideration of climate change. Altogether 734 female fish were collected from January to December, 2016. Total lengths at which 50% fish become sexually matured were 12.7 cm. Spawning took place between April - August. Peak spawning occurred in June and July. Total fecundity varied from 4,800 to 77,976 with an average 31,384±23,747. Further, total fecundity was vastly associated with total length and body weight. Water temperatures during the spawning season averaged 31^{o}C. The spawning event was accelerated by the intense rainfall that occurred during this time.

Tint et al. (2019) studied the morphometric measurements and identification through morphological features of the genus *Tenualosa* during June to November 2018. The differences of morphological features between *T. ilisha* (Hamilton, 1822) and *T. toli* (Valencinnes, 1847) were ascertained.

Khatun et al. (2018) observed the sex ratio, length-weight and length-length relationships, length frequency distribution and physiological state of *Eutropiichthys vacha* from Ganges River, Bangladesh. The sex ratio (SR) demonstrated significant variances from the anticipated assessment of 1:1. Female was found dominant throughout the year, except April. Total Length ranged from 6.2 to 19.9 and 6.5 to 20.6 cm for male and female, respectively. The value of ‘*b*’ (allometric coefficient) was found to have a negative allometry (<3.00) for both sexes, whereas ANCOVA revealed that there were significant differences in LWRs. Further, length-length relationships were found highly significant with r^2 value > 0.962. March and April had a greater percentage of fatty fish, while August had the lowest percentage.

Mandal et al. (2018) studied the length-weight relationships and condition factor of *Tenualosa ilisha* from the marine, coastal and freshwater habitats in India. The *b* values ranged from 2.07-3.68 for combined, 1.78-2.97 for females and 0.75-3.03 for males with r^2 0.72-0.98 in combined, 0.76-0.97 in females and 0.73-0.94 in males. Fulton’s condition factor (K_F) ranged from 0.47 to 3.05, 0.47 to 1.63 and 0.77 to 3.05 in combined, male and female respectively. The relative condition factor ranged from 0.48-2.51, 0.47-1.56 and 0.76-2.33 in the combined population, males females, correspondingly.

Rahman et al. (2018a) studied population biology of *Puntius sophore* from Padma River, Bangladesh including population structure, length-weight relationships, sex ratio, condition factors and fecundity. The sex ratio significantly differs from the predicted ratio of (male female) 1:1. Females were found dominant through the year. The value of ‘*b*’ (allometric coefficient) was found isometric for both sexes. K_F was the best for this species to interpret the well-being of the population. The total fecundity ranged from 1,488 to 18,708 with an average of 5,682 ± 3,703. On the other hand, relative fecundity ranged from 205 to 1,868 with an average of 882.7±369.5. There was a strong correlation between fecundity and body weight and total length.

Hossain et al. (2017a) studied some biological aspects of *Nandus nandus* i.e. population structure, growth, condition factors, form factor ($a_{3.0}$), reproduction and mortality from the Ganges River in Bangladesh. The value of ‘*b*’ (allometric coefficient) specified positive growth (> 3.00) for TL *vs.* BW relationship but isometric growth (~ 3.00) for SL *vs.* BW relationship. K_F found to be the best for this species. Relative Weight (W_R) did not vary significantly from 100 indicated a balanced habitat for the species. The estimated form factor ($a_{3.0}$) was 0.0159 indicating that the body shape of the fish was short and deep. Besides, 9.10 cm TL sized individuals were sexually matured and the natural mortality (M_W) was predicted to be 1.33 y^{-1}.

Sarkar et al. (2017) reported the weight-length relationship (LWR) and relative condition factor (*Kn*) of *Tenualosa ilisha* during June-December, 2013 from the Hooghly estuarine system, India. Total length was 21.0-42.0 cm and body weight ranged 115-775 g. The LWR was $W = 0.0000206(L)^{2.817}$ (r^2= 0.892, p<0.05). The *Kn* value was from 0.981-1.052 with average of 1.013 representing good condition.

Pramanik et al. (2017) studied to select the mesh size of gill net for catching *Tenualosa ilisha* from August to October 2016 using 660 specimens in the Meghna River, Bangladesh. Mean total lengths were 24.7 ± 2.7 cm for 55 mm, 31.2 ± 2.78 cm for 65 mm and 34.33 ± 4.69 cm for 75 mesh sizes, respectively. Selectivity analysis specified an optimal catch length of 26.5 cm for the 5.5 cm, 32.83 cm for the 6.5 cm and 37.09 cm for the 7.5 cm mesh size gill-nets. The catch percentages were 38.78%, 39.10% and 22.12% respectively. 65 mm was selected as suitable mesh size for sustainable production of *T. ilisha* in the Meghna River, Bangladesh.

Hossain et al. (2016a) studied the length-weight relationships (LWRs) for *Labeo bata* and *Dermogenys pusilla* from Ganges River, Bangladesh. The study extended from July, 2013 to June, 2014. Total length ranged from 6.60 to 16.10 and 7.90 to 25.20 cm for *D. pusilla* and *L. bata*, respectively. Total weight for *D. pusilla* and *L. bata* varied from 1.20 to 10.90 and 4.70 to 167.30 g, respectively. All LWRs were found statistically significant with $r^2 \geq 0.976$ ($p < 0.001$).

Hossain et al. (2016b) studied the sex ratio, length-length and length-weight relationships, length frequency distribution and condition factors of *Cabdio morar* from the River Jamuna, Bangladesh. The sex ratio significantly differs from the predicted ratio of (male female) 1:1. The value of '*b*' (allometric coefficient) was found positive allometric (> 3.00) for male but female showed isometric growth (~ 3.00). Length-Weight Relationships indicated significant differences between the sexes. Further, K_F specified significant variances (p < 0.01) between males and females, while female performance (0.88 ± 0.14) was found better than males (0.86 ±

0.15). Besides, the spawning season of *C. morar* ranged from December to March in Jamuna River.

Memon et al. (2016) observed the length-frequency data of *Lepturacanthus savala* (Cuvier, 1829) were collected from Pakistan waters in 2009-2010. Body weight ranges from 1 to 1942 g while length ranges from 5 to 127 cm. The calculated growth parameters were L_∞ = 133.35 cm, K = 0.130 year^{-1} and t_0 = 0.877 through von Bertalanffy equation. The estimated rate of total-, natural- and fishing mortality were 0.49, 0.304 and 0.185 y^{-1}, respectively. Hence, exploitation ratio was calculated as 0.377 y^{-1}. Further, the estimated value of growth performance index ($Ø'$) was 3.364. The estimated value of MSY was 26,983 tons with the estimated biomass of 110,135 tons.

Ahamed et al. (2015) studied the size of sexual maturation of *Puntius sophore* by observing the gonadosomatic index (GSI) from the Old Brahmaputra River in Bangladesh. Different morphometric parameters *i.e.*, FL (fork length), SL (standard length), body and gonad weight (BW, GW) of each individual were measured. The SL *vs.* GSI and SL *vs.* FL were used to estimate the first length of sexual maturation. First sexual maturation length for female was 4.2 cm (SL) based on GSI and 4.0 cm (SL) based on relative growth between SL and FL.

Miah (2015) studied the anthropogenic and climatic factors that change the production area in the Bay of Bengal and breeding pattern of *Tenualosa ilisha*. He found, hilsa production of inland water decreased during last two decades whereas marine production increased 3 times. Major spawning area was also shifted from the upper region to the lower estuaries of Sandwip, Hatia and Bhola. Fishing level in the spawning ground was F=1.36yr^{-1} where F_{msy}=0.6 yr^{-1} in the Meghna River with exploitation (E) 0.70 (E_{msy}>0.5). Fecundity of hlsa was observed 1.5-2.0 million in 35-50 cm length. Shifting of swaning ground and reduced fecundity may seriously affect the hilsa production.

Hossain et al. (2014) discover the breeding ground for *Tenualosa ilisha* in Bangladeshi waters through a geo-referenced habitat database. Among the studied 29,484 km^2 aquatic habitats, merely 6% (=1851 km^2) area is the most appropriate covering of the rivers Meghna, Shahbazpur, Tetulia and Ander Manik as well as the channel of Sandwip island. While, 20% (=5996 km^2) area including river, estuary and nearby shore water bodies remain moderately suitable, and particularly, the offshore deep waters occupying 73% (=21,637 km^2) area is least worthy. The model yields were confirmed subsequently through the field data of fishers' indigenous information with an accurateness of 87%.

Roomiani et al. (2014) observed the reproductive biology of *Tenualosa ilisha* from the rivers of Khouzestan Province and Persian Gulf, Iran using 485 fish samples during April-September 2010. Sex ratio was observed M: F=1:2. Spawning season in AR was April-July and March-August in BR. The LWR was measured as $W= 1.459L^{2.687}$, $W=2.189L^{3.166}$ and $W=1.840L^{2.937}$in PG, AR and BR, correspondingly.

Hossain et al. (2013) observed the life history features of *Eutropiichthys vacha* from Jamuna River, Bangladesh. The experiment was conducted from March, 2010 to February, 2011. Around 350 specimens were collected to analyze sex ratio, LWRs, LLRs, length frequency distribution, condition factors and form factor ($a_{3.0}$). In general, the sex ratio did not deviate significantly from 1:1. The value of '*b*' (allometric coefficient) was found isometric (~*3.00*) for male and combined sexes but female showed a negative allometric growth pattern. Besides, the experiment showed that length-length relationships were extremely correlated with $r^2 > 0.997$ ($p < 0.001$). Relative condition factor (K_R) indicated significant difference between both sexes (F=65.11*;* $p < 0.01$). However, Relative Weight (W_R) was considerably different from 100 indicating imbalance habitat for the species. The calculated $a_{3.0}$ was 0.0060 and 0.0050 for males and females, respectively.

Bhaumik et al. (2012) observed the reproductive biology of *Tenualosa ilisha* from the Hooghly-Bhagirathi stretch during 2011-2012. The study recorded the lowest fecundity ever. Fecundity ranged from 44,002-15,54,894 for 20.8 - 47.5 cm and 105-1175.5 g fishes. Breeding season was January- February and August - September that indicated association with the monsoon and greatness of flood.

Rahman et al. (2012a) observed the sex ratio, length frequency distribution, length-weight, and length-length relationships of *Macrognathus aculeatus* from Ganges

River, Bangladesh. Specimens were captured by different traditional gears i.e. conical trap, cast net and gill net. Altogether 254 specimens were collected for the experiment. Total length ranged from 9.20 to 19.71cm and body weight ranged from 5.10 to 28.60 g.

Hajjej et al. (2011) observed the reproductive biology of *Euthynnus alletteratus*, which is known as little tuna in Tunisia. Altogether 1,086 fish specimens were collected for the experiment from Tunisian coastal water from January 2008 to December 2009. The experiment illustrated that the sex ratio for female was 57.77%. Spawning occurred from June to September. Fork length, at which 50% fish become sexually matured (L_{m50}) were 43.13 and 42.12 cm for females and males, correspondingly.

Manorama and Ramanujam (2011) studied the length-weight relationships of *Puntius shalynius* from Umiam River, Meghalaya, India. The value of '*b*' was found negative allometric (< 3.00) for both sexes. Length-Weight Relationships indicated no differences between the sexes.

Panhwar et al. (2011) studied the biological features and reproductive pattern of *Tenualosa ilisha* during March-October 2004 from Pakistan. Observed sex ratio was 1:1 and growth of female was nearly isometric while the male was allometric.

Solomon et al. (2011) studied the reproductive biology of *Puntius denisonii* from the rivers namely Chaliyar, Chandragiri and Valapattannam. The observed results had a maximum length of 16.2 cm and 13.2 cm for males and females, respectively. Spawning occurred from October to March. The sex ratio significantly differs from the predicted ratio of (male female) 1:1. Males were found dominant through the year. The total fecundity ranged from 376 to 1,098.

Bobori et al. (2010) collected 17 different fish species from three natural lakes in Greece and studied their weight-length relationships. The values of the allometric coefficient *b* varied from 2.117 ± 0.119 to 3.550 ± 0.104, with 87% of the *b* values lying between the anticipated ranges of 2.5-3.5.

Elhasni et al. (2010) observed the reproductive cycle and maturity stages of *Hexaplex trunculus* collected from the Gulf of Gabès, south Tunisia. The male and female gastropods were found separate throughout the life (gonochoristic). The sex ratio significantly differs from the predicted ratio of (male female) 1:1. Females were found dominant (M : F = 1:1.6). The monthly observation of gonad maturation stages, GSI (gonadosomatic index) and *K* (general condition) indicated that gametogenesis occurred throughout the year. Matured males occurred in abundance during November to January. On the other hand, ripe females were found during February to April. The development of gonad was influenced by increasing day length and temperature of the sea water. However, the peak spawning happened in April and May.

Hossain (2010a) studied the length-weight and length-length relationships of four small fish species namely *Aspidoparia morar*, *Amblypharyngodon mola*, *Puntius ticto* and *Lepidocephalus guntea*. Altogether 914 specimens were collected during March 2006 to February 2007 from the Padma River, Bangladesh. The allometric coefficient '*b*' was found isometric (≈3.000) for *A. morar* and *P. ticto*. Further, A. *Mola* and *L. guntea* revealed positive allometric growth. All LLRs were found significant and highly correlated ($r^2 > 0.932$; $p < 0.001$).

Yilmaz et al. (2010) studied length-length as well as length-weight relationships of *Capoeta sieboldii*. Altogether 170 specimens were collected from Hirfanli Lake of Turkey. Length-weight relationships of both sexes showed no statistical difference within or with the season and revealed isometric growth for both sexes. The correlations among total-, fork-, and standard length were found highly significant with $r^2 > 0.92$ ($p < 0.001$). The *K* value for females varied from 1.21 to 1.43 while for male it ranged from 1.12 to 1.36.

Hossain et al. (2009) described the length–weight and length–length relationships for ten indigenous species (SIS) in Bangladesh, namely *Puntius ticto*, *Lepidocephalus guntea*, *Ailia coila*, *Aspidoparia morar*, *Eutropiichthyes vacha*, *Amblypharyngodon mola*, *Mystus vittatus*, *Clupisoma atherinoides*, *Gudusia chapra* and *Glossogobius giuris*. Fish species were collected from the lower part of Ganges by traditional gears. Altogether 2,142 specimens were collected for the experiment for 12 months from

March, 2006 to February, 2007. The allometric coefficient '*b*' was found isometric (*b* = 3.001) for *G. giuris*. Further, the study revealed negative allometric growth for *P. ticto, E. vacha, A. coila, C. atherinoides and A. morar* while remaining species showed positive growth pattern. All LLRs were found significant (p <0.001).

Amin et al. (2008) reported production and exploitation o9 *Tenualosa ilisha* in Bangladesh. Adult fish caught with gill net (10.6-19.1 cm mesh size) during peak period (Sep-Oct: mean 45.7 kg/boat/day). Mean CPUE of immature (152-235 g) was 33.5 kg/boat/day with monofilament net of 6-8 cm mesh size. Each jatka weighed on average 10 grams. With the existing harvest, an extra 150,000- 250,000 MT of jatka may be produced if 10 - 15% of the jatka can be conserved.

Rahman and Cowx (2008) studied population dynamics of *T. ilisha* from the Bangladeshi water including river and marine habitats. L_∞ = 58.8 cm and K= 0.82 y^{-1} were estimated for river population, and L_∞= 61.0 cm and K= 0.80 y^{-1} were estimated for marine populations. The marine and river populations had growth performance indices of 3.47 and 3.45, respectively. The assessed Z, M and F values were 2.38, 1.00 and 1.38 and 2.30, 0.98 and 1.32 yr^{-1}, correspondingly. L_c = 50 was 32.9 cm TL, and 80 mm was the optimum gillnet mesh size. Exploitation for marine and river habitats were 0.57 and 0.58, correspondingly.

Akter et al. (2007) observed the fecundity of *Tenualosa ilisha* from the Padma River, Bangladesh during June-October 2002. Fecundity varied from 558700-1867000 with a mean of 1239360.35±405068.97 for 35-55.7 cm and 600-1775 g fishes. Body weight was the best indicator for the fecundity.

Hossain et al. (2006) observed the length-weight (LWRs) and length-length (LLRs) relationships for eight small indigenous fish species from Mathabhanga River, Bangladesh, namely *Hyporamphus quoi*, *Amblypharyngodon mola*, *Macrognathus aculeatus*, *Channa punctata*, *Puntius sophore*, *Macrognathus pancalus*, *Nandus nandus*, and *Setipinna phasa*. Altogether 2,543 specimens were collected for the experiment by traditional gears for 12 months during the year 2005. The allometric coefficient '*b*' of LWRs ranged from 2.864 to 3.397. The average value was 3.098. Further, the study revealed negative allometric growth for *M. aculeatus* while remaining species showed a positive growth pattern. All LLRs were found significant ($p < 0.001$).

Salam et al. (2005) observed the LWRs and condition factor of *Puntius chola* from Islamabad, Pakistan. Altogether 52 specimens of different sizes were collected. The value of allometric coefficient '*b*' was found 2.80, indicating a negative allometric growth pattern. Condition factor was found constant in measuring length or weight.

Goncalves et al. (2003) observed the population biology of *Diplodus vulgaris* from the south west coast of Portugal. Altogether 1,086 fish specimens were collected for the experiment. Spawning season of the above mentioned species occurs in September - April. Males were sexually mature at 17.27 cm of total length (TL) and females were at 17.65 cm of TL. The growth parameters *i.e.*, L_{∞}, K and t_0 were 27.73 cm, 0.40 per y^{-1}, −0.34 year, respectively through von Bertalanffy equation. The total-, natural- and fishing mortality rate were 0.63 y^{-1}, 0.45 $y^{-1}$and 0.18 y^{-1}, correspondingly as well as exploitation rate was 0.28 per year.

Morey et al. (2003) observed LWRs of 103 different fish species from the western Mediterranean (Iberian coast and Balearic Islands). Seven types of fishing gear were used to collect the specimens. The experiment extended from 1991 to 2001. The '*b*' values ranged from 2.072 to 3.847, with an average value of 3.03.

Amin et al. (2002) studies on the population dynamics and stock assessment of *Tenualosa ilisha* in Bangladesh through length-frequency distribution analysis of FiSAT software. The study discloses that the harvested fishes are higher than the optimal mortality by fishing. In order to achieve an MSY of 1,62,396 tons, the fishing pressure should be decreased from the current level of mortality (2.49 yr^{-1}) to about 1.88 yr^{-1}.

Miah et al. (2000) studied the population dynamics of tjuvenile *Tenualosa ilisha* in the Meghna river (nursery ground) of 8023 specimens' length cohort analysis. The L_{α}, K and t_0 were 30.69 cm, 1.2 yr^{-1} and 0.45 yr^{-1}, respectively. The natural, fishing and total mortality were found to be 1.37 yr^{-1}, 1.41 yr^{-1} and 2.78 yr^{-1}, respectively. as well as the survival rate was 6.2%.

Miah et al. (1997) studied the growth and mortality of *Tenualosa ilisha* using 5,003 specimens from the Meghna River, Bangladesh. The L_α (asymptotic length) was 57 cm, and the primary grow time was 0.50 yr. K value (0.66) designates a moderately longer life span for hilsa. The first capture length was estimated 3.65 cm and larvae length was 1.03 mm at the birth day. Minimum entering age to the fishery (Tr) and the first capture age (Tc) were 0.58 and 0.60 yr, respectively i.e. hilsa juvenile catching starts 36.5 days later of recruitment. The Z was 2.03 yr^{-1} and 13.13 *% T. ilisha* found to be survives in the Meghna River. The natural- and fishing mortality were 0.89 yr^{1} and 1.14 yr^{1}, respectively. The exploitation rate was 0.56, demonstrating a tendency to overexploitation.

Al-Baz and Grove (1995) reported the population bioly of *Tenualosa ilisha* from Kuwait. Length ranged from 14-57 cm and 1-5 years age. The *b* value for male was 2.9836 and 3.104 for female. The Z, M & F were 1.3, 0.5 and 0.8 y^{-1} , respectively. Estimated maturity length was 41.5 cm for female. Breeding occurred during May to July. The peak breeding time was predicted in June.

Chapter

3

Study-I

STUDY-I

Morphometric Relationships and condition factors of the Hilsa Shad *Tenualosa ilisha* in the Meghna River of Southeastern Bangladesh

3.1. Abstract

The current study was on morphometric relationships through length-weight and length-length relationships, meristic features, condition factors (Fulton's, K_F; allometric, K_A; Relative, K_R) and form factor of *Tenualosa ilisha* (Hamilton, 1822) from the Meghna River, Southeastern Bangladesh for the period of July 2018 to June 2019. A total of 1433 individuals were collected from the Meghna River (Chandpur and Laxmipur region, SE Bangladesh). Body weight (BW) and total length (TL) were measured with 0.01 g and 0.01 cm accuracy for each specimen. The TL ranged from 15.3-57.8 cm while the BW was 37.17–2250 g. The overall K_F was 0.7191-1.7098, K_A was 0.0014-0.0151 and K_R was 0.65-1.66 for *T. ilisha* in the Meghna River. The maximum K_R was found in July while the minimum was in January. The K_F was strongly correlated with TL and BW while K_R was with BW in the Meghna River. K_A has no significant relation neither TL nor BW. These findings will help to improve sustainable management policy of hilsa fishery in the Meghna river ecosystem and other adjacent water bodies.

Key words: Fin formula, growth pattern, condition factors, Meghna River

3.2. Introduction

The national fish of Bangladesh, *Tenualosa ilisha* (Hamilton, 1822) is a marine, brackish and freshwater fish belonging to the family Clupeidae (Riede, 2004). It is locally known as *ilish* or *ilsha* while the juvenile known as *Jatka* (Shafi and Quddus, 1982). Hilsa shad is rich in minerals, lipids and amino acids (De *et al*., 2019). It has great economic importance as 12% of total fish production of the country came from Hilsa (DoF, 2020). The Hilsa shad is distributed in Asian region including Bangladesh, Nepal, India, Sri Lanka, Pakistan, China, United Arab Emirates and also in Myanmar, Iraq, Iran, Malaysia, Oman, Kuwait, Qatar, Saudi Arabia, Thailand and Viet Nam (Freyhof, 2014). It is abundant in the Meghna River, Padma River, Rupsha River, Sibsha River, Biskhali River, Tetulia River, Arial Kha River, Galachipa Rirver, Pyra River and a small number of other rivers in the coastal area of Bangladesh (Rahman, 2007). This Clupid categorized as least concern (LC) both in Bangladesh (IUCN Bangladesh, 2015) and worldwide (Freyhof, 2014).

Fish species identification and classification as well as the genetic studies depend primarily on morphometric and meristic characteristics. (Harrison et al., 2007; Azad et al., 2018; Hossen et al., 2020). Sex ratio and length-frequency distribution provides vital evidence to estimate reproductive potential of a fish population (Khatun et al., 2018). length-weight relationships (LWRs) are important to compare life history features of any fish species between two habitats (Rahman et al., 2018a). In addition, the length-length relationships (LLRs) are very significant as some eco-physiological aspects are length dependent (Hossain et al., 2006). On the other hand, form factor ($a_{3.0}$) is used widely to identify the body shape of fish in any aquatic habitat (Froese, 2006). Condition factors are the most beneficial to evaluate the overall health status of fish species as well as considered efficient tools for population management and conservation (Hossain *et al*., 2012a; Rahman *et al.*, 2012b). In addition, population success can be predicted through this quantitative well-being of fishes (Richter, 2007; Hossain *et al.*, 2013, 2016). Furthermore, the relative condition factor (K_R) can be used to examine fish health (Rypel and Richter, 2008) and very essential to estimate the environmental condition of fish stocks (Hossen *et al.*, 2019a).

A few studies have been done on several aspects including LWRs (Flura *et al.*, 2015), population biology (Islam *et al.*, 1987; Amin *et al.*, 2000; Haldar *et al.*, 2001; Rahman *et al.*, 1998; Ahmed *et al.*, 2008; Hossain *et al.*, 2019), stock assessment (Gupta, 1989; Amin *et al.*, 2004), exploitation status (Amin *et al.*, 2002, 2008) of *T. ilisha*. However, none of these studies cover the morphometric and meristic features, condition factors and form factor of fishes covering year round data in the Meghna River and elsewhere. Therefore, the current study was planned to describe the temporal variations of length, weight and condition of *T. ilisha* in the Meghna River, Southeastern (SE) Bangladesh using one-year-round data.

3.3. Objectives

The specific objectives of this study are-

- To assess the morphometric and meristic traits;
- To determine growth pattern through length-weight and length-length relationships
- To determine the condition factors (Fulton's, K_F; allometric, K_A; Relative, K_R) ; and
- To determine the form factor.

3.4. Materials and Methods

3.4.1. Study site and sampling

The study was carried out in the Meghna River, southeastern Bangladesh. A total of 1433 specimen were collected from commercial landing station in Chandpur (23.23º, 90.63º) and Laxmipur (22.85º, 90.67º) region (Plate 3) during July 2018 to June 2019 through traditional fishing gears namely seine net (*Ber jal*; mesh size: 2.5-6.5 cm), and gill net (*Chandi* or *ilish jal*; mesh size: 9-12 cm, *Chap jal*; mesh size: 7-15 cm). As soon as samples were collected, they were promptly stored in ice at the sampling site.

3.4.2. Fish measurement

Different lengths (Plate 4, and Table 3) were measured by measuring board nearest to the 0.01 cm and body weight (BW) was weighed by an electric balance nearest to the 0.01 g for each specimen (Plate 5).

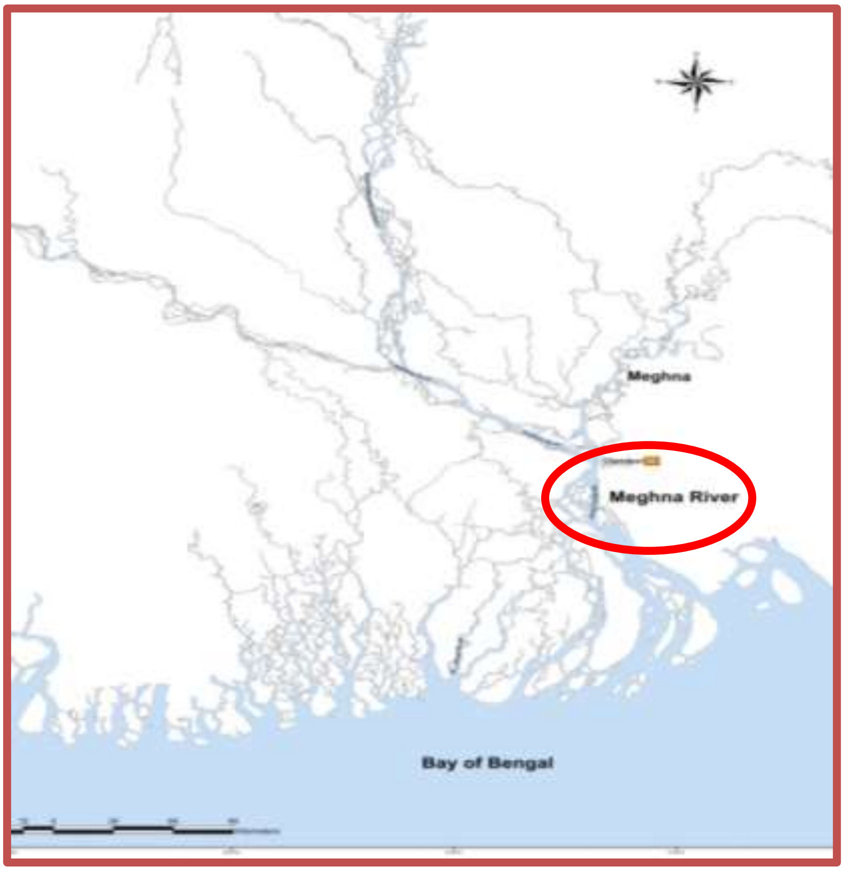


Plate 3. Sampling site in the Meghna River, southeastern Bangladesh

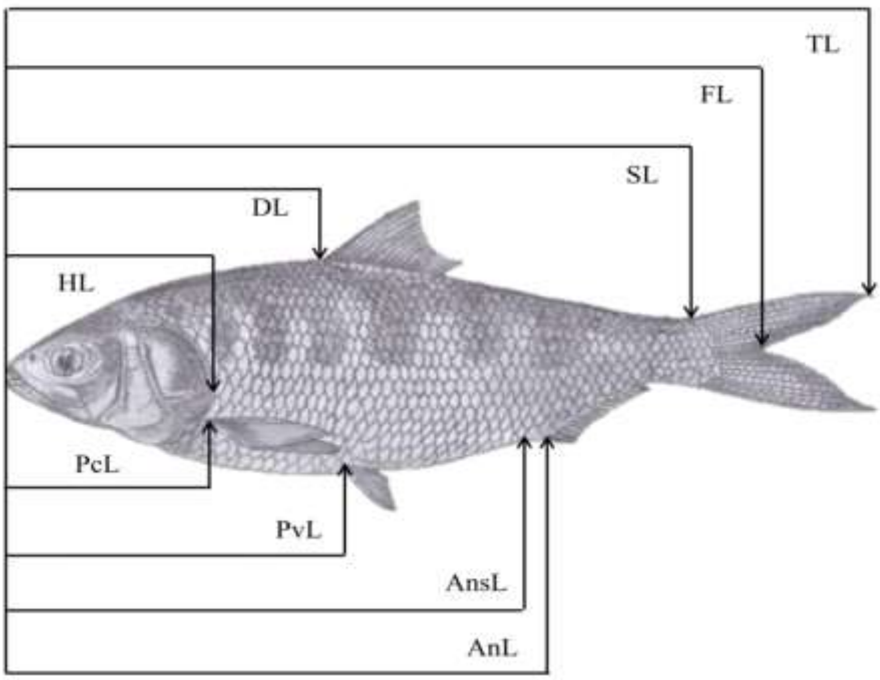


Plate 4. Morphometric measurement of *Tenualosa ilisha* from the Meghna river, southeastern Bangladesh.

Plate 5. Morphometric measurement of *Tenualosa ilisha* in the laboratory.

3.4.3. Meristic counts

By using a magnifying glass, we counted the different fin rays (single fin ray defined as unbranched; and which tip portion separated into few rays defined as branched) of *T. ilisha* across body parts and made a fin formula. The last two soft rays are counted as two separate rays (Kottelat and Freyhof, 2007). The number of scales in the lateral line (pored scales counted from shoulder girdle to the base of caudal fin) and belly scutes were also figured out by using magnifying glass (Plate 6).

Plate 6. Fin ray count of *T. ilisha*

Table 3. Description of different morphometric measurements of the *Tenualosa ilisha* from the Meghna River, southeastern Bangladesh

Length	Starting Point	Ending point
Total length (TL)	Tip of the snout	Ending point of the caudal fin
Fork length (FL)	Tip of the snout	Ending point of Bisectrix of Caudal fin
Standard length (SL)	Tip of the snout	Base of caudal fin
Dorsal length (DL)	Tip of the snout	Anterior point of dorsal fin base
Pectoral length (PcL)	Tip of the snout	Anterior point of pectoral fin base
Pelvic length (PvL)	Tip of the snout	Anterior point of pelvic fin base
Anus length (AnsL)	Tip of the snout	Anterior point of anus
Anal length (AnL)	Tip of the snout	Ending point of anal fin base
Head length (HL)	Tip of the snout	Ending point of bony opercular edge

3.4.4. Length-weight (LWRs) and length-length (LLRs) relationships

LWRs were calculated using the equation: $W = a \times L^b$, where W is the body weight (g) and L represents the length (cm). The parameters a and b were assessed using linear regression study based on natural logarithms: $\ln(W) = \ln(a) + b \ln(L)$. Besides, LLRs *i.e.*, TL *vs.* SL, FL *vs*. SL and SL *vs*. FL were assessed with linear regression analysis (Hossain et al., 2006).

3.4.5. Condition factors

Fulton's condition factor (K_F) was calculated by the equation: $K_F = 100 \times (W/L^3)$ (Fulton, 1904), where W is the BW in g and L is the TL in cm. The scaling factor 100 was used to bring the K_F close to unit.

The allometric condition factor (K_A) was calculated using the equation: $K_A = W/L^b$ (Tesch, 1968), where W is the BW in g, L is the TL in cm and b is the LWRs parameter.

Further, relative condition factor (K_R) was assessed with the equation: $K_R = W/(a \times L^b)$ (Le Cren, 1951), where W is the BW in g, L is the TL in cm and a and b are LWRs parameters. According to Le-Cren (1951), the value of K_R higher than 1 indicates good health and less than 1 indicates relatively poor condition of the fish.

3.4.6. Form factor

The form factor ($a_{3.0}$) was measured according to Froese (2006), as $a_{3.0} = 10^{\log a - s(b-3)}$, where a and b are regression parameters of LWRs and S is the regression slope of *ln a vs. b*. A mean slope S = -1.358 was used.

3.4.7. Statistical Analyses

GraphPad Prism 6.5 software was used for statistical analyses. Homogeneity as well as normality of data was checked by graphic evaluation of histograms and confirmed with the Kolmogorov-Smirnov test. In order to correlate somatic measures (TL and BW) with condition variables, the Spearman's rank test was utilized (K_F, K_A, and K_R). There was a 5% threshold of significance ($p < 0.05$) used to all statistical analyses in the study.

3.5. Results

3.5.1. Morphometric and meristic traits

The body shape of *T. ilisha* is fusiform, fairly deep and compressed. Body colour of this fish is silvery shot with gold and purple. Mouth position of the species is terminal and upper jaw with a distinct median notch when seen from above. The body is covered with cycloid scales. Separate median notch present in upper jaw. About 100-250 fine gill rakers were exist on the lower part of arch. In juveniles, there had been a black blotch underneath the gill opening, followed by a sequence of small spots on the flanks.

Meristic count of *T. ilisha* was given in Table 4 and Plate 7. All morphometric measurements are tabulated in Table 5. The LWRs parameters (a and b) with their 95% confidence intervals and co-efficient of determination (r^2) of *T. ilisha* are given in Table 6. All LWRs were greatly significant ($p < 0.001$).

Table 4. Meristic counts of *Tenualosa ilisha* from the Meghna River, southeastern Bangladesh. Single fin ray defined as unbranched and which tip portion separated into few rays defined as branched.

Meristic data	Numbers	Unbranched	Branched
Dorsal fin rays	15-19	2-4	13-17
Pectoral fin rays	14-16	1	13-15
Pelvic fin rays	6-10	1-2	5-8
Anal fin rays	18-21	1-2	16-20
Caudal fin rays	20-22	2	18-20
Scutes	29-31	-	-
Lateral line scale	42-45	-	-

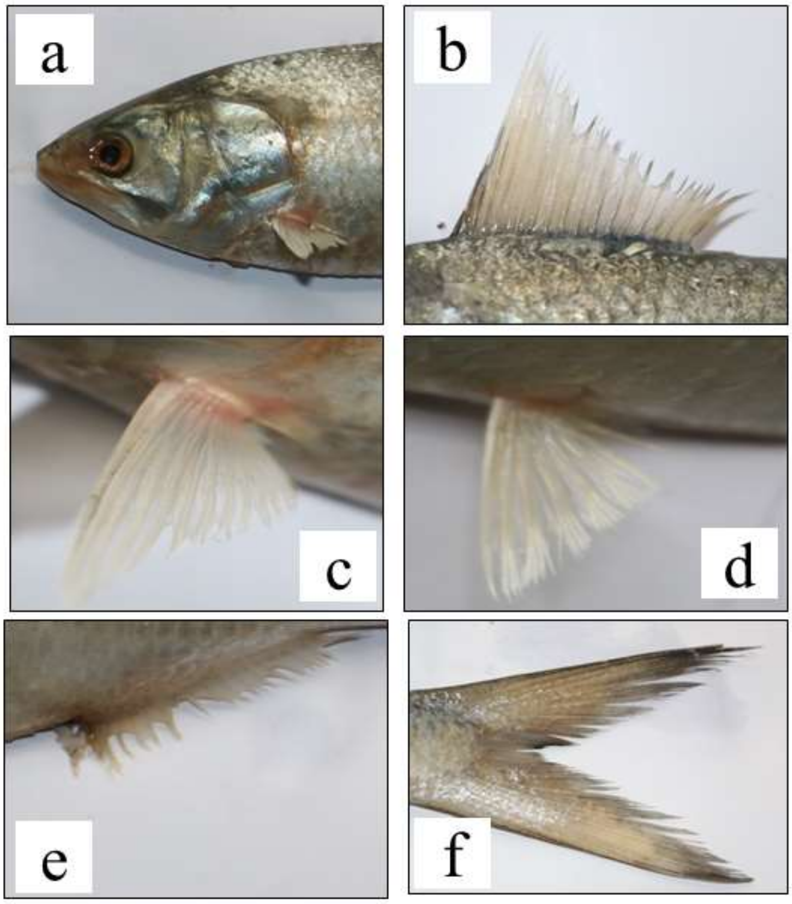


Plate 7. Showing the different body parts such as (a) Head (b) Dorsal (c) Pectoral (d) Pelvic (e) Anal and (f) Caudal fin of *Tenualosa ilisha* from the Meghna River, southeastern Bangladesh

Table 5. Morphometric measurements of *Tenualosa ilisha* from the Meghna River, southeastern Bangladesh.

Measurements	Min (cm)	Max (cm)	Mean ± SD	95% CI
Total length (TL)	15.30	57.80	33.89 ± 7.01	33.53-34.25
Fork length (FL)	13.30	51.00	29.79 ± 6.37	29.46 - 30.12
Standard length (SL)	11.80	47.0	27.22 ± 5.93	26.91- 27.52
Head length (HL)	3.18	13.51	7.77 ± 2.40	6.16 - 8.75
Dorsal length (DL)	4.91	22.01	12.39 ± 3.92	10.61 - 14.57
Pectoral length (PcL)	3.17	12.40	7.44 ± 2.27	5.98 - 9.34
Pelvic length (PvL)	4.62	22.42	13.12 ± 4.00	11.02 - 15.50
Anus length (AnsL)	8.08	32.87	19.30 ± 5.96	17.32 - 21.79
Anal length (AnL)	9.24	33.84	19.88 ± 5.99	16.64 - 22.12
Body weight (BW)	37.18	2250.0	479.23 ± 283.91	464.51 - 493.94

Min, minimum; Max, maximum; SD, standard deviation; CL, confidence interval.

Table 6. Estimated parameters of the length-weight relationships of *Tenualosa ilisha* from the Meghna River, southeastern Bangladesh.

Equation	*a*	*b*	95% CL of *a*	95% CI of *b*	r^2
$BW = a \times TL^b$	0.0067	3.135	0.0060-0.0074	3.107-3.163	0.971
$BW = a \times FL^b$	0.0144	3.05	0.0131 - 0.0158	3.01 - 3.08	0.991
$BW = a \times SL^b$	0.0215	3.01	0.0198 - 0.0233	2.98 - 3.04	0.993
$BW = a \times HL^b$	1.3744	2.72	1.2968 - 1.4566	2.68 - 2.76	0.986
$BW = a \times DL^b$	0.3318	2.80	0.3117 - 0.3532	2.77 - 2.84	0.990
$BW = a \times PcL^b$	1.4599	2.76	1.3589 - 1.5683	2.71 - 2.81	0.979
$BW = a \times PvL^b$	0.2922	2.77	0.2568 - 0.3326	2.71 - 2.84	0.963
$BW = a \times AnsL^b$	0.0908	2.82	0.0816 - 0.1009	2.77 - 2.86	0.983
$BW = a \times AL^b$	0.0586	2.96	0.0538 - 0.0637	2.92 - 3.00	0.990

Note: *a* and *b* are the regression parameters of LWRs; CI, confidence intervals; r^2, coefficient of determination.

3.5.2. Total Length (TL)

The study demonstrated that total length varied from 15.3 to 57.8. Highest TL was found during the month of June. On the other hand, the lowest individuals were recorded during the months of April and May (Table 7). Monthly variation of TL shown in Figure 1.

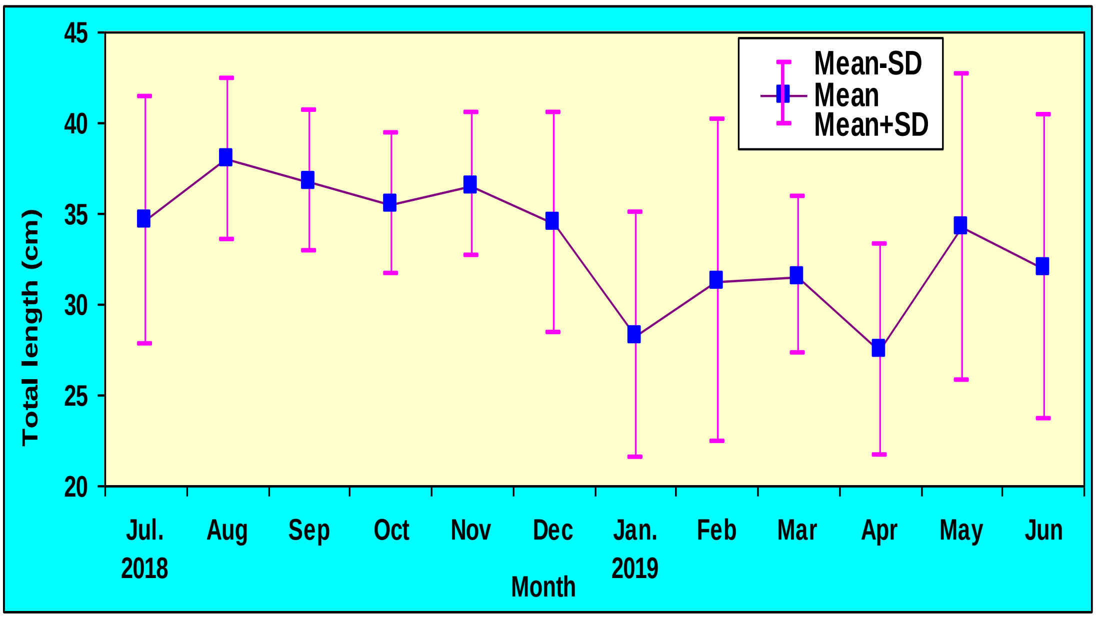


Figure 1. Monthly variations of total length of *Tenualosa ilisha* (Hamilton, 1822) in the Meghna River, southeastern Bangladesh.

Table 7. Descriptive statistics on total length measurements and their 95% confidence limits of *Tenualosa ilisha* from the Meghna River, southeastern Bangladesh.

Month	*n*	Min	Max	Mean ± SD	95% CL
July, 2018	72	17.00	53.00	34.58 ± 6.80	32.98 - 36.18
August	103	27.50	51.00	37.95 ± 4.45	37.08 - 38.82
September	120	27.00	48.00	36.76 ± 3.84	36.07 - 37.46
October	130	25.50	48.00	35.49 ± 3.89	34.82 - 36.17
November	124	28.50	47.00	36.5 ± 3.93	35.81 - 37.20
December	226	19.70	44.50	34.45 ± 6.09	33.65 - 35.25
January, 2019	72	18.00	41.60	28.24 ± 6.74	26.66 - 29.83
February	76	18.90	46.20	31.26 ± 8.92	29.22 - 33.30
March	35	26.00	42.50	31.56 ± 4.34	30.07 - 33.05
April	79	15.30	43.60	27.49 ± 5.82	26.18 - 28.79
May	209	15.30	55.50	34.20 ± 8.43	33.05 - 35.35
June	187	18.50	57.80	32.05 ± 8.37	30.84 - 33.26
Overall	1433	15.30	57.80	33.89 ± 7.01	33.53 - 34.25

Note: *n*, Sample Size; Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, Confidence Limit of Mean.

3.5.3. Body Weight (BW)

The study revealed that the BW ranged from 37.17 to 2250.00 g for *T. ilisha* in the Meghna River. The maximum body weight was recorded in June. On the other hand, the minimum body weight found in April-May (Table 8). Monthly variation of BW was showed in Figure 2.

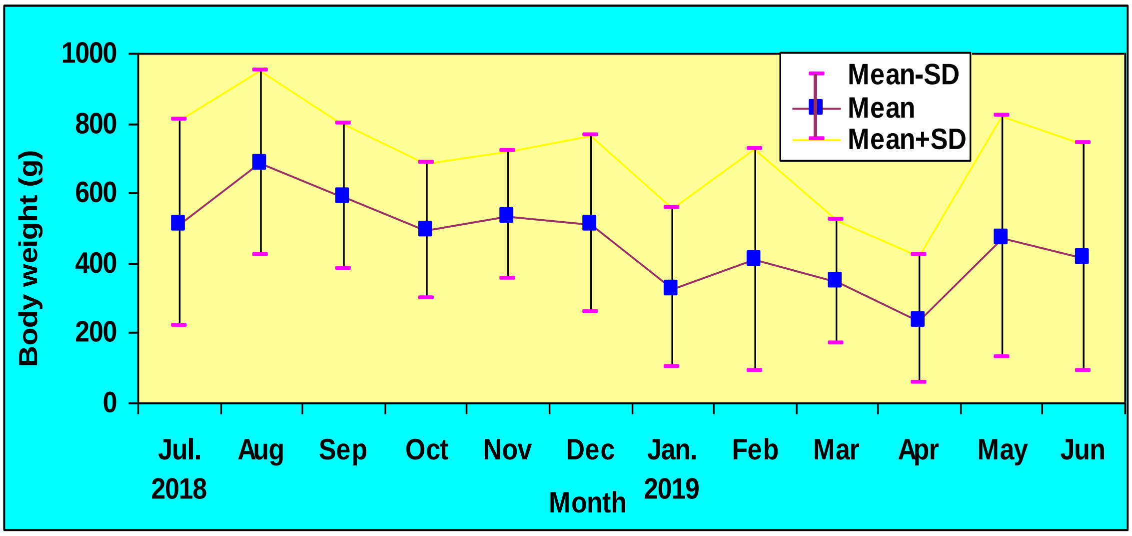


Figure 2. Monthly variations of body weight of *Tenualosa ilisha* (Hamilton, 1822) in the Meghna River, Southeastern Bangladesh.

Table 8. Descriptive statistics on weight measurements and their 95% confidence limits of *Tenualosa ilisha* from the Meghna River, southeastern Bangladesh.

Month	*n*	Min	Max	Mean ± SD	95% CL
July, 2018	72	78.00	1458.00	513.19 ± 294.94	443.89 - 582.50
August	103	248.00	1555.00	686.47 ± 262.66	635.13 - 737.80
September	120	200.00	1265.00	588.93 ± 208.78	551.19 - 626.66
October	130	174.00	1185.00	493.12 ± 193.91	459.47 - 526.76
November	124	225.00	1056.00	536.07 ± 182.36	503.66 - 568.49
December	226	54.98	969.00	511.55 ± 251.58	478.57 - 544.52
January, 2019	72	54.98	921.00	328.27 ± 228.43	274.59 - 381.95
February	76	70.68	100.00	408.22 ± 318.76	335.38 - 481.05
March	35	173.00	933.00	345.63 ± 175.25	285.43 - 405.83
April	79	37.10	929.00	238.16 ± 183.75	197.00 - 279.32
May	209	37.17	1800.00	473.10 ± 344.44	426.14 - 520.07
June	187	68.00	2250.00	415.87 ± 324.24	369.09 - s462.65
Overall	1433	37.18	2250.00	479.23 ± 283.91	464.51 - 493.94

Note: *n*, Sample Size; Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, Confidence Limit of Mean.

3.5.4. Length-weight (LWRs) relationships

The overall *b* value designated a positive allometric growth ($b = 3.135$) that showed in Figure 3. However, isometric growth ($b = 3$) exhibited during February, June to July and December. All LWRs were highly significant ($p < 0.0001$), with r^2 values ≥ 0.936. The monthly sample size (*n*), regression parameters (*a* and *b*) with 95% confidence limit of the LWRs and coefficient of determination (r^2) of *T. ilisha* in the Meghna River SE Bangladesh are presented in Table 9, whereas Figure 4 showed the variation of *b* value.

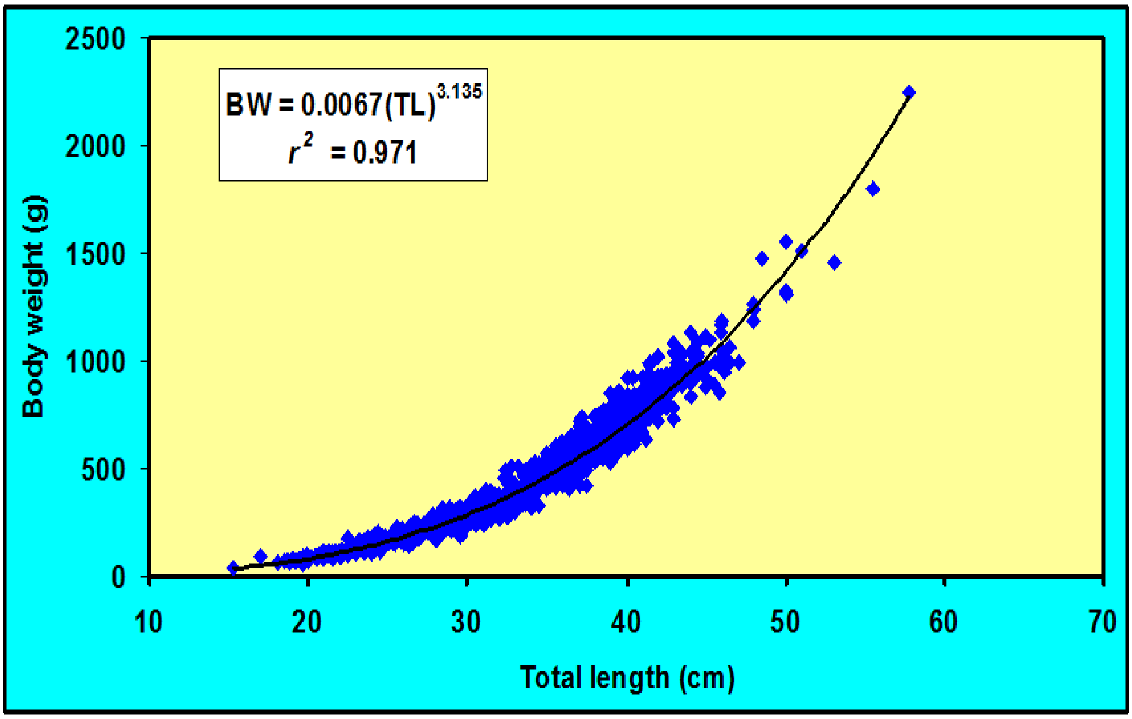


Figure 3. Relations between total length and body weight of *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh.

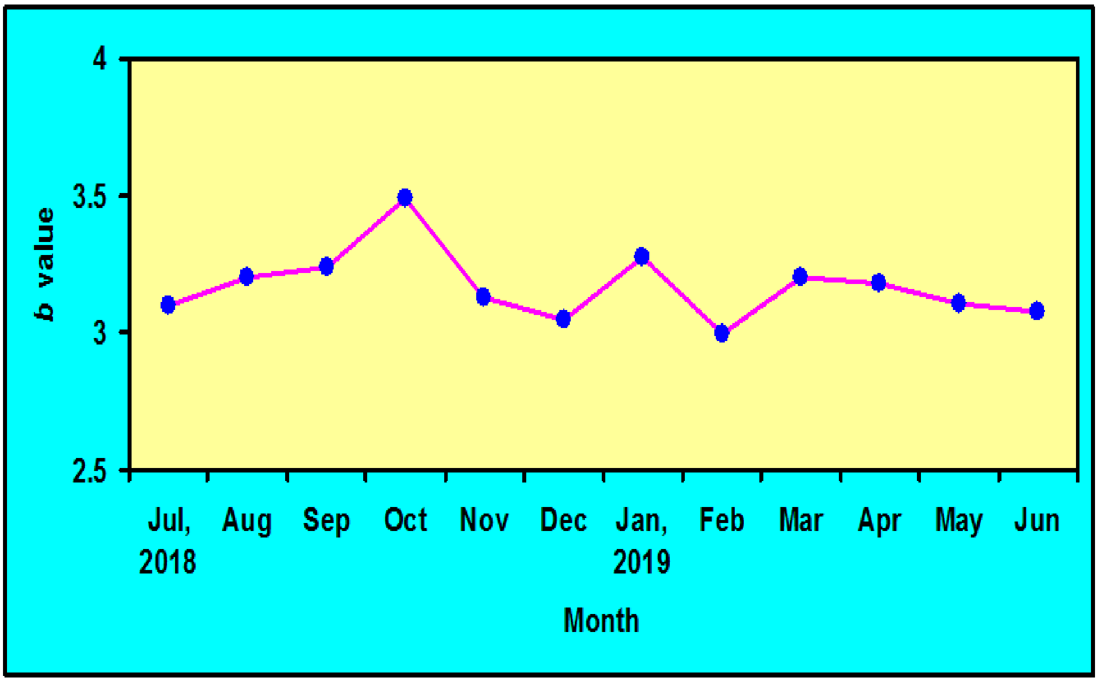


Figure 4. The generalized ln-ln relationships between total length and body weight of the *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh

Table 9. Estimated parameters of monthly length-weight relationships (BW = $a \times TL^b$) of the *Tenualosa ilisha* from the Meghna River, southeastern Bangladesh.

Month	Regression parameters		95% CL of *a*	95% CL of *b*	r^2	GT
	a	***b***				
Jul. 2018	0.0078	3.098	0.0048-0.0126	2.962-3.235	0.967	I
Aug.	0.0058	3.201	0.0034-0.0097	3.057-3.345	0.951	A+
Sep.	0.0048	3.238	0.0030-0.0078	3.106-3.371	0.952	A+
Oct.	0.0018	3.492	0.0010-0.0032	3.332-3.652	0.936	A+
Nov.	0.0066	3.130	0.0042-0.0105	3.001-3.258	0.950	A+
Dec.	0.0095	3.050	0.0069-0.0131	2.959-3.141	0.951	I
Jan. 19	0.0049	3.273	0.0035-0.0067	3.175-3.372	0.984	A+
Feb.	0.0108	2.998	0.0085-0.137	2.928-3.067	0.990	I
Mar.	0.0051	3.202	0.0030-0.0086	3.052-3.352	0.983	A+
Apr.	0.0053	3.181	0.0035-0.0082	3.051-3.311	0.969	A+
May	0.0068	3.104	0.0056-0.0082	3.050-3.157	0.984	A+
Jun.	0.0078	3.079	0.0066-0.0091	3.033-3.125	0.989	I
Overall	0.0067	3.135	0.0060-0.0074	3.107-3.163	0.971	A+

Note: *a*, intercept; *b*, slope; CL, 95% confidence limit; GT, growth type; I, isometric; A+, positive allometric.

3.5.5. Length-Length Relationships (LLRs)

Length-length relationships (LLRs) were also estimated that were greatly correlated with r^2 values ≥ 0.983 and presented in Table 10 and Figure 5. By LLRs one can compare different body length (*i.e.*, TL, FL & SL).

Table 10. The estimated parameters of the length-length relationships (y = $a + b \times x$) of *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh

Equation	Regression parameters		95% CL of *a*	95% CL of *b*	r^2
	a	***b***			
TL = $a + b\times$ FL	1.2800	1.094	1.0872 to 1.4728	1.088 to 1.101	0.988
TL = $a + b\times$ SL	1.9414	1.174	1.7216 to 2.1613	1.182 to 1.166	0.983
SL = $a + b\times$ FL	-0.3366	0.925	-0.498 to -0.176	0.919 to 0.930	0.988

TL, total length; FL, fork length; SL, standard length; *a* and *b* are the regression parameters; CL, confidence intervals; r^2, co-efficient of determination

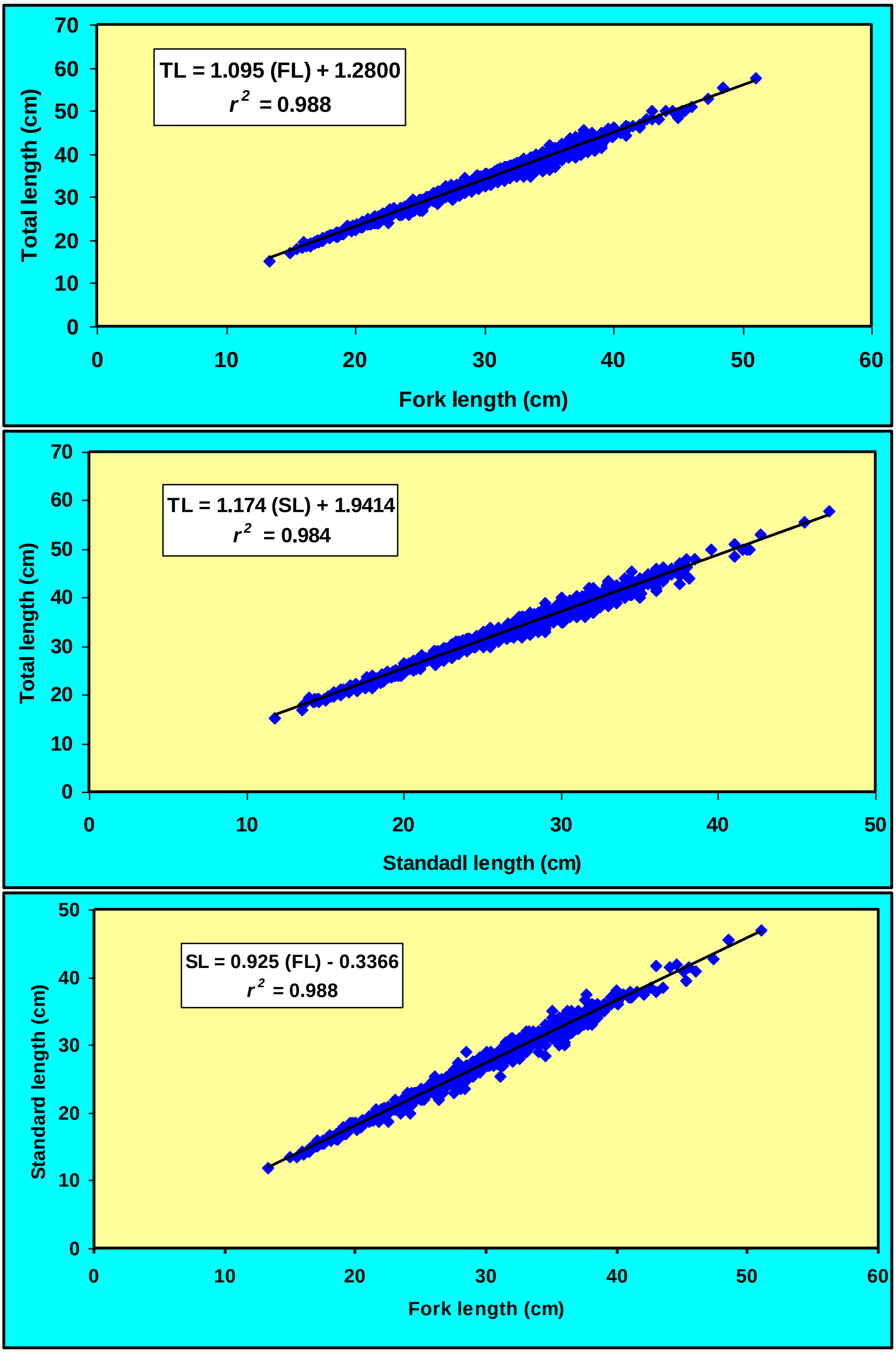


Figure 5. Length-length relationship (TL *vs.* FL, TL *vs.* SL & SL *vs.* FL) of the *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh

3.5.6. Fulton's condition factor (K_F)

The overall K_F value for *T. ilisha* ranged from 0.7191 to 1.7098 in the Meghna River, Se Bangladesh. The lowest and highest value was in December-January and July, respectively (Table 11). Monthly variation of K_F was showed in Figure 6.

Table 11. Descriptive statistics on Fulton's condition factor (K_F) and their 95% confidence limits of *Tenualosa ilisha* from the Meghna River, southeastern Bangladesh.

Month	*n*	Fulton′s condition factor (K_F)			
		Min	Max	Mean ± SD	95% CL
July, 2018	72	0.7848	1.7098	1.1065 ± 0.1331	1.0752 - 1.1378
August	103	0.9544	1.4359	1.1983 ± 0.0154	1.1777 - 1.2189
September	120	0.9293	1.3301	1.1382 ± 0.0891	1.1222 - 1.1544
October	130	0.7817	1.2565	1.0451 ± 0.1187	1.0245 - 1.0657
November	124	0.6894	1.2299	1.0606 ± 0.0843	1.0456 - 1.0756
December	226	0.7191	1.4407	1.1412 ± 0.1422	1.1226 - 1.1598
January, 2019	72	0.7191	1.4407	1.2088 ± 0.1352	1.1770 - 1.2406
February	76	0.8935	1.5028	1.0732 ± 0.0958	1.0513 - 1.0950
March	35	0.9167	1.2415	1.0257 ± 0.0611	1.0033 - 1.0481
April	79	0.7323	1.2489	0.9734 ± 0.1210	0.9463 - 1.0005
May	209	0.7323	1.2181	0.9796 ± 1.1006	009659 - 0.9983
June	187	0.8024	1.2759	1.0253 ± 0.0908	1.0122 - 1.0384
Overall	1433	0.7191	1.7098	1.0767 ± 0.1329	1.0698 - 1.0835

Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, 95% Confidence Limit.

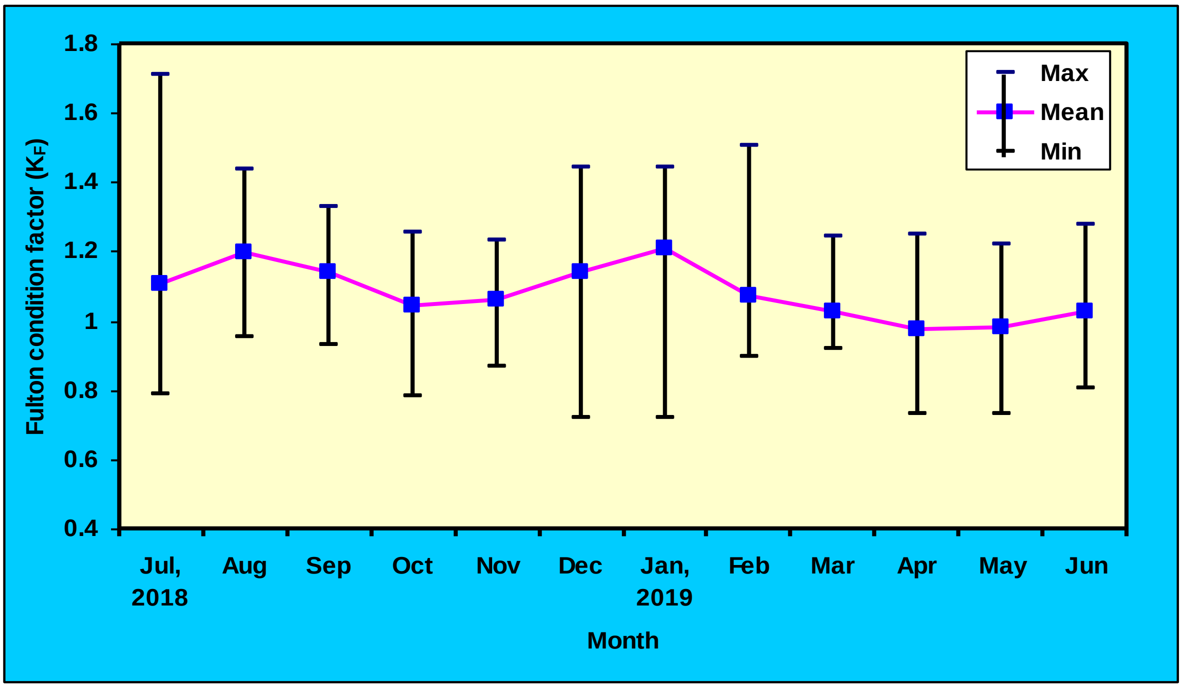


Figure 10. Monthly variations of Fulton's condition factors of *Tenualosa ilisha* from the Meghna River, SE Bangladesh.

3.5.7. Allometric condition factor (K_A)

The overall allometric condition factor (K_A) ranged from 0.0014 to 0.0151. The lowest K_A was in October and the highest was in February (Table 12). Monthly variation of K_A was showed in Figure 7.

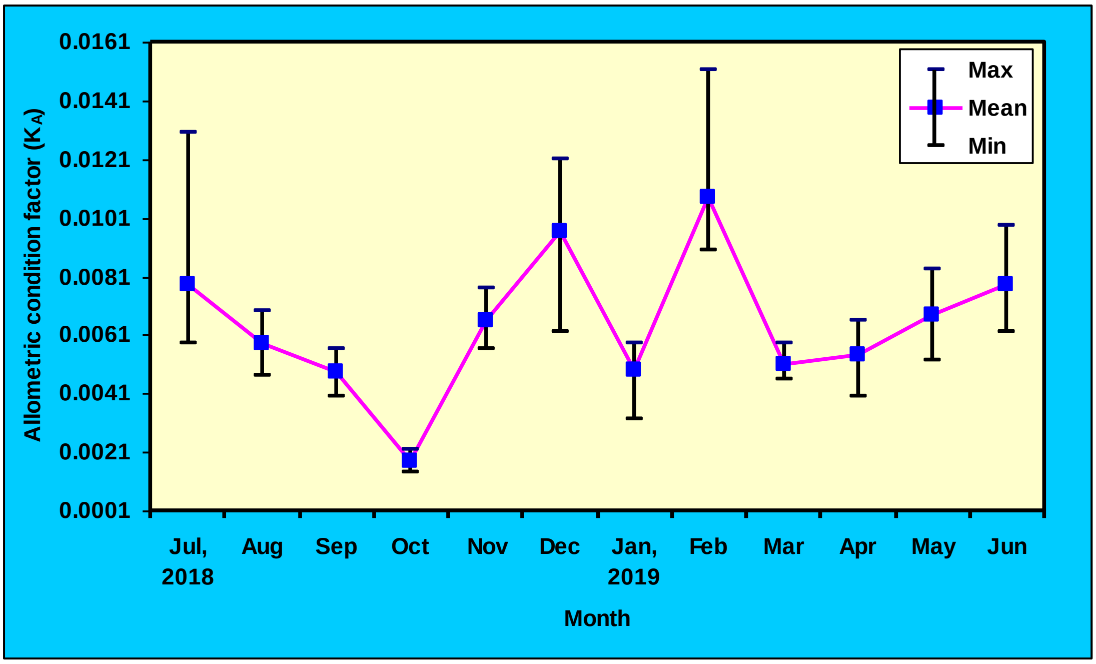


Figure 7. Monthly variations of allometric condition factor of *Tenualosa ilisha* from the Meghna River, SE Bangladesh.

Table 12. Descriptive statistics on Allometric condition factor (K_A) and their 95% confidence limits of *Tenualosa ilisha* from the Meghna River, SE Bangladesh.

Month	*n*	Allometric condition factor (K_A)			
		Min	Max	Mean ± SD	95% CL
July, 2018	72	0.0058	0.0130	0.0078 ± 0.0009	0.0076 - 0.0081
August	103	0.0047	0.0069	0.0058 ± 0.0005	0.0057 - 0.0059
September	120	0.0040	0.0056	0.0048 ± 0.0004	0.0048 - 0.0049
October	130	0.0014	0.0022	0.0018 ± 0.0001	0.0017 - 0.0018
November	124	0.0056	0.0077	0.0066 ± 0.0005	0.0066 - 0.0067
December	226	0.0062	0.0121	0.0096 ± 0.0012	0.0094 - 0.0097
January, 2019	72	0.0032	0.0058	0.0049 ± 0.0005	0.0048 - 0.0050
February	76	0.0089	0.0151	0.0108 ± 0.0009	0.0106 - 0.0110
March	35	0.0046	0.0058	0.0051 ± 0.0003	0.0050 - 0.0052
April	79	0.0040	0.0066	0.0054 ± 0.0006	0.0052 - 0.0055
May	209	0.0052	0.0083	0.0068 ± 0.0007	0.0067 - 0.0069
June	187	0.0062	0.0098	0.0078 ± 0.0006	0.0077 - 0.0079
Overall	1433	0.0014	0.0151	0.0067 ± 0.0024	0.0066 - 0.0068

Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, 95% Confidence Limit.

3.5.8. Relative condition factor (K_R)

The study revealed the overall relative condition factor (KR) from 0.65 to 1.66 for *T. ilisha*. The lowest and highest K_R values were in December and July, respectively in the Meghna River, SE Bangladesh (Table 13). Monthly variation of $K_R$was showed in Figure 8.

Table 13. Descriptive statistics on Relative condition factor (K_R) and their 95% confidence limits of *Tenualosa ilisha* from the Meghna River, SE Bangladesh.

Month	*n*	Relative condition factor (K_R)			
		Min	Max	Mean ± SD	95% CL
July, 2018	72	0.74	1.66	1.00 ± 0.13	0.98 - 1.03
August	103	0.81	1.18	1.00 ± 0.09	0.98 - 1.01
September	120	0.84	1.18	1.01 ± 0.08	0.99 - 1.02
October	130	0.76	1.23	1.00 ± 0.10	0.98 - 1.02
November	124	0.84	1.17	1.01 ± 0.08	0.99 - 1.02
December	226	0.65	1.27	1.01 ± 0.13	0.99 - 1.02
January, 2019	72	0.65	1.18	1.00 ± 0.10	0.97 - 1.02
February	76	0.83	1.40	1.00 ± 0.09	0.98 - 1.02
March	35	0.90	1.14	1.00 ± 0.06	0.98 - 1.02
April	79	0.75	1.24	1.01 ± 0.12	0.99 - 1.04
May	209	0.76	1.22	1.00 ± 0.10	0.99 - 1.01
June	187	0.80	1.26	1.00 ± 0.09	0.99 - 1.02
Overall	1433	0.65	1.66	1.00 ± 0.10	0.99 - 1.01

Note: Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, 95% Confidence Limit.

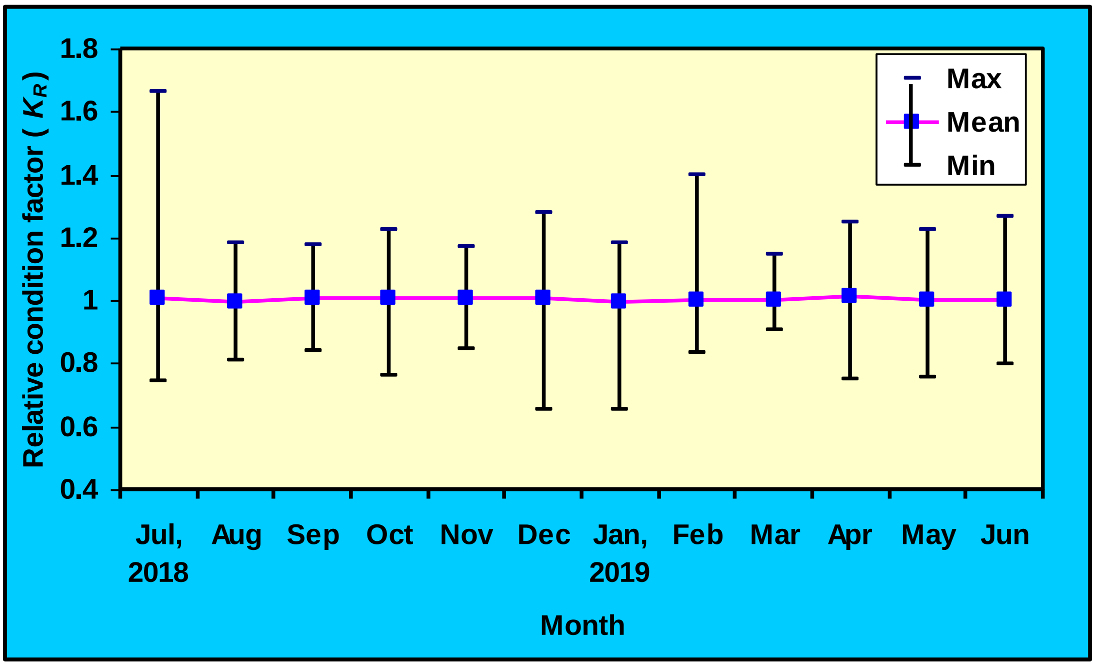


Figure 8. Monthly variations of Relative condition factor (K_R) of *Tenualosa ilisha* from the Meghna River, SE Bangladesh.

KF significantly correlated with both TL and BW, weather K_R is only correlated with BW. Table 14 Showed relationship of condition factors with TL and BW.

Table 14. Relationships of condition factor with total length and body weight of *Tenualosa ilisha* from the Meghna River, SE Bangladesh.

Relationships	r_s values	95% CL of r_s	*p* values	Significance
TL *vs.* K_F	0.2729	0.02229 - 0.3216	<0.0001	****
TL *vs.* K_A	-0.0006	-0.0539 - 0.0527	0.9818	*ns*
TL *vs.* K_R	0.0226	-0.0308 - 0.0758	0.3927	*ns*
BW *vs.* K_F	0.4290	0.3844 - 0.4713	<0.0001	****
BW *vs.* K_A	0.0303	-0.0231 - 0.0835	0.2521	*ns*
BW *vs.* K_R	0.1530	0.1005 - 0.2046	<0.0001	****

Note: *ns*, not significant; ****highly significant

3.5.9. Form Factor

The calculated form factor ($a_{3.0}$) was 0.0102 *Tenualosa ilisha* in the Meghna River Bangladesh that indicate fusiform body shape (Froese, 2006).

3.6. Discussion

The research illustrated the morphological characters and covered linear dimensions in a large number for *T. ilisha.* There is no published information on the meristic count of *T. ilisha* from the Meghna River. However, the dorsal fin rays (D. 15-19 (2-4/13-17)) in dorsal fin are dissimilar to the previous findings of Shafi & Quddus (1982) (D. 18-20), Talwar & Jhingran (1991) (D. iv-v/14-16) and Rahman (2005) (D. 17-19 (3/14-16). Pectoral fins (P. 14-16(1/13-15)) are similar to the earlier study of Bhuiyan (1964) (P. 15), Shafi & Quddus (1982) (P. 15), Talwar & Jhingran (1991) (P. i/14) and Rahman (2005) (14-16). Pelvic fin (6-10(1-2/5-8)) and anal fin (18-21(1-2/16-20)) is more or less similar to the observation of Shafi & Quddus (1982) (P_v. 9; A. 18-20), Talwar & Jhingran (1991) (P_v. i/7; A. ii-ii/16-20) and Rahman (2005) (P_v. 8(1/7); A. 18-23(2-3/16-20). Caudal fin (C. 20-22(2/18-20)) is somewhat similar to the number reported by Shafi & Quddus (1982) (C. 16-20) but disparate to the study of Rahman (2005) (C. 19). Talwar & Jhingran (1991) found 30-33 belly scutes and 45-47 lateral line scales while Narejo et al. (2008) found 30-33 belly scutes from the Indus River, Pakistan are dissimilar to the current study. These variations may ascribe to the geographical reason or difference in counting methods, developmental period, temperature during larval development, etc. (Barlow 1961).

A large quantity of specimens covering various body sizes were collected from commercial catch of the Meghna River in Chandpur and Laxmipur regions throughout the year. However, that the lack of fish smaller than 15.3 cm TL throughout the research was due to the fishing gear selection or low market price (Rahman et al., 2019a, b; Hossen et al., 2019b; Azad et al., 2018). In the study, we found the maximum length as 57.8 cm TL which was more or less similar to the study (57 cm) of Rahman et al., (1999) and Amin et al., (2002) in Bangladesh and Al-Baz & Grove (1995) in Kuwait but smaller than the study (61 cm) of Amin et al., (2004), though FishBase (Froese and Pauly, 2020) showed a maximum length of 60 cm. All other studies (Flura et al., 2015; Sarkar et al., 2017; Roomiani and Jamili, 2011; Bhakta et al., 2019; Mohanty and Nayak, 2017; Bhaumik et al., 2011) found the body length were smaller than the current study. Growth parameters are estimated through the maximum length. Thus, it is essential for fisheries resource management and planning (Hossain et al., 2009; 2014). Mean TL and BW were comparatively smaller in January. September-October is the peak spawning season of Hilsa shad (Hossain et al., 2014) and in January they recruit in the adult stock. Another small peak was in February (Mathur, 1964). The juvenile recruits in April and thus they are small in size and weight. In August maximum mean length and weight were found as the presence of much more food in the River.

The value of *b* from LWRs can be between 2 to 4, although values of 2.5 to 3.5 are also frequent (Carlander 1969; Hassan et al., 2020). The growth is specified as an isometric pattern, when the value of *b* is near to 3 ($b \approx 3.0$) but any significant difference from 3 designates allometric growth, where > 3 indicates positive and < 3 negative (Tesch, 1971). This study remained the value of *b* within 2.998 to 3.492 which was in the prospective limit for fish species stated by Froese (2006). The overall *b* value (b = 3.135) of our study showed positive allometric growth. The present findings are similar to the study of Sujansingani (1957) and Bhaumik et al. (2011) from Hooghly estuary (India), Al-Baz & Grove (1995) from Kuwait. Isometric growth pattern was stated by Amin et al. (2002) in Bangladesh, Bhakta et al. (2019) in Gujarat India and Mohamed et al. (2016) in Iraq. A negative allometric growth was observed by some other researcher including Rahman et al. (2000), Amin et al. (2004), and Rahman et al. (2018) in Bangladesh, Das et al. (2019), De & Datta (1990), Sarker et al. (2017) in India, Roomiani & Jamini (2011) in Persian Gulf, Iran. However, the growth pattern variation might be associated with several reasons fish health together with sex, food availability, gonad maturation, nitration, habitat suitability, seasonal environmental effect on habitat, preservation method and variations in the length ranges observation of captured fish samples (Hasan et al., 2020; Nima et al., 2021), which were not taken into account during this study.

Condition factors indicate the degree of well-being of a fish stock in their innate ecosystem. The higher value of condition factor indicates a better condition of fish species (Maurya et al., 2018). Information on condition of *T. ilisha* in the Meghna River is scant. K_F ranged from 0.7191 to 1.7098 in this study that indicates a healthy and favorable habitat for *T. ilisha*. Mandal et al. (2018) found 0.47-3.05 for combined population in fresh, estuarine and marine waters of India. Dutta et al. (2019) reported K_F 0.9-1.2 from the Sundarban estuary, Bay of Bengal, India. Lower value of condition may be attributed to lower sample size whereas the higher value is attributed to feeding intensity, environmental condition, maturity or spawning events (Mandal et al., 2018).

During the study, relative condition factor (K_R) evaluates the well-being status and productivity of *T. ilisha* in the Meghna River. Mean K_R value throughout the year indicated a balanced habitat for hilsa population. Overall K_R of our study was within 0.99-1.01 while Mandal et al., (2018) reported K_R value varied between 0.98-1.04 and Sarkar et al. (2017) observed it from 0.98 to 1.05 for *T. ilisha* from India. The present study found minimum and maximum K_R value in January and July, while Sarkar *et al*. (2017) stated in August and June in Hooghly estuarine system, India. K_R value may be higher during spawning season (Khan et al., 2001). The difference may have occurred due to gonad maturation, amount of undigested food in the alimentary canal and changes in amount of fat stored in body tissue (Hossain et al., 2017a). Smaller size specimens indicated the higher value of K_R as they have high feeding density. The value gradually decreases with increasing the length as gonadal development occurs. Mohanty and Nayak (2017) also indicated the same matter for *T. ilisha* in the Chilika Lake, India. Reuben et al. (1992) stated that an early stage of fish has higher K_R value. However, Welcome (1979) reported that condition factor in fish decreases with decreasing in size and is also influenced by the reproductive cycle.

The calculated form factor ($a_{3.0}$) was 0.0102 *T. ilisha* indicated fusiform or torpedo body shape (Froese, 2006). The form factor of this species has not been studied earlier. Therefore, it is difficult to compare the finding with other studies.

3.7. Conclusion

The study described the morphometric and meristic features, growth pattern through length-length and length-weight relationships, condition factors and form factor of *T. ilisha* from the Meghna River, SE Bangladesh. This study described fish health depending on the relative condition factor. The findings of this study will help to improve sustainable management policy of hilsa fishery in the Meghna River ecosystem and other adjacent water bodies.

Chapter 4

Study-II

STUDY-II

Estimation of physiological and prey-predator status of the Hilsa Shad, *Tenualosa ilisha* in the Meghna River of Southeastern Bangladesh

4.1. Abstract

The current study was on temporal variation of physiological and prey-predator status of *Tenualosa ilisha* (Hamilton, 1822) from the Meghna River, Bangladesh for the period of July 2018 to June 2019. A sum of 1433 individuals was collected, where its body weight (BW) and total length (TL) were measured with 0.01 g and 0.01 cm accuracy. Physiological status was determined using the equation provided as: $\bar{a} = W/L^b$. If $\bar{a}$ was close to the a value (a, LWR parameter) indicated the fish was in ideal condition, whereas $\bar{a} > a$ pointed to fatty fish and $\bar{a} < a$ to lean fish. The prey-predator status estimated through relative weight. The maximum fatty fish was found in the months of December (44%) while the minimum was in October. The highest percentage of lean fish was found in the month February (41%) and the lowest was in September (22%). The W_R indicated that the habitat was in stable circumstance for *T. ilisha*. The findings of the study will be helpful for consumer preference, further studies and also for the sustainable management of hilsa fishery in the Meghna River and other water bodies.

Key words: *Tenualosa ilisha*, physiological status, prey-predator status, Meghna River

4.2. Introduction

Tenualosa ilisha locally known as ilish, ilsha or hilsa (Shafi & Quddus, 1982) in Bangladesh. This euryhaline species found in marine, brackish and freshwater habitats occurring Bay of Bengal, Indian Ocean, Arabian Sea and Persian Gulf (Amin et al., 2005) covering the country Bangladesh, India, Sri Lanka, Iraq, Iran, Malaysia, Kuwait, United Arab Emirates, Pakistan, Oman, Sumatra, Saudi Arabia, Qatar, Thailand, and Viet Nam (Arai and Amalina, 2014; Freyhof, 2014). It is a commercially essential target species for large-scale fishers in Bangladesh and elsewhere in Asia. About 76% of global hilsa production is supported from Bangladesh while Myanmar, India and other country (Including Thailand, Iran, Malaysia, Iraq, Kuwait, Indonesia, and Pakistan) cover 15%, 4% and 5%, respectively (Islam et al., 2016). Tropical anadromous fish hilsa (Riede, 2004) often shows schooling behavior (Hossain et al., 2019) and migrate from the Bay of Bengal into inland freshwater primarily the Meghna, Tetulia and Andermanik rivers to spawn (Hossain *et al*., 2014). After developing into juveniles (locally known as *Jatka*) return to the open sea. The Meghna River ecosystem is major spawning grounds of hilsa from where found 18% of the total country hilsa production (Hossain et al., 2018).

Condition factor is an index which is used to understand survival, maturity, health status and reproduction of fish (Le Cren, 1951). Further, it is used as a primary determinant of water and overall well-being of a fish population dwelling in a specific ecosystem (Tsoumani et al., 2006). Physiological status of fish (*i.e*., ideal, fatty or lean) help to recognize the physiology of an individual fish species (Sutharshiny et al., 2013) which supports in fisheries management as well as in consumer preference. In addition, relative weight (W_R) is the most used indicator for assessing the status of fish in a specific ecosystem considering prey-predator status (Froese, 2006; Rypel and Richter, 2008).

A several studies have been conducted on *T. ilisha* on the basis of population biology (Amin et al., 2000; Halder et al., 2001; Amin et al., 2002; Halder and Amin 2005; Ahmed et al., 2008), exploitation status (Amin et al., 2008), stock assessment and management (Amin et al., 2004; Bhaumik, 2016; Rahman et al., 2018), Jatka fishing and sustainability (Rahman et al., 1995; Miah et al., 2000), weight-length relationship

(Dutta et al., 2012; Nima et al., 2020) etc. However, to the best of our consciousness, none of these studies covered the demographic information of growth pattern and physiological condition and prey-predator status of *T. ilisha*. Therefore, to describe the physiological and prey-predator status of *T. ilisha*, the present investigation was conducted in the Meghna River, southeastern (SE) Bangladesh using monthly data over one year.

4.3. Objectives

The aims of this study are to-

- Estimate the physiological status; and
- Determine the prey-predator status.

4.4. Materials and Methods

4.4.1. Sampling and Fish measurement

The present study was conducted in the Meghna River in Bangladesh during July 2018 to June 2019. A total of 1433 specimens were collected from commercial landing stations in Chandpur (23.23º, 90.63º) and Laxmipur (22.85º, 90.67º) region. In the laboratory, body weight (BW) as well as total length (TL) was assessed by electronic balance and measuring board with 0.01 g and 0.01 cm accuracy, respectively.

4.4.2. Calculation of physiological status

Individual physiological condition (*i.e.,* ideal, lean or fatty) for *T. ilisha* was estimated using an equation provided by King (2007) as: $\bar{a} = BW/TL^b$. If $\bar{a}$ is near to the a value (a is the LWR parameter), it points to the fish is in ideal condition, whereas variation from the a value is revealing of either fatty or lean fish ($\bar{a} > a$ point to fatty fish and $\bar{a} < a$ to lean fish).

4.4.3. Calculation of prey-predator status

The prey-predator status was estimated through relative weight (W_R): $W_R = (W/Ws) \times 100$ (Froese, 2006), where W is the BW of a specific individual and W_S is the anticipated standard weight for the identical specimen as assessed through $W_S = a \times L^b$, where a and b values were acquired from the relationships between TL and BW.

4.4.4. Statistical Analyses

The average relative weight (W_R) and 100 were compared through Wilcoxon signed rank test (Anderson & Neumann, 1996). All statistical analyses were implemented through GraphPad Prism 6.5 software in this study considering 5% significance level ($p < 0.05$). Before analysis similarity and normality of data were checked.

4.5. Results

The BW of *T. ilisha* was ranged 37.17–2250 g while and the smallest size was 15.3 cm in TL while the largest one was 57.8 cm in TL during the study period from the Meghna River.

4.5.1. Physiological status

In this study, the maximum proportion of fatty fish was found in December (44%). The percentage of fatty fish started to increase in April and continued until July. From August fatty fish were decreasing gradually and minimum in October. After November it gradually increased and continued until February. The maximum percentage of lean fish found in February (41%) and the lowest was in September (22%). The monthly deviations of physiological condition *i.e.*, ideal, lean or fatty for *T. ilisha* are given in Figure 9.

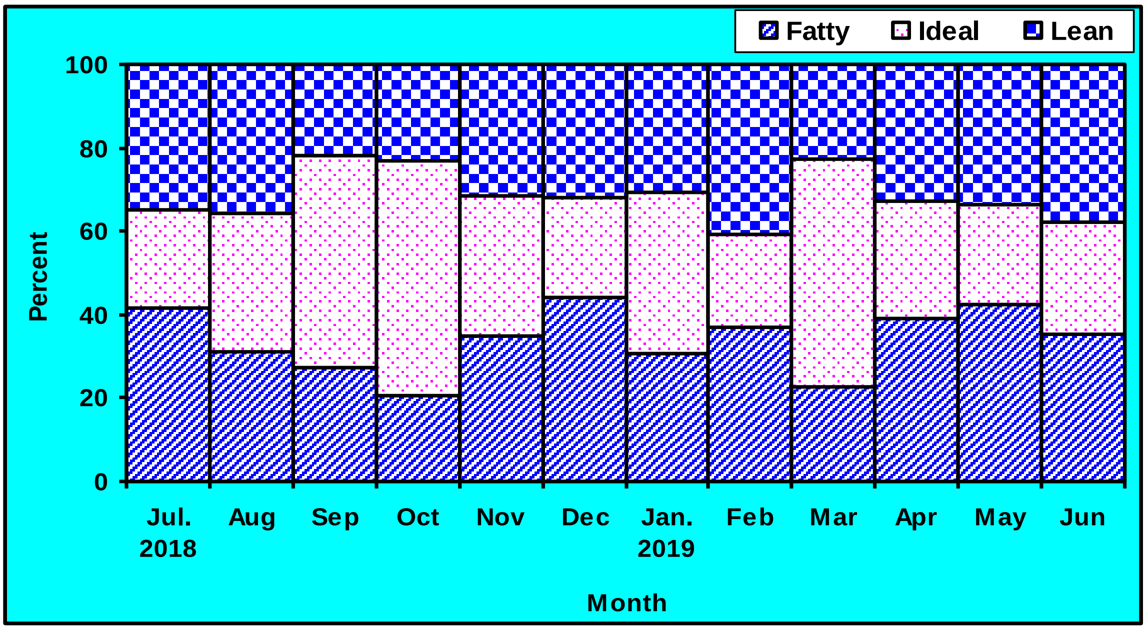


Figure 9. Monthly variation of physiological condition (*i.e.*, ideal, fatty or lean) for *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh.

4.5.2. Prey-predator status

Prey-predator status of *T. ilisha* was estimated through the relative weight (W_R) in the Meghna River, SE Bangladesh. The overall W_R value ranged from 65.05 to 166.06. Minimum recorded in December-January and maximum recorded in July (Table 15 and Figure 10). Mean W_R exposed no significant variances from 100 in the Meghna River through Wilcoxon rank test (p <0.0001) (Figure 11).

Table 15. Descriptive statistics on relative weight (W_R) and their 95% confidence limits of *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh.

Month	*n*	Relative Weight (W_R)			
		Min	**Max**	**Mean ± SD**	**95% CL**
July, 2018	72	73.95	166.06	100.44 ± 12.45	97.52 - 103.37
August	103	80.78	118.16	99.58 ± 8.47	97.93 - 101.24
September	120	83.60	117.67	100.67 ± 7.57	99.30 - 102.03
October	130	76.06	122.56	100.44 ± 10.02	98.70 - 102.18
November	124	84.29	116.66	100.74 ± 7.84	99.34 - 102.13
December	226	65.22	127.44	100.73 ± 12.61	99.07 - 102.38
January, 2019	72	65.05	118.29	99.68 ± 9.58	97.43 - 101.93
February	76	83.26	140.02	100.04 ± 8.93	98.00 - 102.08
March	35	90.36	114.30	100.28 ± 5.68	98.33 - 102.23
April	79	74.88	124.47	101.14 ± 11.79	98.50 - 103.78
May	209	75.44	122.43	100.07 ± 9.97	98.71 - 101.43
June	187	79.90	126.26	100.21 ± 8.64	98.96 - 101.45
Overall	1433	65.05	166.06	100.36 ± 9.91	99.84 - 100.87

Note: Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, Confidence Limit.

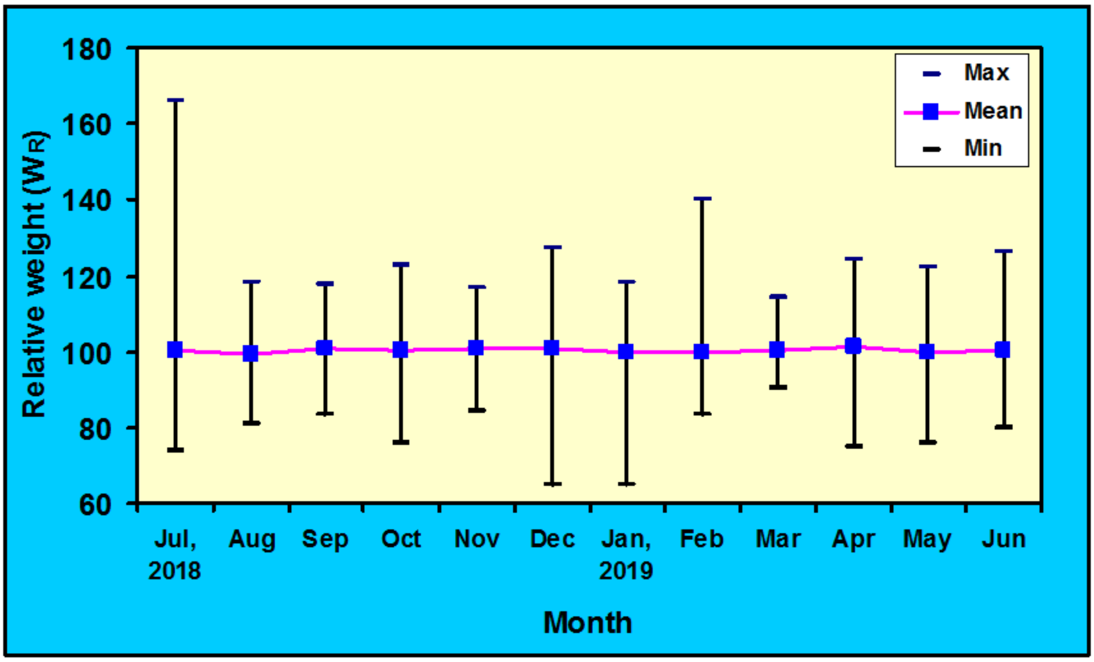


Figure 10. Monthly variations of relative weight of *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh.

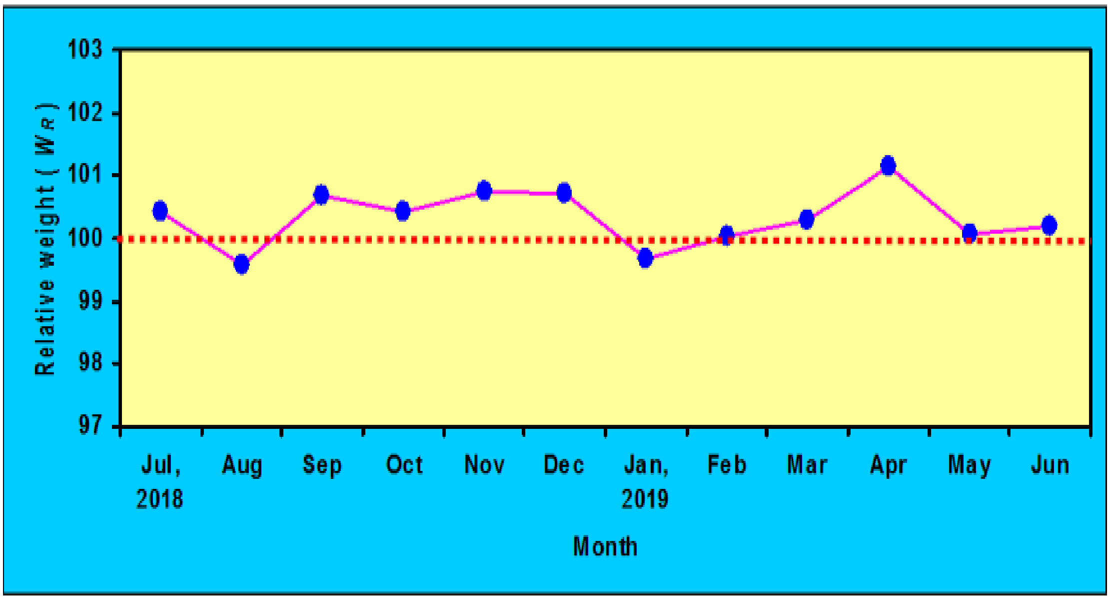


Figure 11. Prey-predator status through relative weight (W_R) of *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh.

Relative weight (W_R) significantly correlated with BW of *T. ilisha* in the Meghna river habitat, SE Bangladesh rather than TL (Table 16).

Table 16. Relationships of condition factor with body measurements (TL and BW) of *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh.

Relationships	r_s values	95% CL of r_s	*P* values	Significance
TL *vs.* W_R	0.2263	-0.0307 - 0.0759	0.3920	*ns*
BW *vs.* W_R	0.1530	0.1005 - 0.2047	<0.0001	****

Note: *ns*, not significant; ****highly significant

4.6. Discussion

A few studies have been done by various researchers on several aspects of Hilsa shad *T. ilisha*. However a study on physiological condition (*i.e.*, ideal, lean or fatty) and prey-predator status of Hilsa is not done by anyone. To fulfill the gap, the present investigation was done in the Meghna River, SE Bangladesh by collecting a large number of individuals covering different body lengths throughout the year. Absence of specimen smaller than 15.3 cm can be accredited of fishing gear selectivity or absence of smaller individuals throughout the sampling (Azad et al., 2020; Islam et al., 2020). In the study we found 57.8 cm which was more or less similar to the study (57 cm) of Rahman et al. (1999) & Amin et al. (2002) in Bangladesh and Al-Baz & Grove (1995) in Kuwait but smaller than the study (61 cm) of Amin et al. (2004) though Fishbase showed a maximum length of 60 cm (Forese & Pauly, 2021). All other studies (Bhaumik et al., 2011; Roomiani & Jamili, 2011; Sarker et al., 2017; Bhakta et al., 2019) found the body length was smaller than the current study. However, differences in body length may be ascribed to geographic distribution and influences of environment like temperature of water, availability of food etc. (Hossain et al., 2015; Hassan et al., 2020).

In the current study minimum number of fatty fish was found in October and lowest the percentage of lean fish was in September due to peak-spawning season (Rahman et al., 2012). The proportion of fatty fish began to raise in November and maximum fatty fish (44%) was found in December attributable to the resting phase after peak-spawning season. The maximum percentage of lean fish found in the month February (41%). Hossain et al. (2019) indicated that the abundance of juvenile hilsa was found during January to May in the river Meghna. A minor peak-spawning was also indicated in the February to April by Mathur (1964) and Moula et al. (1991). The proportion of fatty fish began to rise in April and continued until July. Juveniles became nourished in the Meghna River that is the largest nursery ground for hilsa and returned to Bay of Bengal with their parents (Hossain et al., 2019). Physiological status of fish may also be fluctuating for environmental effect on habitat, habitat changes, primary productivity, food availability or nutrition etc.

The W_R declining below 100 for a population indicates lower prey or a high level of predator activity; while above 100 indicate a surplus of prey or a poorer predator (Froese, 2006). In our study, the mean W_R have no significant variance from 100 specifying the habitation for *T. ilisha* populations was in balanced condition. We found no reference about the relative weight of *T. ilisha* elsewhere. Therefore, it is difficult to compare the finding with other studies.

4.7. Conclusion

The current study designated temporal variation of physiological and prey-predator status of *T. ilisha* from the river Meghna, Bangladesh. The findings will be cooperative for consumer preference as well as support in sustainable management of hilsa fishery in the Meghna river ecosystem and other adjacent water bodies.

Chapter

5

Study-III

STUDY-III

Reproductive Biology of the Hilsa Shad *Tenualosa ilisha* in the Meghna River of Southeastern Bangladesh

5.1. Abstract

The aim of the study was to explore various reproductive aspects (size at sexual maturity, spawning season and fecundity) of *Tenualosa ilisha* from the Meghna River, SE Bangladesh in relation to hydro-climatic variability and mostly importantly suggest various management approaches for sustainable management and conservation. A total 603 female specimens of *T. ilisha* were collected using Gill net and Bag net through January to December 2020. Body weight (BW) and total length (TL) of each sample was taken to 0.01 cm and 0.01 g accuracy by measuring board and an electric balance. The TL_{50} (the length at which 50% of specimens become matured) was calculated by using four models ((i) TL *vs.* Gonadosomatic index (GSI), Modified gonadosomatic index (MGSI) and Dobriyal index (DI) model, (ii) logistic model (iii) maximum length based model (L_{max}) and from the following three models, mean L_m was 26.10 cm. Based on monthly variation in GSI, MGSI and DI value, *T. ilisha* spawn all over the year with two peaks in October and April in the Meghna River. Macroscopic observations of gonads showed five maturity stages. Based on macroscopic features, Hilsa spawn throughout the year but highest percentages in October. The total fecundity (F_T) ranged from 65999 to 1575850. Fecundity was found to be highly correlated with TL and BW. Suitable temperature considered as 25-26°c for the spawning. Furthermore, mean air temperature is increasing by 0.029 °C y^{-1}, and rainfall is decreasing by 2.96 mm y^{-1}. The result will be supportive for the sustainable management and conservation of *T. ilisha* through setting permissible mesh size of fishing gear and rearrangement of existing ban period in the Meghna River, Bangladesh and adjoining ecosystems.

Keywords: *Tenualosa ilisha*, size at sexual maturity, fecundity, spawning season, environmental factors, management approaches

5.2. Introduction

The national fish of Bangladesh, *Tenualosa ilisha* belongs to the sub-family Alosinea of Clupeidae family (Riede, 2004). Hilsa is usually known as Ilish in Bangladesh, Ilisha, Ilishmach and Hilsa in India, Hilsa shad in Myanmar, Palo/ Pulla in Pakistan, Shour in Iraq, Ullam in Sri Lanka and Ca Chay in Viet Nam (Forese and Pouly 2021). It widely found in riverine, coastal, and marine habitats including Bay of Bengal, Persian Gulf, Arabian Sea, Vietnam Sea, Red Sea, and the river systems namely Padma, Meghna, Jamuna, Karnafuly, Pyra and other coastal rivers in our country; the Irrawaddy of Myanmar; the Indus of Pakistan; Euphrates and Tigris of Iraq and Iran; the Shatt-Al Arab; the rivers of India—namely the Ganga, Hooghly, Bhagirathi, Brahmaputra, Rupnarayan, Godavari, Tapti, Narmada, and other coastal rivers (Rahman et al., 2012). Hilsa is mainly a plankton feeder (Bhaumik, 2016). Hora (1938) recorded that hilsa fry (2.0-4.0 cm) mainly feed on copepods, diatoms, ostracods and daphnia and whereas; the younger hilsa (up to 10.0 cm) feed on polyzoa, insects and smaller crustaceans. *T. ilisha* is an anadromous, nutritionally, biologically, economically and socio-culturally exigent fish species in the Indo-Pacific region (Rahman et al., 2020). Hilsa shad species generate billions of dollars in the Bangladeshi economy and are the single most important fishery in Bangladesh (Islam et al., 2016). It contributes a lot of to the fish export earning of Bangladesh. The demand for this delicious fish is increasing day by day in domestic and abroad (Akter et al. 2007). The hilsa is a highly prized fish in Bangladesh and west Bengal of India (Hora, 1954). In Bangladesh and globally, this fish is considered to be of least concern (Freyhof, 2014; IUCN Bangladesh, 2015).

To protect hilsa from this degradation, some management policies have been taken by the Department of Fisheries (DoF) government of Bangladesh. First of all, they banned the catch, transport and storage of juvenile (Jatka) for a certain period of time in Bangladesh waters (MoFL 2014). Later, they banned the fishing of hilsa during peak spawning season (October) of this fish (MoFL 2017). This is the most important strategy to recover hilsa resources from destruction so the correct and pinpoint ban period is now the demand of time. In addition, Government of Bangladesh formulated a hilsa fishery management action plan (HFMAP) to revive the fishery. Brood fish will be protected during peak spawning season and juvenile will be after peak spawning season through establishing sanctuaries. Harmful gear will be eradicated, protection of migratory routes protection, control overfishing, and providing food incentives are also the main focused areas of HFMAP.

Fisheries management is successfully determined by a precise evaluation of biological factors such as reproduction (e.g., size at sexual maturity, spawning season, and fecundity), growth parameters and stock assessment (Sabbir et al. 2021b). Reproduction is a continuous developmental process throughout ontogeny, requiring energetic, ecological, anatomical, biochemical and endocrinological adaptations (Caputo et al., 2000). Information on fish reproduction is also important in aquaculture. It is an important factor to meet the requirement of continuous supply of food fish and fish seeds throughout the year (Cakici and Ucuncu, 2007).

Maturation size of fishes is extensively used as a sign of smallest allowable capture length (Lucifora et al. 1999). In addition, size at sexual maturity in fish is essential to determine the reason for variations in maturation size. Spawning season estimation is indispensible to conserve the adult specimens from extensive fishing (Templeman 1987). As part of fish biology, it's crucial to understand fecundity so we can better understand why fish populations fluctuate and how to improve our harvesting efforts (Akter et al. 2007). The fecundity can be expressed in a number of ways, such as total number of eggs produced by a female during the average life-span or number of ripening eggs in the female ovaries before laying (Shrivastava, 1999). The study of it's very essential to understand the population dynamics. It must be known to assess the reproductive potentialities of a fish stock (Lagler, 1956) and to understand reproductive strategy (Nazari et al., 2003).

Fisheries resources are at risk from environmental issues such as pollution as well as other hazards including overfishing, and contamination (Rose, 2005). Moreover, the first step in recognizing the relationships between population and environment, as well as identifying a fish population's vulnerabilities to climate change, is to evaluate the environmental and biological onsets of fish reproduction. (Khatun et al., 2019). Ecological parameters, largely temperature and precipitation, have continuous effects on fish reproduction (Shoji et al., 2011). Each stage of fish reproduction is controlled through temperature (Pankhurst and Porter, 2003). Fluctuations of temperature signify a vibrant arena to understand the reproductive potency of fish population in any habitat because of its direct effect on gametogenesis process and breeding timing (Pankhurst and Mundy, 2011). Moreover, larval assemblages can be monitored through the basic abiotic factor (temperature) of marine and freshwater species (Houde and Zastrow, 1993; Jakobsen et al., 2009). Similarly, rainfall is an additional essential reason prompting the total chain of hydrological events via river runoff (Patrick, 2016). Spawning rhythm of fish is frequently reduced due to lack of sufficient rainfall (Owiti and Dadzie, 1989). Rainfall aids fish spawning by lowering water temperatures and increasing dissolved oxygen levels. Besides, it stimulates natural spawning by offering available hydration for reproductively mature fish (Ahamed et al., 2018). Furthermore, numerous ecological parameters such as pH, salinity, dissolved oxygen, and photoperiod have a significant impact on the reproductive biology of fish in a specific aquatic habitat. To confirm inclusive fish reproduction, it is necessary to uphold an optimal DO (dissolved oxygen) level for metabolic activities. Alternatively, pH indicates whether a certain habitat is acidic or alkaline. The higher the pH level (9-14), the more it influences fish physiology by denaturing cell membranes and affecting several indicators of any aquatic habitat (Brown and Sadler, 1989).

There are a very few studies that provide some information on the reproductive aspect of *T. ilisha*. Hence, it is the first study from the Meghna River and also observed the effect of environmental and hydrological parameters on the reproduction of *T. ilisha*.

5.3. Objectives

The main purpose of this study is to-

- Determine the size at first sexual maturity;
- Estimate the spawning and peak spawning season;
- Identify the effect of environmental factors on the GSI.

5.4. Materials and Methods

5.4.1. Fish measurement

This study was conducted based on female individuals only. Male and female individuals were identified by microscopic observation of gonads. Bodyweight (BW) and total length (TL) of each individual were weighed with 0.01 g and 0.01 cm precision using electric balance and measuring board. Subsequently, ovaries (gonads) were removed carefully through dissection of the ventral side and weighed (GW) to the nearest 0.01 g precision. Further, the gonads were examined microscopically to distinguish the maturity status of fish specimens.

Plate 8. Dissecting, gonad separation, and weighing of gonad for *T. ilisha* from the Meghna River, southeastern Bangladesh in the laboratory.

5.4.2. Size at first sexual maturity (TL_m)

The TL_m was determined with three indices (i) gonadosomatic index (GSI) *vs.* TL; (ii) modified gonadosomatic index (MGSI) *vs.* TL; and (iii) Dobriyal index (DI) *vs.* TL. The Gonadosomatic index was measured using the equation: GSI (%) = (GW/BW) × 100 (Nikolsky, 1963). Modified gonadosomatic index was determined by the equation: MGSI (%) = (GW/BW-GW) × 100 (Nikolsky, 1963). Dobriyal index was calculated by the equation: DI= $\sqrt[3]{GW}$ (Dobriyal et al., 1999). Furthermore, specimens with GSI equal to or greater than the crucial GSI value (GSI at lowest length during sexual maturity) were nearly identified as mature female *T. ilisha* (Fontoura et al., 2009; Hossain et al., 2012b; Rahman et al., 2018b).

Moreover, TL_{50} indicated the smallest length cessation wherein 50% of the total specimens were matured. To analyze the data for TL_{50}, a logistic curve based on King (2007) was used to plot the proportion of mature people (PMI) against TL class as PMI= 100/[1+ exp{-f (TL_m -TL_{50})}] where, f is the growth coefficient and TL_m is the median value of each TL class. However, all individuals that are mature in a fish stock do not complete the breeding cycle simultaneously. Consequently, even in the largest TL class, the PMI was less than 100 percent. Therefore, the data were adjusted to overcome an unnecessarily high estimate of TL_{50}, using the well-known principle of King (2007).

5.4.3. Spawning season

Spawning season was determined through monthly observation of gonadal changes. Subsequently, spawning and peak spawning season were assessed using GSI, MGSI and DI. Stages of gonad maturation and seasonal gonadal development were documented by gross morphological (physical) investigation of gonads. Maturation phases were identified based on macroscopic appearances according to the gradation of opaqueness of ovary, steadiness and vascularization, and overall gonad coloration (Kesteven, 1960; Lagler, 1978; Shinkafi et al., 2011; Nath, 2013).

5.4.4. Fecundity

According to Murua et al. (2003) total fecundity (F_T) was estimated by gravimetric method. The relationships within fecundity, total length and body weight were done by, $F_T = m \times (TL)\ n$ (non-linear) and $F_T = m + n \times (BW)$ (linear regression), where m and n are the parameters of regression analysis.

5.4.5. Environmental factors

To assess the impact of environmental variables on *T. ilisha* GSI, water quality parameters [water temperature (^{o}C), dissolved oxygen (DO; mg/L) and pH] were collected monthly from the sample sites using APHA (2005) methodology. Throughout the sampling months, a fixed sampling hour (9.00 - 10:00 a.m.) was maintained to ensure that the collected parameters were identical over time and location. Further, monthly data on average temperature (^{o}C) and rainfall (mm) were collected from the meteorological station of Dhaka, Bangladesh.

5.4.6. Statistical Analyses

GraphPad Prism 6.5 software was used for statistical analyses with a significance level of 5%. The Kolmogorov-Smirnov test was applied to confirm the similarity of data set. A chi-square test was used to see that the sex ratio deviated from the expected value of 1:1. (male: female). Furthermore, a Spearman rank test was used to correlate environmental factors with GSI in order to determine the impact of environmental influences on gonadal maturity and spawning.

5.5. Results

A total 603 female specimens were collected from January to December 2020, where total length (TL) was extended from 18.5 to 55.5 cm and the BW varied from 65.26–1800 g. Besides, gonad weight (GW) ranged between 0.70 to 162.63 g (Table 17).

Table 17. Descriptive statistics on the total length, body and gonad weight measurements of female *Tenualosa ilisha* in the Meghna River, SE Bangladesh.

Characters	Min	Max	Mean ± SD	95% CL
Total length; TL (cm)	18.50	55.5	32.78 ± 7.26	32.20 - 33.36
Body weight; BW (g)	65.26	1800.0	452.85 ± 283.60	430.16 - 475.53
Gonad weight; GW (g)	0.70	162.63	35.09 ± 30.71	32.60 - 37.57

Min, minimum; Max, maximum, SD, standard deviation; CI, confidence limits.

5.5.1. Sex ratio

All together 1223 (male = 669, Female = 603) specimens were collected for the study. The overall sex ratio differed statistically (male: female = 1.11:0.90) from the predicted 1:1 ratio. Further, the monthly sex ratio indicated that males were dominated in August and maximum female fish were found in November (Table 18, Figure 12).

5.5.2. Size at first sexual maturity (TL_m)

For the estimation of size at sexual maturity used four models such as (i) TL vs. GSI, MGSI and DI model, (ii) logistic model (iii) Maximum length based model. According to the following four models, the mean L_m was 25.00-27.50 cm (26.10 cm) in the Meghna River (Table 19, Figure 13-14).

Table 18. Monthly sex ratio (male: female = 1:1) of *Tenualosa ilisha* from the Meghna River, southeastern Bangladesh.

Month	Number of specimens Male	Female	Total	Sex ratio (M : F)	χ^2 (df=1)	Significance
January	65	48	113	1.35 : 0.74	2.56	*ns*
February	57	47	104	1.21 : 0.82	0.96	*ns*
March	58	43	101	1.35 : 0.74	2.23	*ns*
April	61	48	109	1.27 : 0.79	1.55	*ns*
May	60	44	104	1.36 : 0.73	2.46	*ns*
June	51	56	107	0.91 : 1.10	0.23	*ns*
July	56	50	106	1.12 : 0.89	0.34	*ns*
August	74	40	114	1.85 : 0.54	10.14	*
September	45	61	106	0.74 : 1.36	2.42	*ns*
October	63	39	102	1.62 : 0.62	5.65	*
November	25	77	102	0.32 : 3.08	26.51	*
December	54	50	104	1.08 : 0.93	0.15	*ns*
Overall	669	603	1272	1.11 : 0.90	3.42	*ns*

df, degree of freedom; *ns*, not significant; * significant at 5% level ($\chi^2 > \chi^2_{t\ 1,\ 0.05}$ = 3.84).

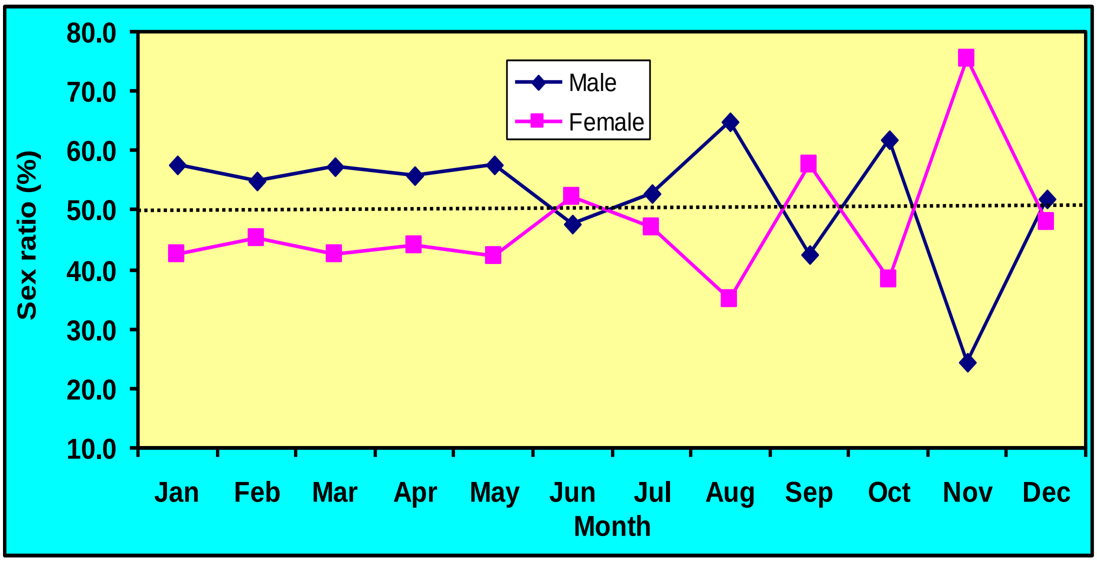


Figure 12. Sex ratio of Tenualosa ilisha from the Meghna River, southeastern Bangladesh

Table 19. Calculation of size at sexual maturity of *Tenualosa ilisha* from the Meghna River, southeastern Bangladesh

Methods	Size at sexual maturity (L_m) (cm)
Maximum length based	25.43 (19.43 - 33.03)
GSI based	26.50
Logistic models based	27.50
Mean	26.10

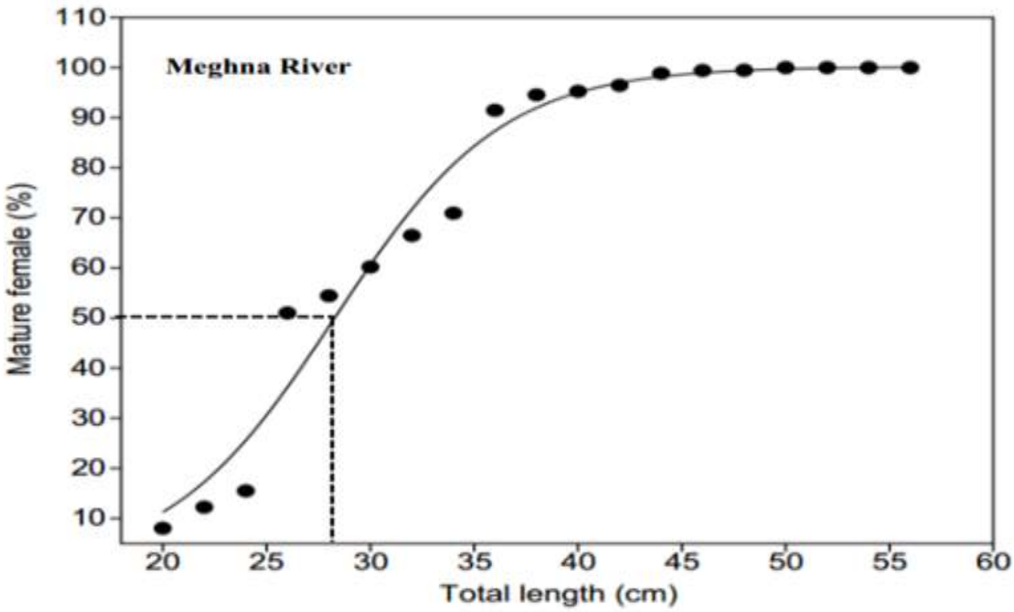


Figure 13. The logistic curve fitted to the data shows the adjusted percentage of mature females of *Tenualosa ilisha* versus total length.

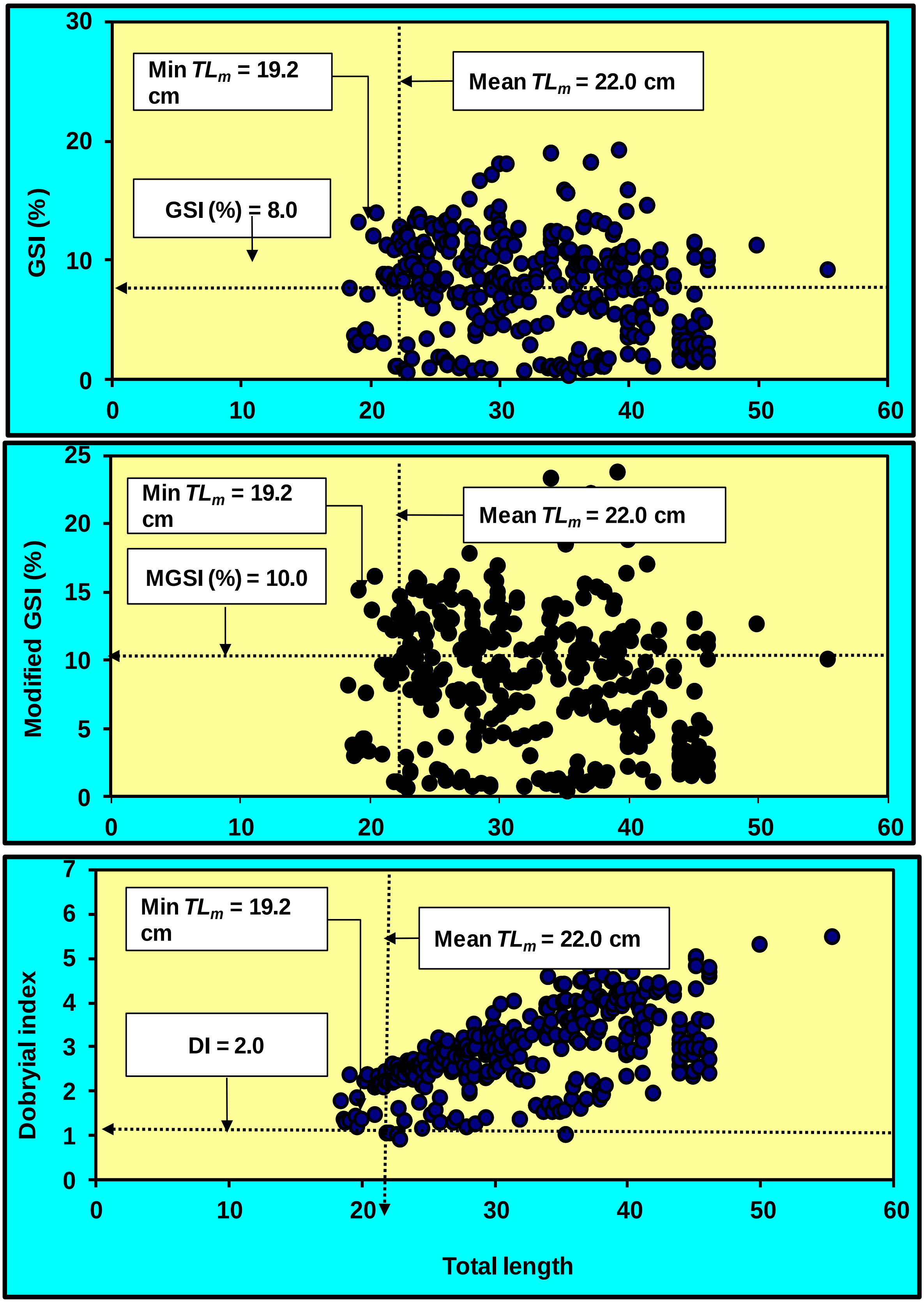


Figure 14. Relationship between gonadosomatic index (GSI), Modified gonadosomatic index (MGSI) and Dobriyal index (DI) with total length of *Tenualosa ilisha* in the Meghna River, southeastern Bangladesh.

5.5.3. Microscopic observation of gonad and Spawning season

Five maturity stages were identified using macroscopic examination (Plate 9). Developing condition of female gonad was found throughout the year except December. The highest mature gonads were detected in October and the lowest was in May. Spawning season can be determined through spawning individuals based on fish gonads with successively or partly spent and spent phases (Figure 15).

According to variation in GSI, MGSI and DI spawning were observed throughout the year with two peaks in October and April from the Meghna River. Monthly variations of GSI for female *T. ilisha* from three unit stock were represented in Figure 16.

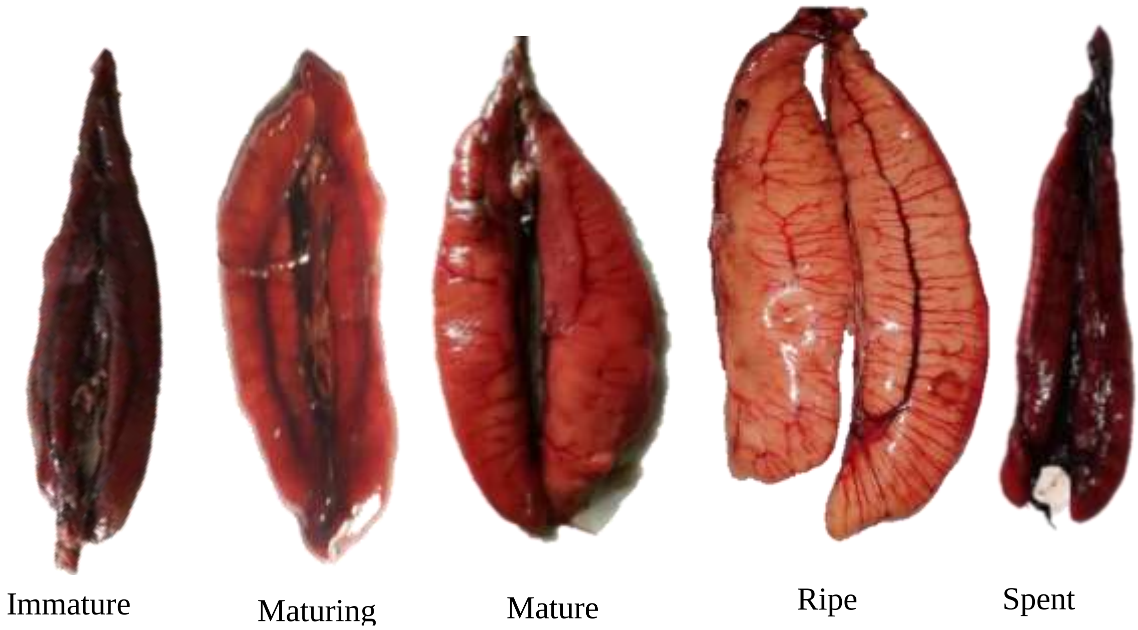


Plate 9. Five maturation stages of gonad of female *Tenualosa ilisha* from the Meghna River, SE Bangladesh.

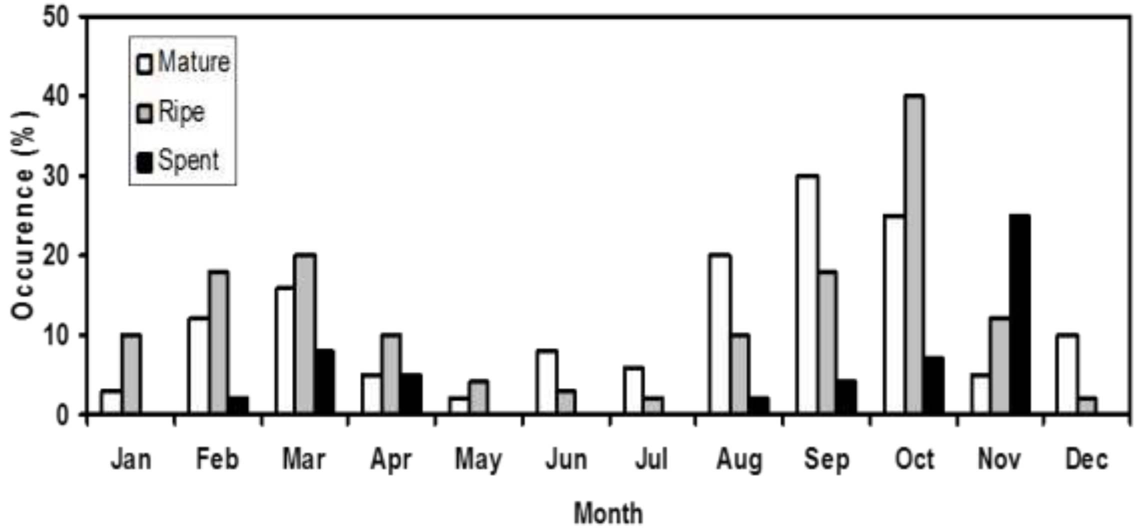


Figure 15. Sequential variations in the existence of spawning maturation phases of *Tenualosa ilisha* from the Meghna River, southeastern Bangladesh.

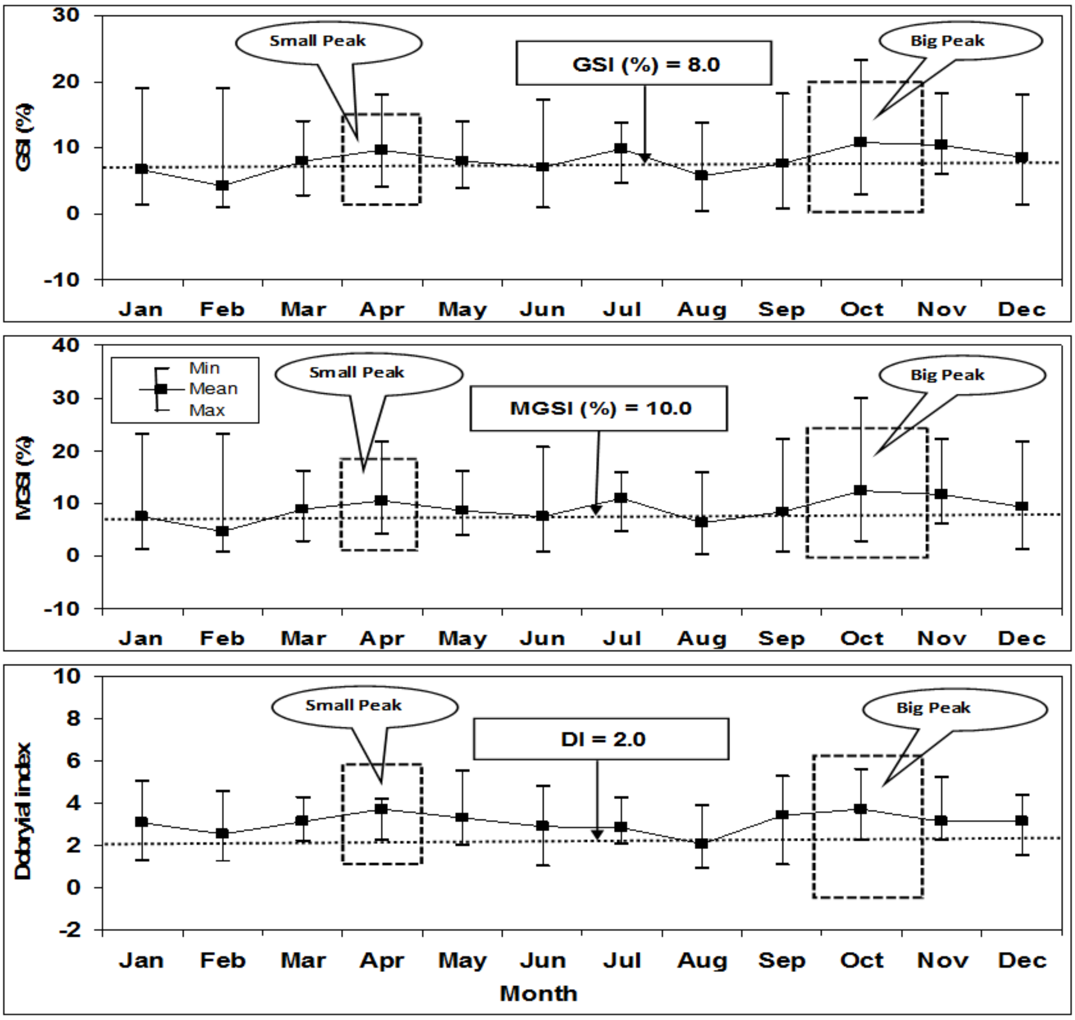


Figure 16. Monthly variations of gonadosomatic index (GSI), Modified gonadosomatic index (MGSI), Dobriyal index (DI) with maximum and minimum values of female *Tenualosa ilisha* in the Meghna River, southeastern Bangladesh.

5.5.4. Fecundity

Around 30 female specimens were used to assess the fecundity of *T. ilisha*. The total fecundity ranged from 65999 to 1575850 (719705 ± 399226) for the Meghna River. Significant relationship was documented between fecundity *vs.* TL, and fecundity *vs.* BW (Table 20). Also, significant linear correlations were found for natural log *(ln)* transfer of F_T -*TL*, F_T –*BW* (Figure 17).

Table 20. Relationships of fecundity with TL and BW of *Tenualosa ilisha* from three different unit stocks in Bangladesh

Correlation	r_s value	95% CL of r_s	*p* value	Significance
F_T *vs*. TL	0.951	0.898 - 0.976	< 0.0001	****
F_T *vs*. BW	0.933	0.863 - 0.968	< 0.0001	****

r, Spearman rank correlation values; CL, confidence limit.

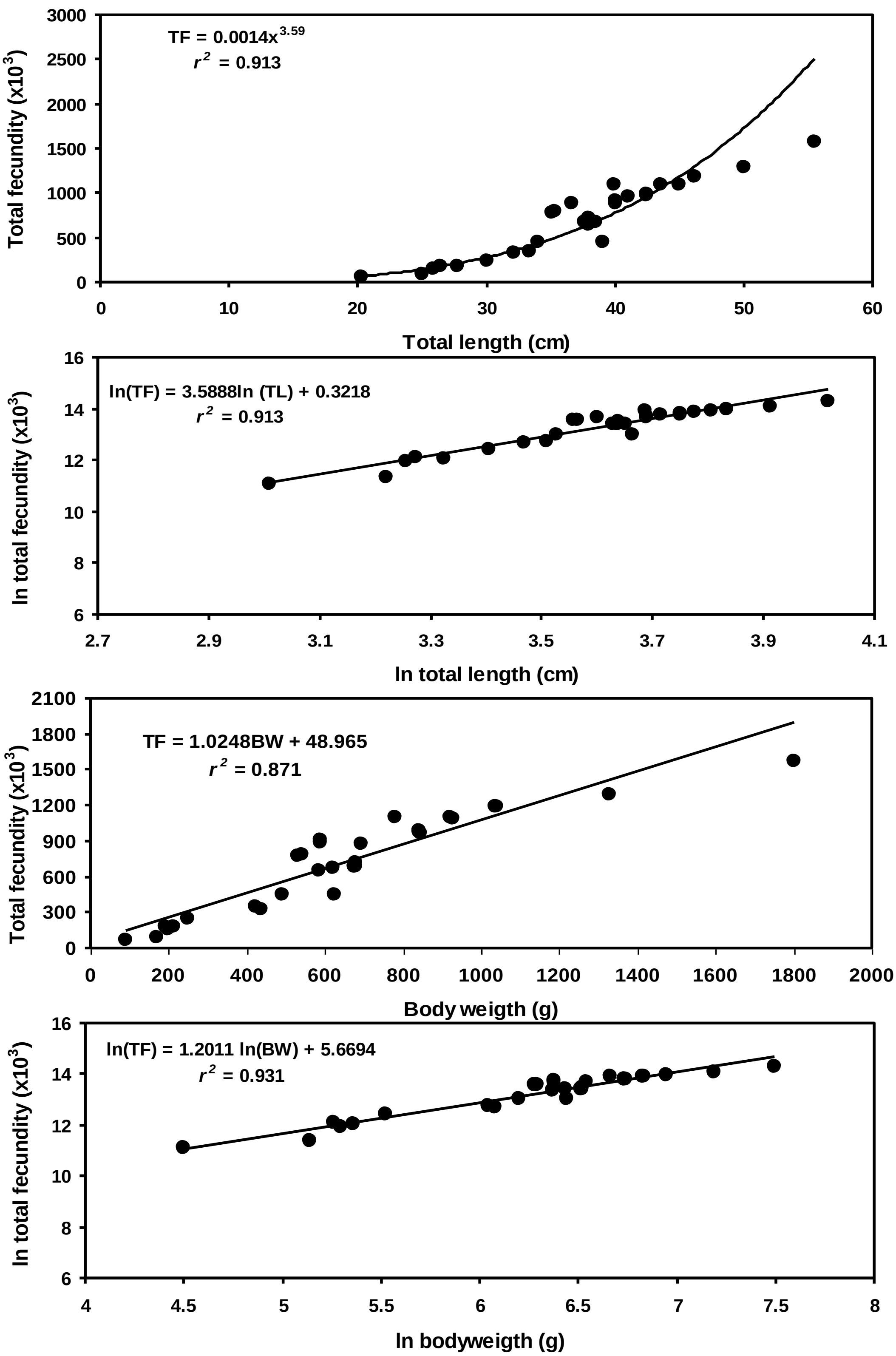


Figure 17. The relationships between (i) total length *vs.* fecundity (ii) body weight *vs.* fecundity (iii) ln total length *vs.* ln fecundity (iv) ln body weight *vs.* ln fecundity of of *Tenualosa ilisha* in the Meghna River, southeastern Bangladesh.

5.5.5. Environmental factors

Relationships between GSI and hydrological parameters (temperature, DO, pH, TDS and total alkalinity) and climate parameters (air temperature and rainfall) were given in Table 21. According to the GSI value, 25-26º C temperature was considered as suitable for the spawning of Hilsa from the Meghna River that was observed in October. So, water temperature has an impact on their spawning as October is their peak spawning period (Figure 18).

A long data series (1964 to 2018) of air temperature and of rainfall were organized to detect its variation over time. Yearly mean air temperature is increasing by 0.029 °C y^{-1} (r^2 = 0.350), and rainfall is decreasing by 2.96 mm y^{-1}(r^2= 0.018). (Figure 19).

Table 21. Relationship between environmental factors with GSI of *Tenualosa ilisha* in the Meghna River, SE Bangladesh.

Relationship	r_s value	95% CL of r_s	*p* values	Significance
Water Temperature *vs.* GSI	-0.5344	-0.8482 to 0.0571	0.0735	*
Air Temperature *vs.* GSI	-0.3916	-0.7956 to 0.2535	0.2097	ns
Rainfall *vs.* GSI	-0.5541	-0.8559 to 0.0292	0.0616	ns
DO *vs.* GSI	0.3891	-0.2381 to 0.7873	0.2113	ns
pH *vs.* GSI	-0.1543	-0.6690 to 0.4605	0.6322	ns
TDS *vs.* GSI	0.3886	-0.2387 to 0.7870	0.2120	ns
Salinity *vs.* GSI	0.5362	-0.0546 to 0.8489	0.0723	ns
Resistivity *vs.* GSI	-0.6729	-0.8995 to -0.1611	0.0165	*
Conductivity *vs.* GSI	0.6112	0.05730 to 0.8774	0.0347	*

Note: GSI, Gonadosomatic index; DO, Dissolved Oxygen; TDS, Total Dissolved Solid; r_s, Spearman rank correlation values; CL, confidence limit; *p*, level of significance; *ns*, not significant; * significant ($p \leq 0.05$).

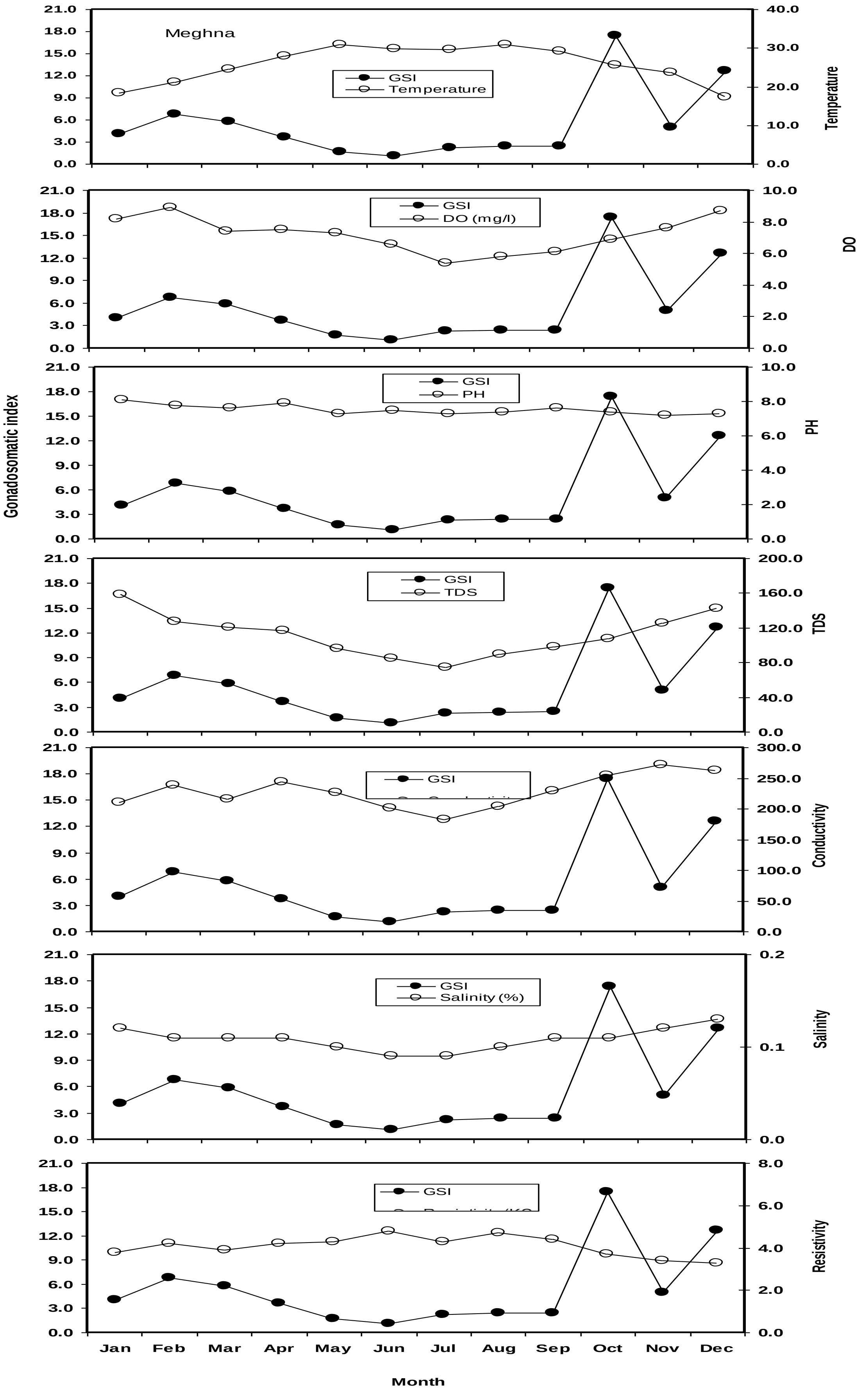
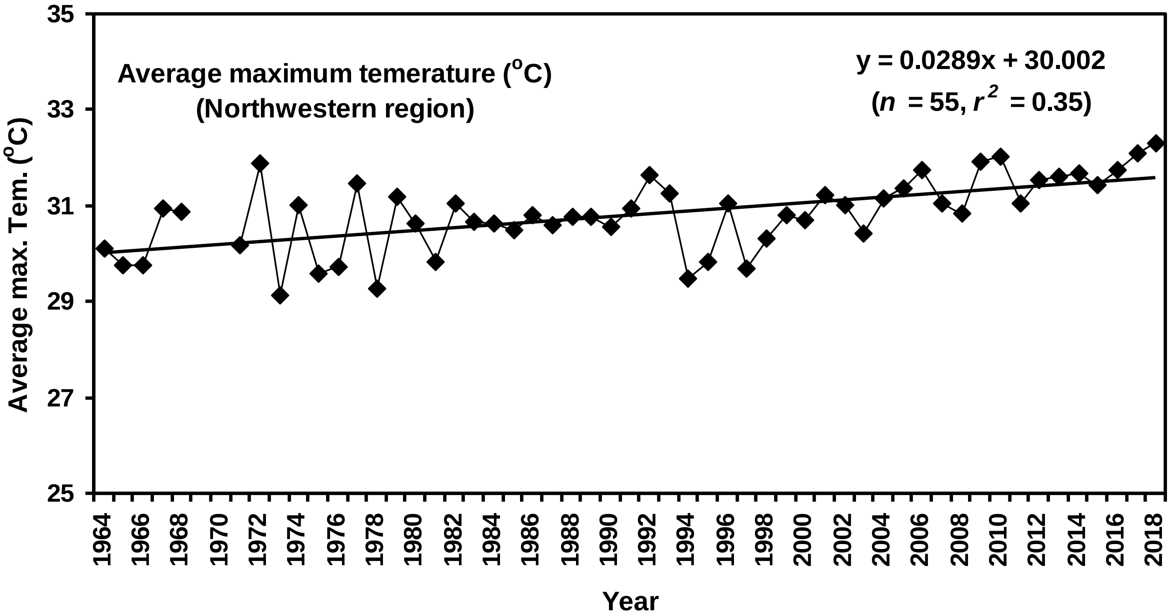


Figure 18. Relationship between Gonadosomatic index (GSI) with environmental factors of female *Tenualosa ilisha* in the Meghna River, SE Bangladesh.



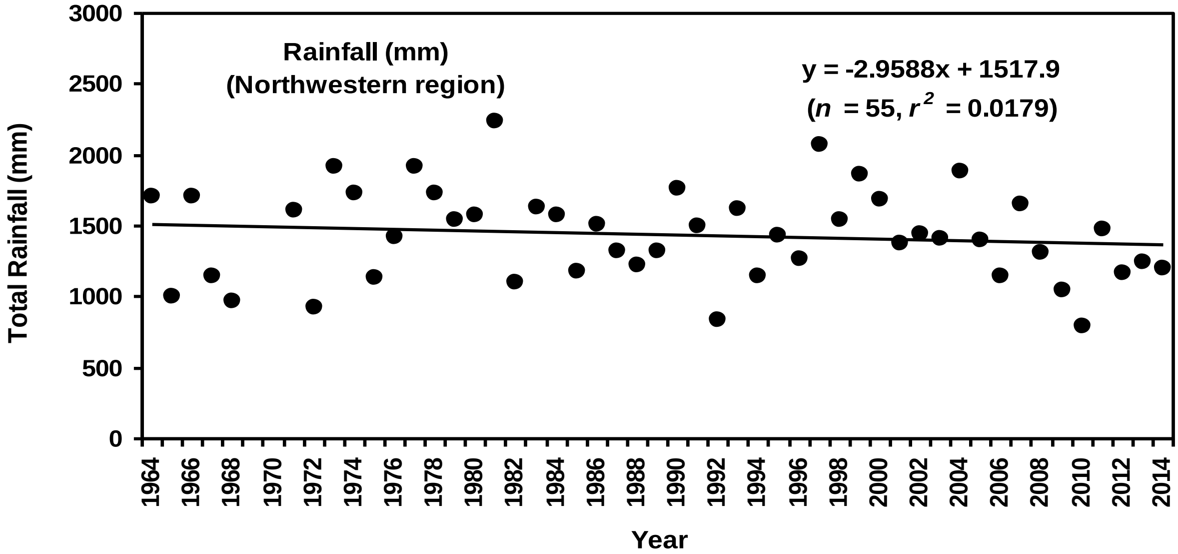


Figure 19. Annual average maximum temperature (°C) and rainfall (mm) in the southeastern region, Bangladesh during 1964 to 2018.

5.6. Discussion

Suitable management of fish stocks is significantly subjected to careful assessment of the maturity status (Rahman et al., 2018b). Where histological observation facilities are scarce, different macroscopic and biological indexes are normally used as a rather cost- effective and easy technique for relating ripeness status of fish (West, 1990; Khatun et al., 2019). Further, GSI was used effectively by a good number of researchers to assess the maturity status of fish (Fontoura et al., 2009; Hossain et al., 2012b, 2017b; Rahman et al., 2018b). Understanding of reproductive consequence is vital to evaluate the life history of any fish stock (Hossain et al., 2017b). There is no available work which was to study the biological aspect of *T. ilisha* in relation to hydro-environmental variability in three different unit stock in Bangladesh and most importantly also suggest the sustainable management approaches for its conservation at a time in a single work.

Determining length at first sexual maturity (TL_m) is critical simultaneously for distinguishing between several populations of an fish species and for anticipating a basis that ultimate variations in first maturation length are due to fishing pressure or other causes (Hossain et al., 2010b). Further, it is crucial for fisheries biologists to manage and conserve a particular fish stock in any aquatic ecosystem (Lucifora et al., 1999). Length at maturity is a key population parameter that is enormously vital in the fisheries management of exploited stocks (Sabbir et al., 2021a). According to Beverton and Holt (1957), to maintain the stock biomass, fish should be allowed to reproduce at least once before being captured (Trippel 1995).In the present study, we used four models (GSI, MGSI, DI *vs*.TL, logistic, and L_{max}) for the estimation of L_m. From the three models the mean value of L_m was 26.10 cm (TL) in the Meghna River, Bangladesh. Previously L_m was estimated in twenty water bodies worldwide where the lowest value 18.00 cm recorded from Iraq (Almukhtar et al. 2016) and highest value was 43.00 cm recorded from Godavari river, India (Rajyalakshmi, 1973). Further, the study denotes the first extensive information on sexual maturity of *T. ilisha* that could be supportive for determining the mesh size to limit catching smaller mature individuals to make available them for breeding (Rahman et al., 2018b).

Spawning period is very momentous for the migration of fishes for spawning purposes and for the estimation of spawning time (Wilding et al., 2000). In this research, according to the variation of GSI value the spawning season of *T. ilisha* was throughout the year with two peaks in October and April from the Meghna River. Previously the spawning season of *T. ilisha* was estimated in fifteen worldwide water bodies and their findings were similar to this as they observed the spawning season was throughout the year except the finding of Narejo et al. 1999 (July-August), Milton, 2010 (July-November and February-May), Panhwar et al. 2011 (May-October), and Almukhtar et al. 2016 (March-November) from Indus River, Pakistan, BoB, Bangladesh River Sindh, Pakistan and Shatt al Arab River, Iraq, respectively. However, this difference may be ascribed to population densities, water temperature, environmental influences, rainfall, food availability and seasonality (Mitu, 2017; Khatun et al., 2019).

The estimation of the fecundity and explanation of reproductive strategies are essential topics in population dynamics, fish physiology and biology (Hunter et al., 1992). Fecundity is an essential feature in fishes to comprehend differences between population size as well as relevant to fisheries management (Rahman et al. 2018). In the current study, fecundity of *T. ilisha* the total fecundity ranged from 65999 to 1575850 in the Meghna River. In addition, previously fecundity of *T. ilisha* was estimated in twenty-five water-bodies in Bangladesh and other countries. Among them the lowest fecundity was 30097-92070 found in Ukai reservoir, India (Bhaumik et al. 2013) and highest was 1500000-2000000 also recorded in BoB, Bangladesh (Miah, 2015). Probably this difference occurred because fishes live under different conditions as well as to great extent upon nutrition, variation in stock (Ruzzante et al., 1998) and differences in methodological technique used for fecundity assessment (Alonso-Fernández et al., 2009). According to Dulcic et al. (1998) when the size distribution of a fish stock is known, the relationship between size and fecundity is used as a fast means of estimating fecundity. In our study, significant correlations were observed between F_T *vs.* TL and F_T *vs.* BW for *T. ilisha*. Akter et al. (2007), Mondal et al. (2008) and Almukhtar et al. (2016) have also reported positive correlation of fecundity with body weight and total length for *T. ilisha* from Padma, Patuakhali, Bangladesh and Shatt Al Arab River, Iraq, which strongly support our findings. Whereas, Islam and Talbot (1968) observed no close relation between total length and body weight from Indus River.

Marine and estuarine fisheries are already being impacted by global climate change. (Klyashtorin 1998; Loukos et al. 2003; Guisande et al. 2004; Roessig et al., 2004; Lloret et al. 2004). In the current study, we observed 25-26 ºC temperature was suitable for the spawning of Hilsa in Meghna River. This temperature is considered as optimum temperature for Hilsa spawning and this temperature remains in October which is the peak spawning season for Hilsa population. Through the long data series of climatic factor (air temperature and rainfall) from 1964 to 2018 and observed that average annual air temperature was increasing by 0.029 °C y^{-1} while rainfall showed reducing trend by 2.96 mm y^{-1} which worryingly envisage the shifting of spawning period for *T. illisha* in Bangladesh. Also, increase of air temperature has impact on ecosystem and hilsa fishery such as changes in ecosystem, blockage of migratory route and high turbidity of water (Mahmud, 2020).

5.7. Conclusion

The length at sexual maturity of *T. ilisha* was established to fix suitable capture size, thus providing them opportunity for breeding. The spawning season of *T. ilisha* in the three unit stocks was confirmed through several methods and from this we highly recommended to rearrange the banning period to ensure the protection of mother hilsa. Additionally, the long data series on climate change indicated that temperature is rising and rainfall is decreasing day by day. From this we can predict that after 20 years the spawning season might be shifting that must be taken into attention for the well sustainability of *T. ilisha* in Bangladesh and surrounding countries.

Chapter

6

Study-IV

STUDY-IV

Growth Modeling of the Hilsa Shad *Tenualosa ilisha* in the Meghna River of Southeastern Bangladesh

6.1. Abstract

The present study describes ages and growth parameters, and recruitment of *T. ilisha* using monthly length-frequency distributions. Growth parameters were estimated through the von Bertalanffy equation. In total, 1272 specimens ranging from 15.3 to 55.5 cm in total length (TL) were collected from the Meghna River southeastern Bangladesh from January to December 2020. Results revealed that the growth parameters of *T. ilisha* was the von Bertalanffy model as L_t = 57.62 (1-exp(-1.13(t-0.009))). The estimated L_∞ = 57.62 cm, K = 1.13 y^{-1}, W_∞ = 2024.6 g, t_0 = 0.009, t_{max} = 4.17 year. The overall growth-performance index ($Ø'$) was 3.38. In addition, the age of *T. ilisha* was estimated as 3.10 years. Scientists and conservationists will be able to establish early management methods and policies based on the findings of this study of *T. ilisha* to ensure long-term survival in the Meghna River and its adjacent ecosystems.

Keywords: Growth parameters, von Bertalanffy, *Tenualosa ilisha*, Meghna River, Bangladesh

6.2. Introduction

The Hilsa shad, *Tenualosa ilisha* (Hamilton, 1822) is a large scale targeted fish species in the Meghna River, southeastern region of Bangladesh that widely distributed in Bangladesh, India, Srilanka, Pakistan, Iraq, Iran, Kuwait, etc. The length-frequency distribution (LFD) is an important biological metric for recognizing the progressive rates of growth, recruitment, mortality, and biomass in a specific habitat through mathematical manner (Beverton and Holt, 1979; Neuman and Allen, 2001). Nevertheless, knowledge on growth, recruitment, mortality, exploitation rate and maximum sustainable yield is important for developing such models (Hossain et al., 2017a). As an aquatic organism, fish growth mostly is influenced by gender, maturation and environmental influences (Sabbir et al., 2021b). Fish with a fast growth rate possesses advantages in a variety of ways. Fast growth not only gives the fish protection from predators, but it also helps them to carry huge numbers of eggs, resulting in larger eggs with better chances of survival for the larvae. (Hossain et al. 2017a).

Asymptotic length (L_∞), growth coefficient (K), maximum reported age (t_{max}), and age at zero length (t_0) is essential for constructing ecosystem models (Froese & Binohlan, 2000). Apart from that, these criteria permit to assess the life-history traits and preliminary findings of assessed parameters from earlier ones are attainable (Stergiou & Karachle, 2006). Rapid growth rate is beneficial in many ways, for example, it usually suffers fewer predation than smaller ones. In addition, recruitment and growth have outstanding consequences to maintain maximum sustainable yield of a fish stock (Ahmed et al., 2012).

Present study describes the age and growth patterns of hilsa shad, *T. ilisha* by studying the length data of collected samples over a 12-month period from southeastern region of Bangladesh in the Meghna River.

6.3. Objectives

The aims of this study were-

- To estimate the growth parameters *i.e.*, growth coefficient, age at 0, age at maturity
- Measure the life span, longevity, and growth performance index.

6.4. Materials and Methods

6.4.1. Sampling and measurement

Monthly samples of *T. ilisha* were collected from the Chandpur to Lakshmipur during January to December 2020 using traditional fishing gears including gill nets, seine nets, etc. Total length (TL) was estimated by a measuring board nearest to the 0.01 cm. For body weight (BW), an electric balance to the precision of 0.01 g accuracy was used for each individual.

6.4.2. Length-Frequency Distribution (LFD)

In the multiple samples method, the length-frequency distributions (LFDs) from collected samples at different times were organized sequentially one after one according to the sampling dates and the modes of a single cohort were drawn as they progressed along the length axis. The ages of mode of a single cohort or all cohorts were assessed from the spawning date (Hossain and Ohtomi, 2010). The growth, therefore, was assessed using monthly length-frequency data. LFD for *T. ilisha* with 1 cm interval were constructed for each sample. It was necessary to create a file containing LFD data with a stable class size.

6.4.3. Growth parameters based on length, Life span, Growth performance index and Longevity

The growth parameters of *T. ilisha* from the Meghna River were estimated through the length based model of von Bertalanffy-

$$L_t = L_\infty \, [1\text{-exp}\{-K\,(t\text{-}t_0)\}]$$

where, L_t is the TL (cm) at age t (month), L_∞ is the asymptotic TL (cm), K is the growth coefficient (year^{-1}), and t_0 is the hypothetical age when the TL would be zero. (von Bertalanffy, 1938).

The largest observed length from collected specimens was used to determine the asymptotic length (L_∞) through-

$$\log(L_\infty) = 0.044 + 0.9841 * \log(L_{max})$$ (Froese & Binohlan, 2000)

The L_m of *T. ilisha* was calculated based on observed largest TL through-

$$\log (L_m) = -0.1189 + 0.9157 * \log (L_{max}) \text{ (Binohlan \& Froese, 2009)}$$

The t_0 was estimated by employing the equation of King (2007)-

$$t_0 = t+1/K (\ln [(L_\infty - L_1 / L_\infty])$$

Growth patterns of BW for *T. ilisha* was also modeled by fitting the von Bertalanffy equation to the mean BWs at ages-

$$W_t \equiv W_\infty (1 - \exp(-k(t - t_0)))^3 \text{ (von Bertalanffy, 1938)}$$

Where, W_t is BW (g) at age t (year), W_∞ is asymptotic body weight, k is growth coefficient, t is age and t_0 is the theoretical age at zero weight. BWs of both at each age group were calculated from their corresponding mean TLs using the length-weight relationship (LWRs).

The values for L_∞ and k that obtained from the best fitted model were used to compare growth performance indices (ϕ') with the model of Pauly and Munro (1984)-

$$\phi' = \log_{10} k + 2 \log_{10} L_\infty$$

From the parameters of L_∞ and K of the von Bertalanffy growth equation, the potential longevity of *T. ilisha* was calculated using the formula of Pauly and Munro (1984) as: $T_{\max} = 3/K$.

Besides, age at maturity (t_m) was calculated through the equation of

$$t_m (50\%) = (-1/1)*\ln(1-L_m/L_\infty) \text{ (king, 2007)}$$

The growth coefficient (K) was assessed by-

$$K = \ln(1+L_m/L_\infty)\ t_m \text{ (Beverton, 1992)}$$

The age at zero length was assessed by-

$$\log (-t_0) = -0.3922 - 0.2752 \log L_\infty - 1.038 \log K \text{ (Pauly, 1980)}$$

6.4.4. Length-, and age at first Recruitment

Length at first recruitment, L_r (mean length of first modal group) was estimated through LFDs of 0.2 cm intervals using Excel-add-in-Solver.

Age at first recruitment t_r was calculated by,

$$t_r = (-1/k)*\ln(1-L_r/L_\infty).$$

6.4.5. Statistical analyses

Microsoft® Excel-add-in-Solver was used to perform all the statistical analyses considered at 5% level of significance.

6.5. Results

6.5.1 Length-frequency distribution (LFD)

The LFD for *T. ilisha* exposed that the minimum size was 15.3 cm in TL while the maximum one was 55.5 cm in TL. LFDs presented that the 24-29 cm TL size group had a numerical superiority in the stock (Figure 20). Additionally, 35-39 cm TL size group was placed as the second dominant size group in the Meghna River. A very few large size specimens were present in the Meghna River stock. Monthly length frequency distribution with model progress of *Tenualosa ilisha* from Meghna River was shown in Figure 21.

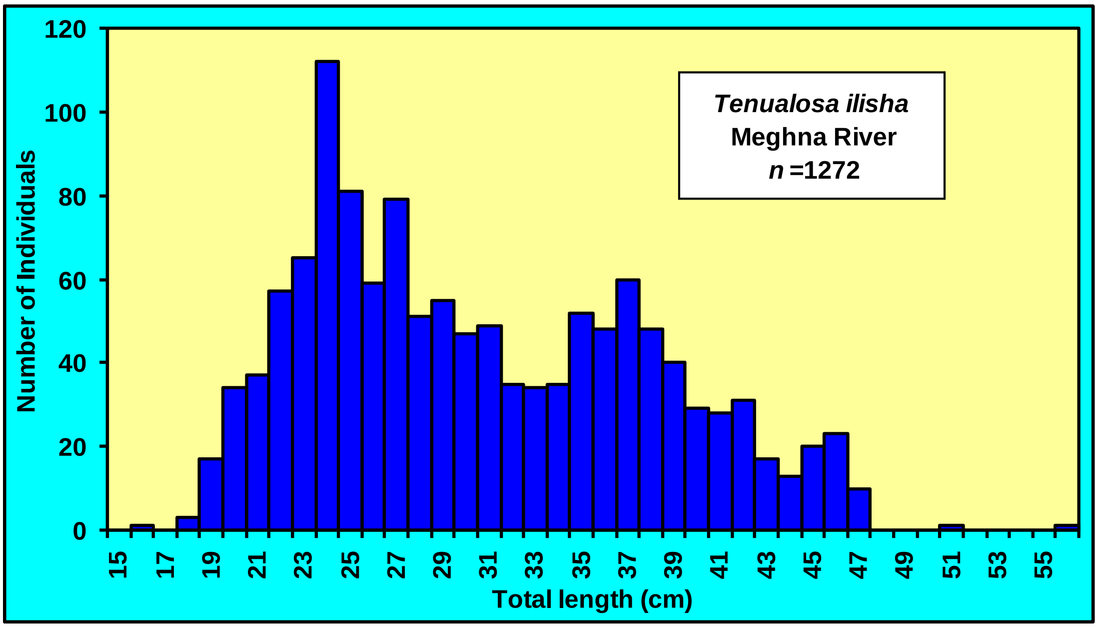


Figure 20. Length frequency distribution of the *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh.

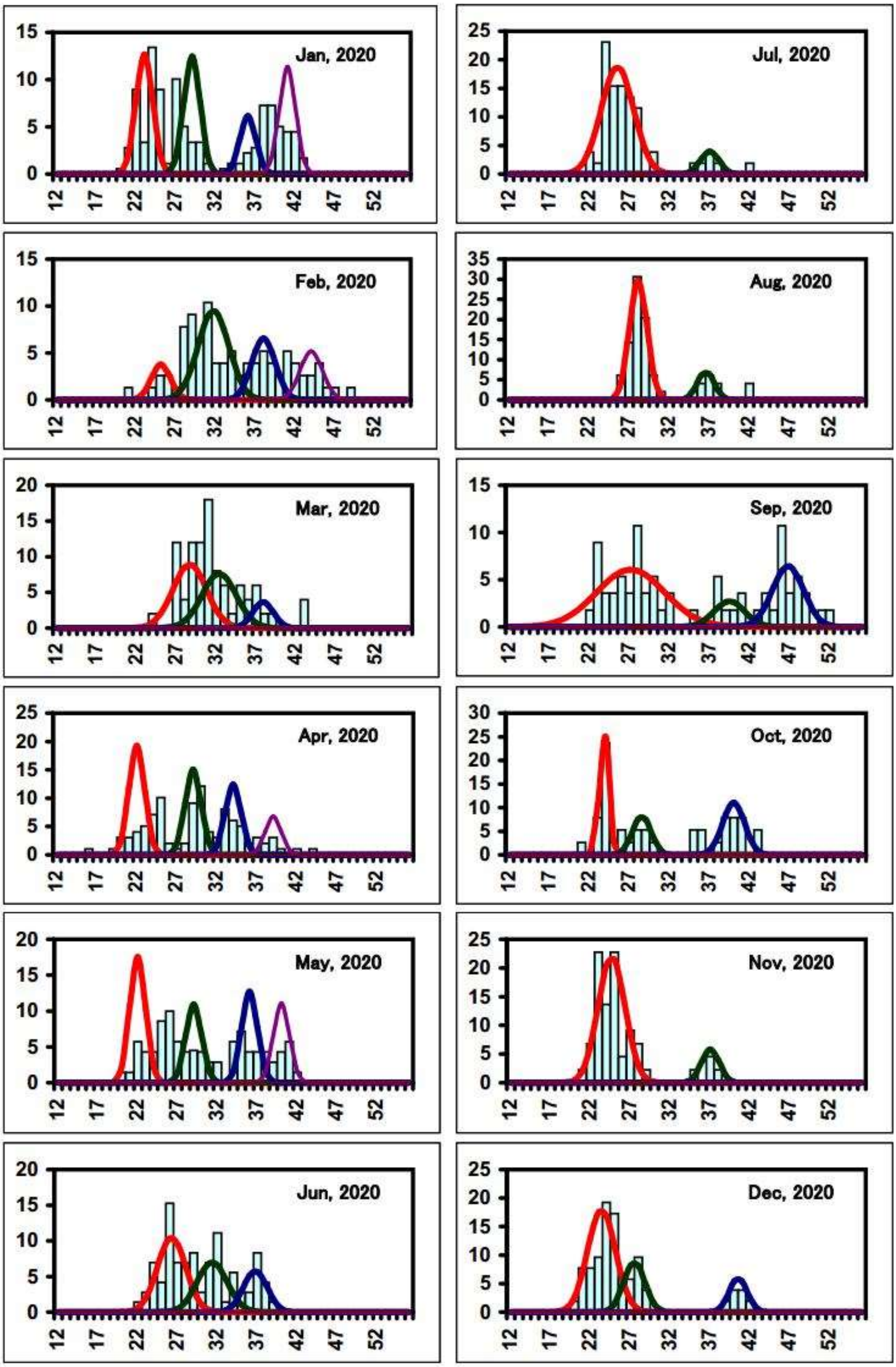


Figure 21. Monthly length frequency distribution with model progress of *Tenualosa ilisha* from Meghna River, SE Bangladesh.

6.5.2. Growth parameters based on length, Life span, Growth performance index and longevity

The estimated growth parameters through the von Bertalanffy equation for *T. ilisha* were L_∞ = 57.62 cm, K = 1.13 and t_0 = 0.009 year^{-1} (Figure 22).

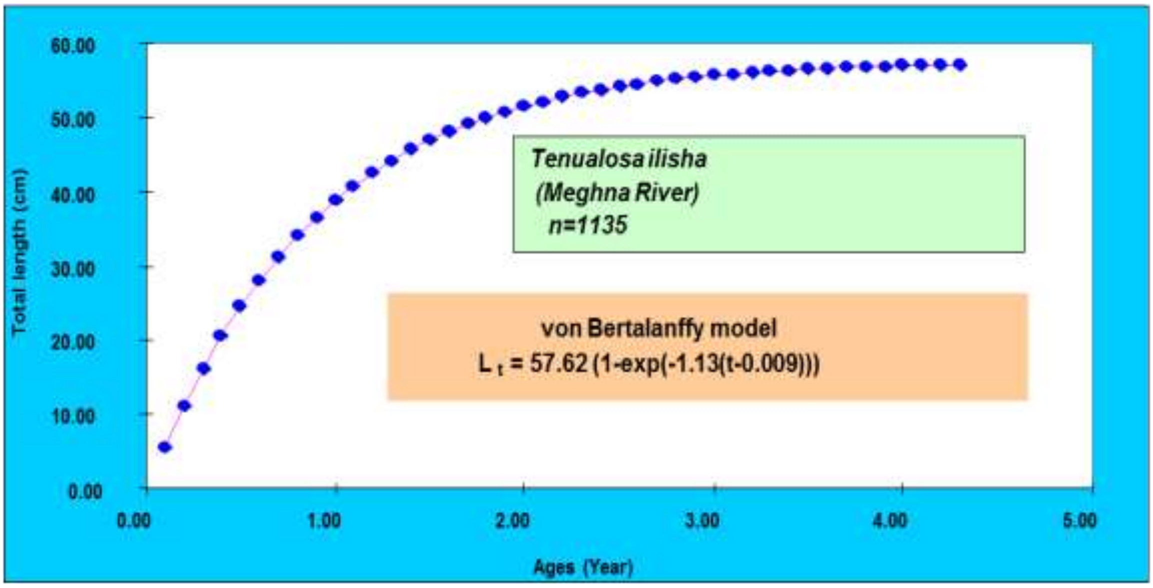


Figure 22. von Bertalanffy growth curve (TL_∞ = 57.62 cm, K = 1.13 year-1, t_0= 0.009) based on length of *Tenualosa ilisha* in the Meghna River.

The analysis of the LFD through FiSAT tool of *T. ilisha* by the Powell-Wetherall procedure provided an initial TL_∞ value of 49.0 cm and Z/K of 1.68 (Figure 23).

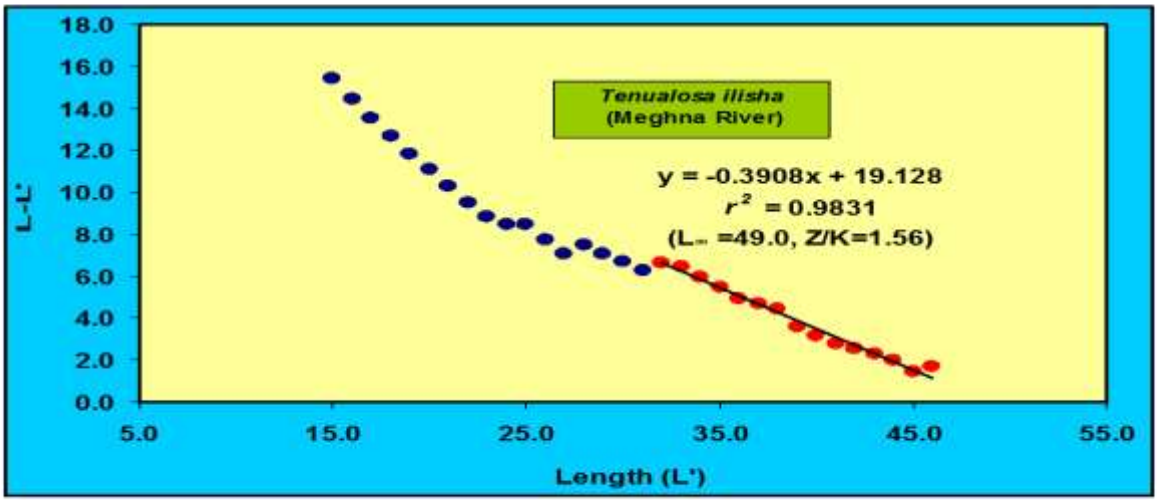


Figure 23. A Powel-Wetherall plot for the *T. ilisha* in Meghna River. Solid red symbols are used in the regression which provides asymptotic TL of 49 cm and Z/K of 1.68.

The calculated life span, growth performance index and longevity for *T. ilisha* were presented in Table 22.

Table 22. Growth parameters obtained from fitting von Bertalanffy models based on maximum total lengths of *Tenualosa ilisha* in the Meghna River, southeastern Bangladesh

Parameters	Values
Maximum length (L_{max})	51.0 cm TL
Asymptotic length (L_{∞})	57.62 cm TL
Asymptotic weight (W_{∞})	2024.6 g
Size at sexual maturity (L_m)	30.08 cm TL
Age at first sexual maturity (t_m)	0.74 year
Growth coefficient (K)	1.13 year^{-1}
Life-span (t_{max})	4.17 year
Growth performance indexes ($Ø'$)	3.38
Age at zero length (t_0)	0.009 year

6.5.3. Length-, and age at first Recruitment

The length of first recruitment for *T. ilisha* was 18 cm TL in the Meghna River Bangladesh (Figure 24).

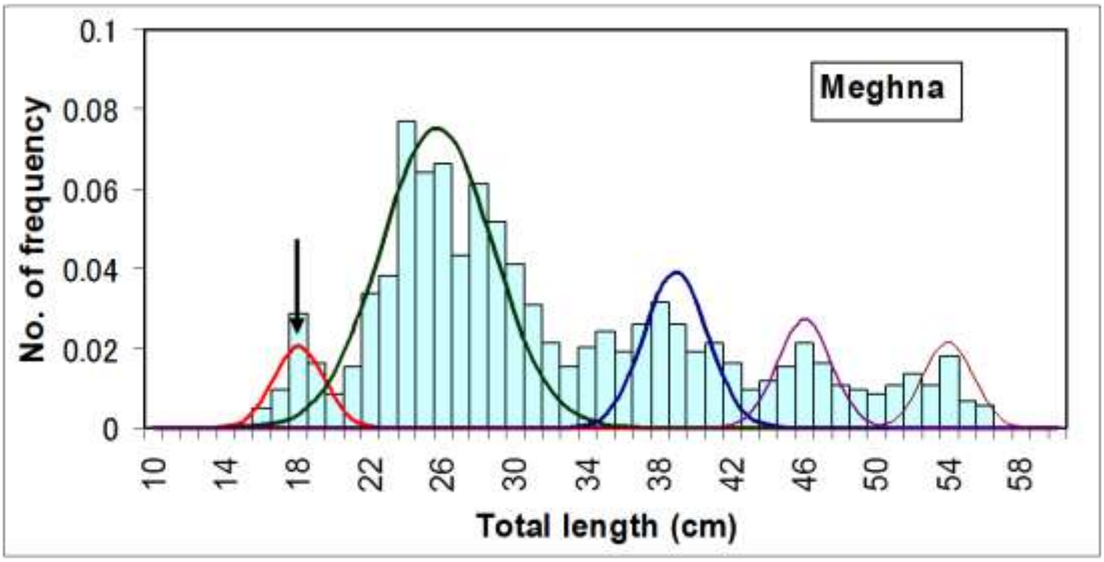


Figure 24. Length at first recruitment of *Tenualosa ilisha* in the Meghna River, SE Bangladesh.

6.6. Discussion

Several approaches have been used to assess the growth of fish, including LFD, mark-recapture approach, and growth of hard parts including otoliths, scales, and vertebrae (King, 2007). However, length-frequency distributions in the sub-tropical fisheries is the most commonly used technique for growth estimation (Bergstrom, 1992).

A few studies have been done by various researchers on several aspects of Hilsa shad *T. ilisha*. The growth of *T. ilisha* was expressed by the von Bertalanffy model. This model is the most frequently used in fisheries, and is a good descriptor of fish growth patterns (Soriano et al., 1992). Absence of specimen smaller than 15.3 cm can be accredited of fishing gear selectivity or absence of smaller individuals throughout the sampling (Azad et al., 2020; Islam et al., 2020). In the study we found 57.8 cm which was more or less similar to the study (57 cm) of Rahman et al. (1999) & Amin et al. (2002) in Bangladesh and Al-Baz & Grove (1995) in Kuwait but smaller than the study (61 cm) of Amin et al. (2004) though Fishbase showed a maximum length of 60 cm (Forese & Pauly, 2020). All other studies (Bhaumik et al., 2011; Roomiani & Jamili, 2011; Sarker et al., 2017; Bhakta et al., 2019) found the body length was smaller than the current study. However, differences in body length may be ascribed to geographic distribution and influences of environment like temperature of water, availability of food etc. (Hossain et al., 2015; Hassan et al., 2020).

Amin et al. (2002) reported L_∞ = 60.00 cm and K = 0.82 yr^{-1}. Further, the same researcher (Amin et al., 2004) reported L_∞ = 61-66 cm and K=0.67-0.83 yr^{-1}. The present study estimated growth equations showed a L_∞ (57.62 cm) was lower than their findings but K value (1.13 y^{-1}) was slightly higher. The estimated Z/K value (1.68) within the range (2.025-5.485) reported by Amin et al. (2004). The fact that the von Bertalanffy model might have limitations for estimating fish growth might explain why the assessed L_∞ was greater than the largest individual. (Vigliola et al., 1998). A direct comparison of growth parameters is not biologically feasible for fishes as its growth pattern is nonlinear (Cartaxana, 2003). Variation of values may be attributed as sex difference, fish size, food or predation, etc. (Roff, 1983; Beckman et al., 1989; Colloca, 2002).

The growth performance index ($Ø'$) is an indicator of the well-being of aquatic animals relative to their environment (Gabche and Hockey, 1995), and it is easy for comparison the growth either between sexes of same species or between species rather than comparing L_{∞} and K, as these two parameters are basically inversely associated (Pauly and Munro, 1984). Consequently, $Ø'$ was used to compute the least variance compared to other available indices (Pauly and Munro, 1984). The studied growth performance indices (3.38) found no differences with the finding of Amin et al. (2002, 2004) (3.47, 3.34-3.50). The differences in ϕ may be occurring between the sexes that can attribute to the life-history strategy stated above to explain the size differences between males and females.

6.7. Conclusion

This study provides the comprehensive study on the growth parameters, growth performance index and longevity of the *T. ilisha* from the Meghna River, southeastern Bangladesh. Growth parameters found in the present study would be useful for stock assessment of this species. In addition, this study will help fisheries biologists, managers, and conservationists develop management plans and principles for the sustainable maintenance of this large scale targeted fish species in the Meghna River and its adjoining ecosystems based on the findings of this study.

Chapter 7

Study-V

STUDY-V

Stock Assessment of the Hilsa Shad *Tenualosa ilisha in* the Meghna River of Southeastern Bangladesh

7.1. Abstract

The study provides complete information on mortality, exploitation rate (*E)* and maximum sustainable yield (MSY) of *Tenualosa ilisha* based on monthly sampling of 1272 specimens from the Meghna River, southeastern Bangladesh, from January to December, 2020. Data of length–frequency were analyzed with excel based program and FAO-ICLARM Stock Assessment Tool. Fishing mortality (F = 0.97 year^{-1}) rate was lower than natural mortality (M =1.57year^{-1}). Further, estimated exploitation rate (E=0.63) was higher than the maximum permissible exploitation rate (E_{max} = 0.47). Consequently, overfishing is the greatest pivotal threat for *T. ilisha* stock in the context of Meghna River, southeastern Bangladesh. The MSY was calculated at 286,327 MT. The outcomes will be very effective to introduce sustainable hilsa fishing management plans in the Meghna River and surrounding ecosystems.

Keywords: Mortality, Exploitation, MSY, *Tenualosa ilisha*, Meghna River, Bangladesh.

7.2. Introduction

Fish and fisheries products are the most important source of protein for humans all over the world (Roy et al., 2020). Because of this growing demand for food fishes, natural stocks, especially in the open-water habitat, are under enormous fishing pressure. Consequently, Fish is regarded as a natural resource that is not renewable (Sabbir et al., 2021b). Thus, it is necessary to assess the life-history including growth pattern and parameters, reproductive features, recruitment and mortality of fish stocks for ensuring sustainable management practice to conserve the wild population (Foster and Vincent, 2004). Further, the absence of knowledge about such events on riverine fisheries is an obstacle to instigating appropriate harvesting strategy in the riverine ecosystems (Dinh et al., 2009) and this requires rapid research.

Knowledge on maximum sustainable yield and exploitation rate is important for developing such models (Hossain et al., 2017a). Recruitment and growth have notable impacts to maintain maximum sustainable yield of a population (Ahmed et al., 2012). Fish growth is reliant on sex, maturation state or fluctuation of environmental issues (Dall et al., 1990). Fish with a rapid growth rate have numerous advantages. Fish that grow at a fast rate are able to protect them from predators, may produce a large number of eggs, as well as resulting in laying bigger eggs with better odds of larval survival (Hossain et al. 2017a).

The Hilsa shad, *Tenualosa ilisha* (Hamilton, 1822) is a euryhaline, pelagic-neritic, anadromous fish and frequently shows schooling behavior in coastal waters (Riede, 2004; Hossain et al. 2019). It belongs to the family Clupeidae, order Clupeiformes. In Bangladesh, adult individuals are locally known as *Ilish*, whereas juveniles are popular as *Jatka*. This species is distributed in Bangladesh, Nepal, Sri Lanka, India, Pakistan, China, United Arab Emirates and also in Myanmar, Iraq, Iran, Malaysia, Oman, Kuwait, Qatar, Saudi Arabia, Thailand and Vietnam (Freyhof, 2014). This clupeid is considered as least concern (LC) both in Bangladesh and worldwide (Freyhof, 2014; IUCN Bangladesh, 2015). *T. ilisha* is a vital aquatic resource in Bangladesh and a commercially target fish species for large-scale fishermen in the country.

Several studies have been conducted on *T. ilisha* including maturity and spawning, age and growth, stock profile, net selectivity, catch trend, biology and fisheries, etc. However, none of these studies covered Stock assessment from the Meghna River. Thus, the aim of the present study was to describe the stock assessment of *T. ilisha* from the Meghna River, southeastern (SE) Bangladesh.

7.3. Objectives

The main objectives of this study are to-

- Estimate mortality and exploitation rate;
- Determine biomass and survival rate;
- Estimate maximum sustainable yield (MSY).

7.4. Materials and Methods

7.4.1. Sampling and Fish measurement

Monthly samples of *T. ilisha* were collected from the Chandpur to Lakshmipur during January to December 2020 using traditional fishing gears including gill nets, seine nets, etc. In the laboratory, total length (TL) was estimated by a measuring board nearest to the 0.01 cm. For body weight (BW), an electric balance to the precision of 0.01 g accuracy was used for each individual.

7.4.2. Estimation of mortality and exploitation

The length-converted catch curve approach was used to compute total mortality (Z) (Gayanilio et al., 2002). Natural mortality (*M*) was calculated as-

$$\log_{10}M = -0.0066 - 0.279\log_{10} L_\infty + 0:6543\log_{10}K + 0:0463\log_{10}T$$

Where, *M* is the natural mortality, L_∞ the asymptotic length, *K* denotes to the growth constant, and *T* is the annual average temperature (^{o}C) of habitat in which the stocks live.

By subtracting natural mortality (M) from total mortality (Z), the fishing mortality (F) was intended: $F = Z - F$

Besides, exploitation rate (*E*) was assessed through-

$E = F/Z = F / (F + M)$ (Gulland, 1983).

Subsequently, maximum yield (E_{max}), the rate of exploitation at which the secondary increment in Y'/R is 10% its virgin biomass ($E_{0.1}$) and the rate of exploitation at which the stock is reduced to half of its initial value of virgin biomass ($E_{0.5}$) were assessed from the knife-edge selection (Beverton and Holt, 1979) using FiSAT II.

7.4.3. Biomass and maximum sustainable yield (MSY)

At the $E_{0.5}$ level, the optimal length at first capture (L_c) was estimated. The steady state biomass (SSB) was intended through the length-structured virtual population analysis (VPA) routine in FiSAT II. Subsequently, MSY of *T. ilisha* was assessed as-

MSY = 0.5*SSB*Z (Gulland, 1983).

7.5. Results

7.5.1. Mortality

Total mortality (*Z*) was assessed 2.54 year^{-1} (Figure 25). Further, natural-, and fishing mortality were calculated 1.57 and 0.97 year^{-1}, correspondingly (Table 23).

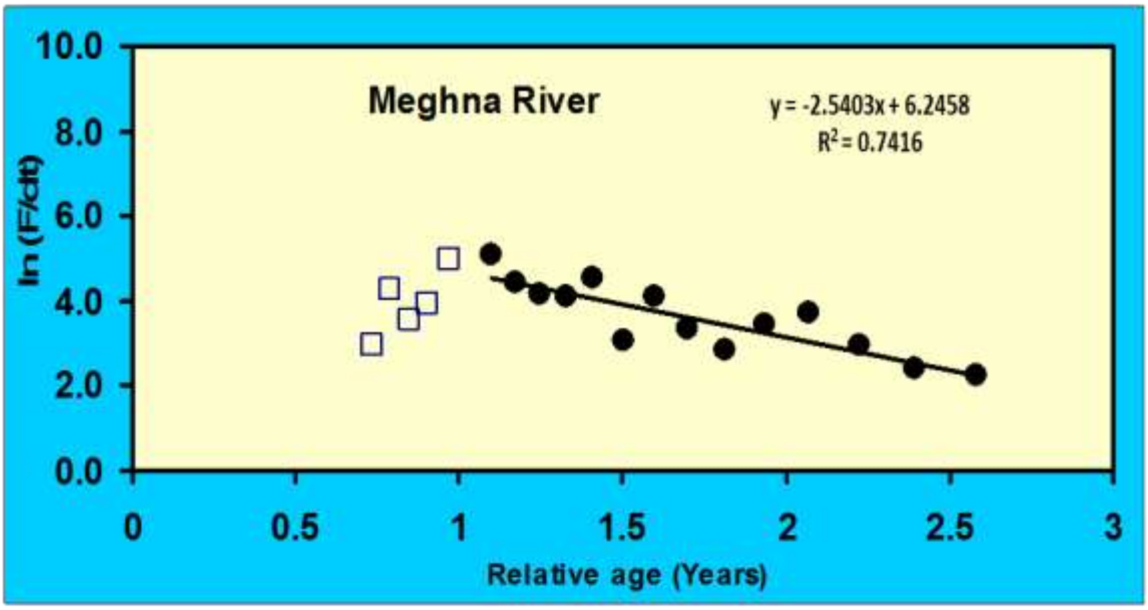


Figure 25. Estimation of total mortality (Z) of *Tenualosa ilisha* from the Meghna River, southeastern Bangladesh.

7.5.2. Biomass and Maximum sustainable yield

Biomass of *T. ilisha* was estimated at 290.00 Kg from the Meghna River, SE Bangladesh with a survival rate of 29% and individual weight of 50.23 g at 1.4 years age (Figure 26). The estimated values of *E*, E_{max}, $E_{0.1}$, and $E_{0.5}$ were 0.63, 0.47, 0.40 and 0.30, correspondingly (Table 23, Figure 27-28). The predicted MSY of *T. ilisha* was at 286,327 MT (Figure 29).

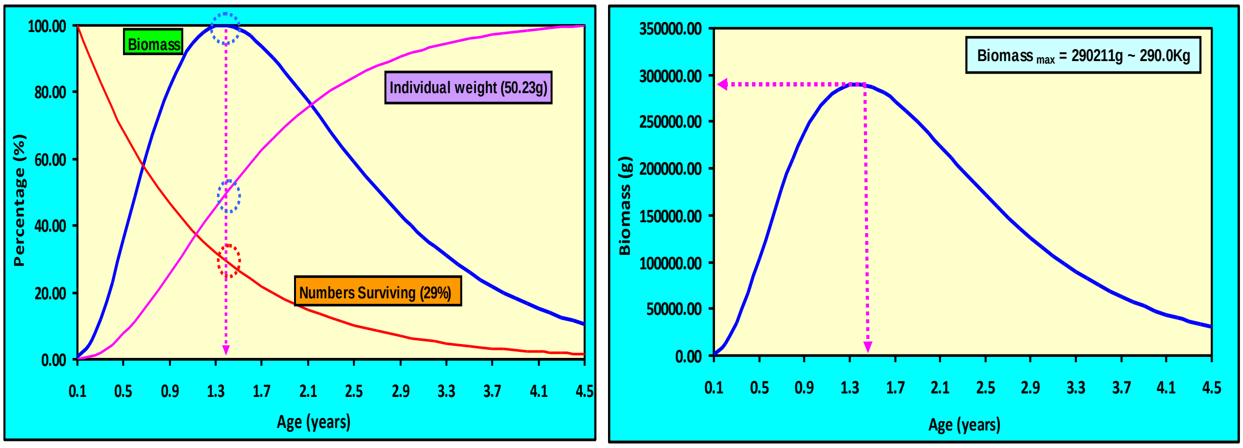


Figure 26. Percent of biomass, survival rate and individual weight of *Tenualosa ilisha* in the Meghna River, southeastern Bangladesh.

Table 23. Mortality and Fishery parameters of *Tenualosa ilisha* in the Meghna River, southeastern Bangladesh.

Description of Parameters	Values
Total mortality (*Z*)	2.54 $year^{-1}$
Natural mortality (*M*),	1.57 $year^{-1}$
Fishing mortality (*F*)	0.97 $year^{-1}$
Exploitation ratio (*E*)	0.63
Maximum yield (E_{max})	0.47
$E_{0.1}$	0.40
$E_{0.5}$	0.30
Length at first capture (L_c)	36.35 cm TL
Maximum sustainable yield	286,327 MT

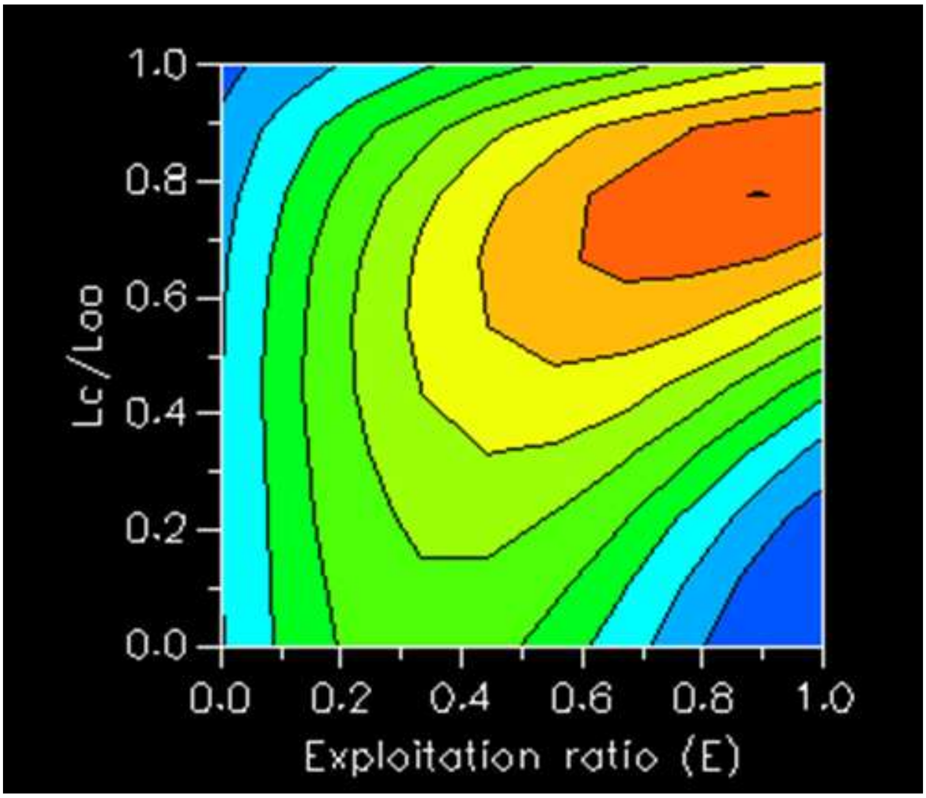


Figure 27. Yield Isopleths, showing optimum fishing activity of *Tenualosa ilisha* in the Meghna River, southeastern Bangladesh

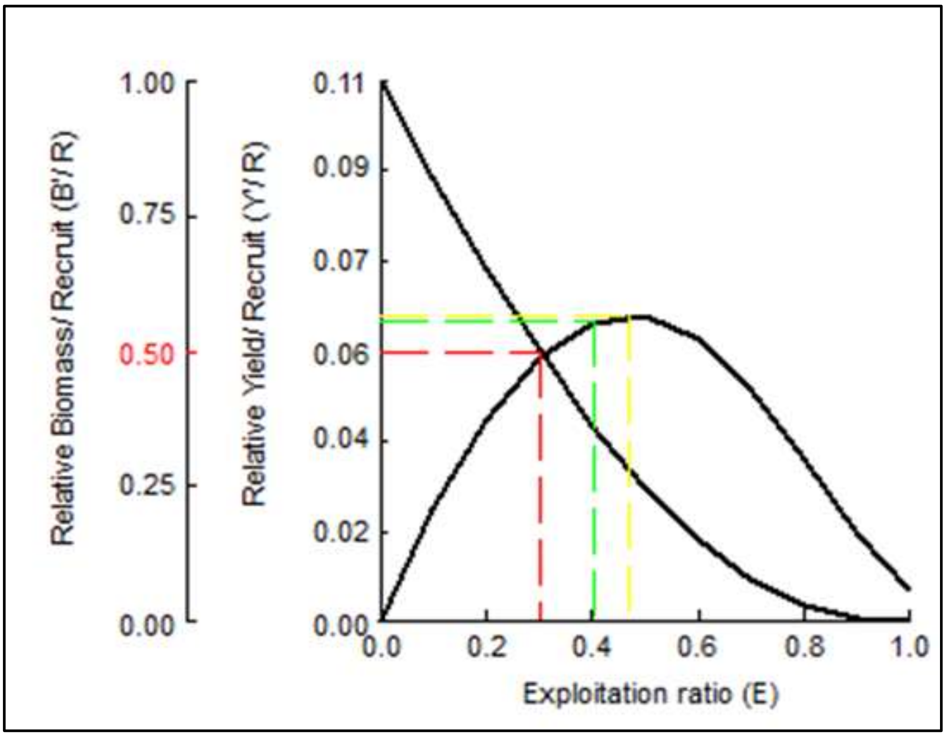


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Figure 28. Yield-per-recruit and average biomass per recruit models, showing levels of yield index of *Tenualosa ilisha* in the Meghna River, southeastern Bangladesh.

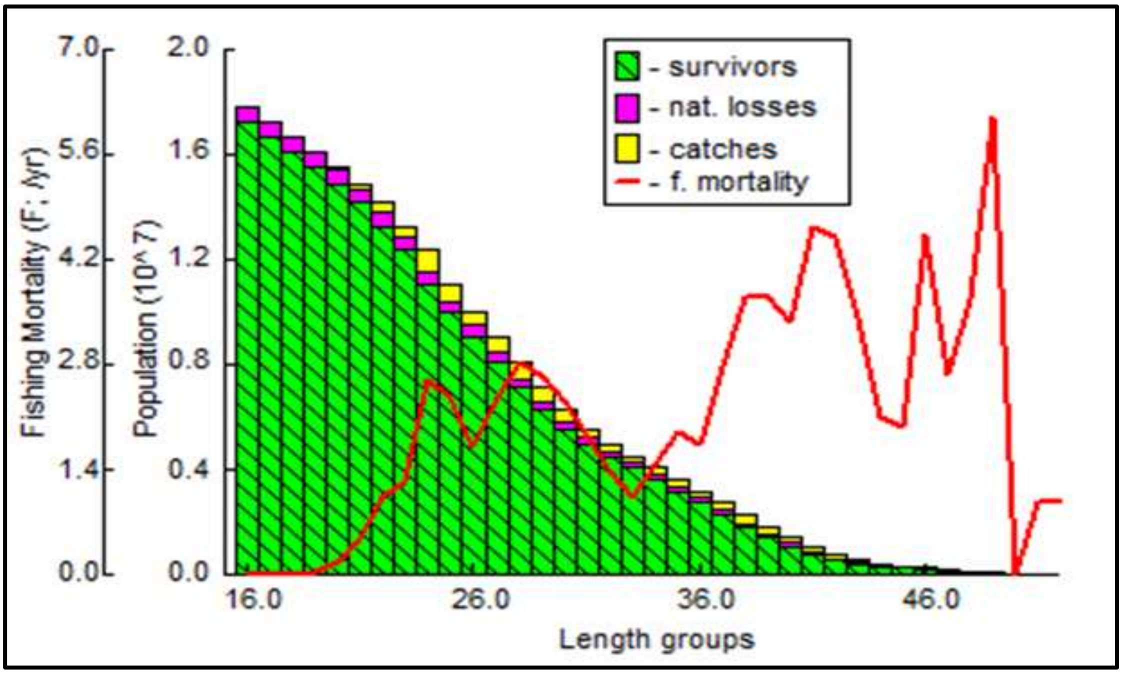

Figure 29. Virtual population analysis of *Tenualosa ilisha* in the Meghna River, southeastern Bangladesh.

7.6. Discussion

Stock assessment is indispensable to get maximum advantage from any wild population without impeding the stock. Knowledge on stock assessment of *T. ilisha* is very limited in literature. In this study, a huge number of samples (1272) were collected using traditional fishing gears including seine and gill net for twelve months from the Meghna River, SE Bangladesh.

Impending yields and stock biomass of any riverine habitat can be predicted by determining the growth parameters (Dadzie et al., 2017). With the intention of determine the abundance of a fish population, the mortality rate must be determined. This allows harvest restrictions to be set in order to maximize the benefit to the resource's stakeholders. Total mortality (Z) was estimated2.54 y^{-1}. The natural mortality (M =1.57 y^{-1}) rate is almost identical to fishing mortality (F = 0.97 year^{-1}). Exploitation level (E=0.63) was higher than the maximum permissible exploitation rate ($E_{max} =$ 0.47). According to Gulland (1971), when E is more than 0.50, the stock is generally considered to be overfished. Thus, the *T. ilisha* stock of Meghna River is considered overfishing. Consequently, the fishing composition of hilsa in the Meghna River was dominated by smaller size (24-29) of fish.

Total mortality of the present study was lower than that of reported (3.77 year^{-1}) by Amin et al. (2002), more or less similar (2.61 year^{-1}) to Rahman et al. (1998) and Higher (2.03 year^{-1}) than Miah and Shafi (1995). The estimated *F* was 2.49 year^{-1} by Amin et al. (2004) and M was 1.28y^{-1} while Miah and Shafi (1998) reported 1.16 y^{-1} and Rahman et al. (2000) reported 1.18y^{-1}. Amin et al. (2004) reported the *Z* values 3.29, 3.43, and 3.77 from the commercial catches in 1997 1998, and 1999, correspondingly. The *M* and *F* were 1.28, 1.25, 1.28 and 2.01, 2.18 and 2.49 during 1997, 1998 and 1999, correspondingly (Table 1).

Amin et al. (2002) reported E=0.66 and E_{max}=0.59 from Bangladesh using commercial harvest during January to December 1999. Amin et al. (2004) stated E_{max} ranged from 0.59 to 0.69 during 1997-1999 with an average of 0.61. Finally, the MSY of *T. ilisha* was calculated as 2876,327 MT, if the recommended length at first capture (L_c = 36.35 cm TL) is maintained.

7.7. Conclusion

This study describes the mortality, exploitation and MSY of *T. ilisha* from the Meghna River, SE Bangladesh. However, overfishing is the biggest concern for the *T. ilisha* population in the context of Meghna River, SE Bangladesh. Therefore, fishing activity must be managed at a level to ensure that the wild stock can remain productive and healthy. There should be a restriction on illegal gear, and the mesh size should be raised to minimize the capturing of smaller matured individuals, so that they have the opportunity to spawn. The findings will be a valuable tool for fishery personnel to develop sustainable management techniques to conserve this prominent fish species from possible future collapse.

Chapter

8

General Discussion

GENERAL DISCUSSION

Life history traits will be helpful to know the breeding period and migratory roots for hilsa shad and it would be very useful for hilsa management. To earn foreign currency and to fulfill the fish demand and protein requirement for the people of Bangladesh, an increase in hilsa production is very essential (Ahmed et al., 2008). But unfortunately our fishermen catch large-scale of brood and small-sized hilsa (locally known as *jatka*) in the spawning period that adversely affect the hilsa production in Bangladesh. For sustainable conservation and to get plentiful production of hilsa, the life history features of *T. ilisha* are very indispensible in the aspects of Bangladesh.

A large quantity of specimens covering various lengths was collected from commercial catch of the Meghna River in Chandpur and Laxmipur regions throughout the year. However, that the lack of fish smaller than 15.3 cm TL throughout the research was due to the fishing gear selection or low market price (Rahman et al., 2019a, b; Hossen et al., 2019b; Azad et al., 2018). In the study, we found the maximum length as 57.8 cm TL which was more or less similar to the study (57 cm) of Rahman et al., (1999) and Amin et al., (2002) in Bangladesh and Al-Baz & Grove (1995) in Kuwait but smaller than the study (61 cm) of Amin et al., (2004), though FishBase (Froese and Pauly, 2020) showed a maximum length of 60 cm. All other studies (Flura et al., 2015; Sarkar et al., 2017; Roomiani and Jamili, 2011; Bhakta et al., 2019; Mohanty and Nayak, 2017; Bhaumik et al., 2011) found the body length were smaller than the current study. Growth parameters are estimated through the maximum length. Thus, it is essential for fisheries resource management and planning (Hossain et al., 2009; 2014). Mean TL and BW were comparatively smaller in January. September-October is the peak spawning season of Hilsa shad (Hossain et al., 2014) and in January they recruit in the adult stock. Another small peak was in February (Mathur, 1964). The juvenile recruits in April and thus they are small in size and weight. In August maximum mean length and weight were found as the presence of much more food in the River.

The value of b from LWRs can be between 2 to 4, although values of 2.5 to 3.5 are also frequent (Carlander 1969; Hassan et al., 2020). The growth is specified as an isometric pattern, when the value of b is near to 3 ($b \approx 3.0$) but any significant difference from 3 designates allometric growth, where > 3 indicates positive and < 3 negative (Tesch, 1971). This study remained the value of *b* within 2.998 to 3.492 which was in the prospective limit for fish species stated by Froese (2006). The overall *b* value (b = 3.135) of our study showed positive allometric growth. The present findings are similar to the study of Sujansingani (1957) and Bhaumik et al. (2011) from Hooghly estuary (India), Al-Baz & Grove (1995) from Kuwait. Isometric growth pattern was stated by Amin et al. (2002) in Bangladesh, Bhakta et al. (2019) in Gujarat India and Mohamed et al. (2016) in Iraq. A negative allometric growth was observed by some other researcher including Rahman et al. (2000), Amin et al. (2004), and Rahman et al. (2018) in Bangladesh, Das et al. (2019), De & Datta (1990), Sarker et al. (2017) in India, Roomiani & Jamini (2011) in Persian Gulf, Iran. However, the growth pattern variation might be associated with several reasons fish health together with sex, food availability, gonad maturation, nitration, habitat suitability, seasonal environmental effect on habitat, preservation method and variations in the length ranges observation of captured fish samples (Hasan et al., 2020; Nima et al., 2021), which were not taken into account during this study.

Condition factors indicate the degree of well-being of a fish stock in their innate ecosystem. The higher value of condition factor indicates a better condition of fish species (Maurya et al., 2018). Information on condition of *T. ilisha* in the Meghna River is scant. K_F ranged from 0.7191 to 1.7098 in this study that indicates a healthy and favorable habitat for *T. ilisha*. Mandal et al. (2018) found 0.47-3.05 for combined population in fresh, estuarine and marine waters of India. Dutta et al. (2019) reported K_F 0.9-1.2 from the Sundarban estuary, Bay of Bengal, India. Lower value of condition may be attributed to lower sample size whereas the higher value is attributed to feeding intensity, environmental condition, maturity or spawning events (Mandal et al., 2018). During the study, relative condition factor (K_R) evaluates the well-being status and productivity of *T. ilisha* in the Meghna River. Mean K_R value throughout the year indicated a balanced habitat for hilsa population. Overall K_R of our study was within 0.99-1.01 while Mandal et al., (2018) reported K_R value varied between 0.98-1.04 and Sarkar et al. (2017) observed it from 0.98 to 1.05 for *T. ilisha* from India. The present study found minimum and maximum K_R value in January and July, while Sarkar *et al*. (2017) stated in August and June in Hooghly estuarine system, India. K_R value may be higher during spawning season (Khan et al., 2001).

The difference may have occurred due to gonad maturation, amount of undigested food in the alimentary canal and changes in amount of fat stored in body tissue (Hossain et al., 2017a). Smaller size specimens indicated the higher value of K_R as they have high feeding density. The value gradually decreases with increasing the length as gonadal development occurs. Mohanty and Nayak (2017) also indicated the same matter for *T. ilisha* in the Chilika Lake, India. Reuben et al. (1992) stated that an early stage of fish has higher K_R value. However, Welcome (1979) reported that condition factor in fish decreases with decreasing in size and is also influenced by the reproductive cycle. The calculated form factor ($a_{3.0}$) was 0.0102 *T. ilisha* indicated fusiform or torpedo body shape (Froese, 2006). The form factor of this species has not been studied earlier. Therefore, it is difficult to compare the finding with other studies.

In the current study minimum number of fatty fish was found in October and lowest the percentage of lean fish was in September due to peak-spawning season (Rahman et al., 2012). The proportion of fatty fish began to raise in November and maximum fatty fish (44%) was found in December attributable to the resting phase after peak-spawning season. The maximum percentage of lean fish found in the month February (41%). Hossain et al. (2019) indicated that the abundance of juvenile hilsa was found during January to May in the river Meghna. A minor peak-spawning was also indicated in the February to April by Mathur (1964) and Moula et al. (1991). The proportion of fatty fish began to rise in April and continued until July. Juveniles became nourished in the Meghna River that is the largest nursery ground for hilsa and returned to Bay of Bengal with their parents (Hossain et al., 2019). Physiological status of fish may also be fluctuating for environmental effect on habitat, habitat changes, primary productivity, food availability or nutrition etc.

The W_R declining below 100 for a population indicates lower prey or a high level of predator activity; while above 100 indicate a surplus of prey or a poorer predator (Froese, 2006). In our study, the mean W_R have no significant variance from 100 specifying the habitation for *T. ilisha* populations was in balanced condition. We found no reference about the relative weight of *T. ilisha* elsewhere. Therefore, it is difficult to compare the finding with other studies.

Determining length at first sexual maturity (*TL_m*) is critical simultaneously for distinguishing between several populations of an fish species and for anticipating a basis that ultimate variations in first maturation length are due to fishing pressure or other causes (Hossain et al., 2010b). Further, it is crucial for fisheries biologists to manage and conserve a particular fish stock in any aquatic ecosystem (Lucifora et al., 1999). Length at maturity is a key population parameter that is enormously vital in the fisheries management of exploited stocks (Sabbir et al., 2021a). According to Beverton and Holt (1957), to maintain the stock biomass, fish should be allowed to reproduce at least once before being captured (Trippel 1995).In the present study, we used four models (GSI, MGSI, DI *vs*.TL, logistic, and L_{max}) for the estimation of L_m. From the three models the mean value of L_m was 26.10 cm (TL) in the Meghna River, Bangladesh. Previously L_m was estimated in twenty water bodies worldwide where the lowest value 18.00 cm recorded from Iraq (Almukhtar et al. 2016) and highest value was 43.00 cm recorded from Godavari river, India (Rajyalakshmi, 1973). Further, the study denotes the first extensive information on sexual maturity of *T. ilisha* that could be supportive for determining the mesh size to limit catching smaller mature individuals to make available them for breeding (Rahman et al., 2018b).

Spawning period is very momentous for the migration of fishes for spawning purposes and for the estimation of spawning time (Wilding et al., 2000). In this research, according to the variation of GSI value the spawning season of *T. ilisha* was throughout the year with two peaks in October and April from the Meghna River. Previously the spawning season of *T. ilisha* was estimated in fifteen worldwide water bodies and their findings were similar to this as they observed the spawning season was throughout the year except the finding of Narejo et al. 1999 (July-August), Milton, 2010 (July-November and February-May), Panhwar et al. 2011 (May-October), and Almukhtar et al. 2016 (March-November) from Indus River, Pakistan, BoB, Bangladesh River Sindh, Pakistan and Shatt al Arab River, Iraq, respectively. However, this difference may be ascribed to population densities, water temperature, environmental influences, rainfall, food availability and seasonality (Mitu, 2017; Khatun et al., 2019).

The estimation of the fecundity and explanation of reproductive strategies are essential topics in population dynamics, fish physiology and biology (Hunter et al., 1992). Fecundity is an essential feature in fishes to comprehend differences between population size as well as relevant to fisheries management (Rahman et al. 2018). In the current study, fecundity of *T. ilisha* the total fecundity ranged from 65999 to 1575850 in the Meghna River. In addition, previously fecundity of *T. ilisha* was estimated in twenty-five water-bodies in Bangladesh and other countries. Among them the lowest fecundity was 30097-92070 found in Ukai reservoir, India (Bhaumik et al. 2013) and highest was 1500000-2000000 also recorded in BoB, Bangladesh (Miah, 2015). Probably this difference occurred because fishes live under different conditions as well as to great extent upon nutrition, variation in stock (Ruzzante et al., 1998) and differences in methodological technique used for fecundity assessment (Alonso-Fernández et al., 2009). According to Dulcic et al. (1998) when the size distribution of a fish stock is known, the relationship between size and fecundity is used as a fast means of estimating fecundity. In our study, significant correlations were observed between F_T *vs.* TL and F_T *vs.* BW for *T. ilisha*. Akter et al. (2007), Mondal et al. (2008) and Almukhtar et al. (2016) have also reported positive correlation of fecundity with body weight and total length for *T. ilisha* from Padma, Patuakhali, Bangladesh and Shatt Al Arab River, Iraq, which strongly support our findings. Whereas, Islam and Talbot (1968) observed no close relation between total length and body weight from Indus River.

Marine and estuarine fisheries are already being impacted by global climate change. (Klyashtorin 1998; Loukos et al. 2003; Guisande et al. 2004; Roessig et al., 2004; Lloret et al. 2004). In the current study, we observed 25-26 ºC temperature was suitable for the spawning of Hilsa in Meghna River. This temperature is considered as optimum temperature for Hilsa spawning and this temperature remains in October which is the peak spawning season for Hilsa population. Through the long data series of climatic factor (air temperature and rainfall) from 1964 to 2018 and observed that average annual air temperature was increasing by 0.029 °C y^{-1} while rainfall showed reducing trend by 2.96 mm y^{-1} which worryingly envisage the shifting of spawning period for *T. illisha* in Bangladesh. Also, increase of air temperature has impact on ecosystem and hilsa fishery such as changes in ecosystem, blockage of migratory route and high turbidity of water (Mahmud, 2020).

Amin et al. (2002) reported L_∞ = 60.00 cm and K = 0.82 yr^{-1}. Further, the same researcher (Amin et al., 2004) reported L_∞ = 61-66 cm and K=0.67-0.83 yr^{-1}. The present study estimated growth equations showed a L_∞ (57.62 cm) was lower than their findings but K value (1.13 y^{-1}) was slightly higher. The estimated Z/K value (1.68) within the range (2.025-5.485) reported by Amin et al. (2004). The fact that the von Bertalanffy model might have limitations for estimating fish growth might explain why the assessed L_∞ was greater than the largest individual. (Vigliola et al., 1998). A direct comparison of growth parameters is not biologically feasible for fishes as its growth pattern is nonlinear (Cartaxana, 2003). Variation of values may be attributed as sex difference, fish size, food or predation, etc. (Roff, 1983; Beckman et al., 1989; Colloca, 2002).

The growth performance index (Ø′) is an indicator of the well-being of aquatic animals relative to their environment (Gabche and Hockey, 1995), and it is easy for comparison the growth either between sexes of same species or between species rather than comparing L_∞ and K, as these two parameters are basically inversely associated (Pauly and Munro, 1984). Consequently, *Ø′* was used to compute the least variance compared to other available indices (Pauly and Munro, 1984). The studied growth performance indices (3.38) found no differences with the finding of Amin et al. (2002, 2004) (3.47, 3.34-3.50). The differences in ϕ may be occurring between the sexes that can attribute to the life-history strategy stated above to explain the size differences between males and females.

Stock assessment is indispensable to get maximum advantage from any wild population without impeding the stock. Knowledge on stock assessment of *T. ilisha* is very limited in literature. Impending yields and stock biomass of any riverine habitat can be predicted by determining the growth parameters (Dadzie et al., 2017). With the intention of determine the abundance of a fish population, the mortality rate must be determined. This allows harvest restrictions to be set in order to maximize the benefit to the resource's stakeholders. Total mortality (Z) was estimated2.54 y^{-1}. The natural mortality (M =1.57 y^{-1}) rate is almost identical to fishing mortality (F = 0.97 $year^{-1}$). Exploitation level (E=0.63) was higher than the maximum permissible exploitation rate (E_{max} = 0.47). According to Gulland (1971), when E is more than

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Total mortality of the present study was lower than that of reported (3.77 $year^{-1}$) by Amin et al. (2002), more or less similar (2.61 $year^{-1}$) to Rahman et al. (1998) and Higher (2.03 $year^{-1}$) than Miah and Shafi (1995). The estimated *F* was 2.49 $year^{-1}$ by Amin et al. (2004) and M was $1.28y^{-1}$ while Miah and Shafi (1998) reported 1.16 y^{-1} and Rahman et al. (2000) reported $1.18y^{-1}$. Amin et al. (2004) reported the *Z* values 3.29, 3.43, and 3.77 from the commercial catches in 1997 1998, and 1999, correspondingly. The *M* and *F* were 1.28, 1.25, 1.28 and 2.01, 2.18 and 2.49 during 1997, 1998 and 1999, correspondingly (Table 1). Amin et al. (2002) reported *E*=0.66 and E_{max}=0.59 from Bangladesh using commercial harvest during January to December 1999. Amin et al. (2004) stated E_{max} ranged from 0.59 to 0.69 during 1997-1999 with an average of 0.61. Finally, the MSY of *T. ilisha* was calculated as 2876,327 MT, if the recommended length at first capture (L_c = 36.35 cm TL) is maintained.

Chapter 9

Management Measure

MANAGEMENT MEASURES

The information was collected from different fishers, eye witnesses, daily national and international print and electronic news media, survey data from different government and non-government organizations and finally from the research findings. The management approaches shown in Table 24 and Figure 30.

Table 25. A simple guide to fisheries management approach for maintaining sustainable yield of *Tenualosa ilisha* in the Meghna River, southeastern Bangladesh.

Goals	Objectives	Management Measures
Biological	• To maintain the stock at all times above 50% of its mean exploited level	✓ Fishing in the peak spawning period must be banned. ✓ Spawning ground should be protected ✓ Illegal gear should be banned ✓ Maximize mesh sizes and escape gaps.
Environmental	• To ensure the suitability of all the environmental factors (rainfall, temperature, dissolved oxygen, Salinity, pH etc.)	✓ The temperature of the world's environment is increasing every year ✓ Duration of rainfall has been reducing gradually for different climatic issues ✓ A durable management strategy should be adopted for its sustainable management.
Socio-economic	• Maximize employment opportunities. • Maximize the net income of fishers	✓ To be studied

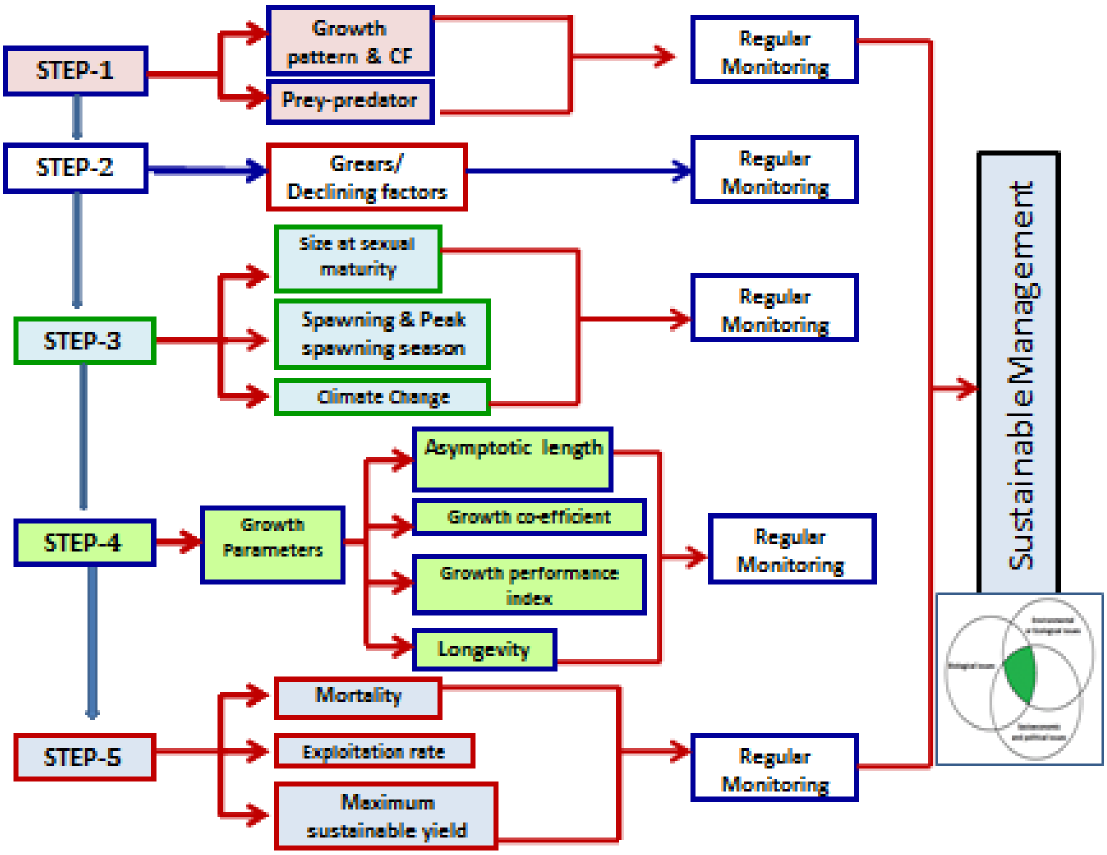

Figure 30. Management approaches for Sustainable fishery of *Tenualosa ilisha* in the Meghna River, southeastern Bangladesh.

Chapter 10

Conclusion

CONCLUSION

This study provides complete and comprehensive information on length-weight and length-length relationships, form factor, condition factors, physiological and prey-predator status, size (minimum) at first sexual maturity, spawning season, peak season, effect of environmental factors on the GSI, growth parameters using VBGF and stock assessment of *T. ilisha* from the Meghna River, southeastern Bangladesh. The study revealed that the growth pattern was positive allometric (b < 3.0) for the Meghna river population. Based on the values of Spearman rank correlation test, Fulton's condition factor (K_F) was the best-fitted model. Maximum fatty fish found in December. The Meghna River is estimated as a suitable and balanced habitat for hilsa stock. Sexual maturity was gained at about 26.10 cm in TL. The peak spawning season was in October and a minor peak in April. The total fecundity ranged from 65999 to 1575850. Fecundity was found to be highly correlated with TL and BW. Suitable temperature considered as 25-26°c for the spawning. The study revealed growth coefficient (K = 1.13 year^{-1}), growth performance index ($Ø'$ = 3.38) and life-span (t_{max} = 4.17 year). Further, asymptotic length (L_∞) of *T. ilisha* was 57.62 cm. Total-, natural- and fishing mortality recorded 2.54, 1.57 and 0.97 year^{-1}, respectively. Exploitation level (E=0.63) was higher than the maximum permissible exploitation (E_{max} = 0.47). Consequently, the fishing composition of *T. ilisha* in the Meghna River was dominated by smaller size (23-29) of fish. Finally, the MSY was estimated at 876,327 MT, if the recommended length at first capture (L_c = 36.35 cm TL) is maintained. The outcomes of the study will be helpful for fisheries scientists, managers and ecologists to develop sustainable management plans and policies to conserve the remaining *T. ilisha* stocks in the Meghna River and neighboring ecosystems.

Chapter

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Temporal variations of length, weight and condition of Hilsa shad, *Tenualosa ilisha* (Hamilton, 1822) in the Meghna River, Southeastern Bangladesh

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ABSTRACT

The current study was on temporal variations of length, weight, and condition of *Tenualosa ilisha* (Hamilton, 1822) from the Meghna River, Southeastern Bangladesh for the period of July 2018 to June 2019. A total of 1433 individuals were collected from the Meghna River (Chandpur and Laxmipur region, SE Bangladesh). Bodyweight (BW) and total length (TL) were measured with 0.01 g and 0.01 cm accuracy for each specimen. The relative condition factor (K_R) was calculated by the equation of Le Cren (1951): $K_R = W/(a \times L^b)$ where W is the body weight (g) and L is the total length (cm) and *a* & *b* is the length-weight relationship parameters estimated with linear regression analyses. The value of $K_R \sim 1$ indicates good health, >1 indicates over bodyweight with compare to length, whereas <1 indicates a relatively poor condition of fish. The TL ranged from 15.3-57.8 cm while the BW was 37.17–2250 g. The overall K_R for *T. ilisha* was 0.65-1.66 in the Meghna River. The maximum K_R was found in July while the minimum was in January. The K_R was strongly correlated with BW in the Meghna River. These findings will help to improve the sustainable management policy of hilsa fishery in the Meghna river ecosystem and other adjacent water bodies.

INTRODUCTION

The national fish of Bangladesh, Hilsa shad, *Tenualosa ilisha* **(Hamilton, 1822)** is a marine, brackish and freshwaters fish belonging the family Clupeidae **(Riede, 2004)**. It is locally known as *ilish* or *ilsha* while the juvenile known as *Jatka* (Shafi and Quddus, 1982). Hilsa shad is rich in minerals, lipids and amino acids **(De *et al*., 2019)**. It has great economic importance as 12% of total fish production of the country came from Hilsa **(DoF, 2019)**. This fish species is distributed in Asian countries including Bangladesh, Nepal, Sri Lanka, India, Pakistan, China, United Arab Emirates and also in Myanmar, Iraq, Iran, Malaysia, Oman, Kuwait, Qatar, Saudi Arabia, Thailand and Viet Nam **(Freyhof, 2014)**. It is abundant in the Meghna River, Padma River, Rupsha River, Sibsha River, Biskhali River, Tetulia River, Arial Kha River, Galachipa Rirver, Pyra River and a small number of other rivers in the coastal area of Bangladesh **(Rahman, 2007)**. This Clupid categorized as least concern (LC) both in Bangladesh **(IUCN Bangladesh, 2015)** and worldwide **(Freyhof, 2014)**.

Condition factors are the most constructive parameters for assessing the health of fish species and the whole aquatic community, as well as to act as functional tools for natural population management and conservation **(Hossain *et al*., 2012a, 2012b; Rahman *et al.*, 2012)**. Moreover, it quantitatively assesses the well-being of fish and predicts its future population success **(Richter, 2007; Hossain *et al.*, 2013a, 2016)**. Furthermore, the relative condition factor (K_R) can be used to examine fish health **(Rypel and Richter, 2008; Hossain *et al.*, 2009, 2013b)** as well as very important to estimate the environmental condition of fishes **(Hossen *et al.*, 2019a)**.

A few studies have been carried out on length weight relationship **(Flura *et al.*, 2015)**, population biology **(Islam *et al.*, 1987; Rahman *et al.*, 1998; Amin *et al.*, 2000; Haldar *et al.*, 2001; Ahmed *et al.*, 2008; Hossain *et al.*, 2019)**, stock assessment **(Gupta, 1989; Amin *et al.*, 2004)**, exploitation status **(Amin *et al.*, 2002, 2008)** of *T. ilisha*. However, to the best of our knowledge, none of these studies cover the condition of fishes covering year round data in the Meghna River and elsewhere. Therefore, the present study was designed to describe the temporal variations of length, weight and condition of *T. ilisha* in the Meghna River, Southeastern (SE) Bangladesh using one-year-round data.

MATERIALS AND METHODS

The present study was conducted in the Meghna River in Bangladesh during July 2018 to June 2019. A total of 1433 specimens were collected from commercial landing stations in Chandpur (23.23, 90.63) and Laxmipur (22.85, 90.67) region (Figure 1), SE Bangladesh. Total length (TL) was measured by measuring board nearest to the 0.01 cm and body weight (BW) were measured by an electronic balance nearest to the 0.01 g for each specimen.

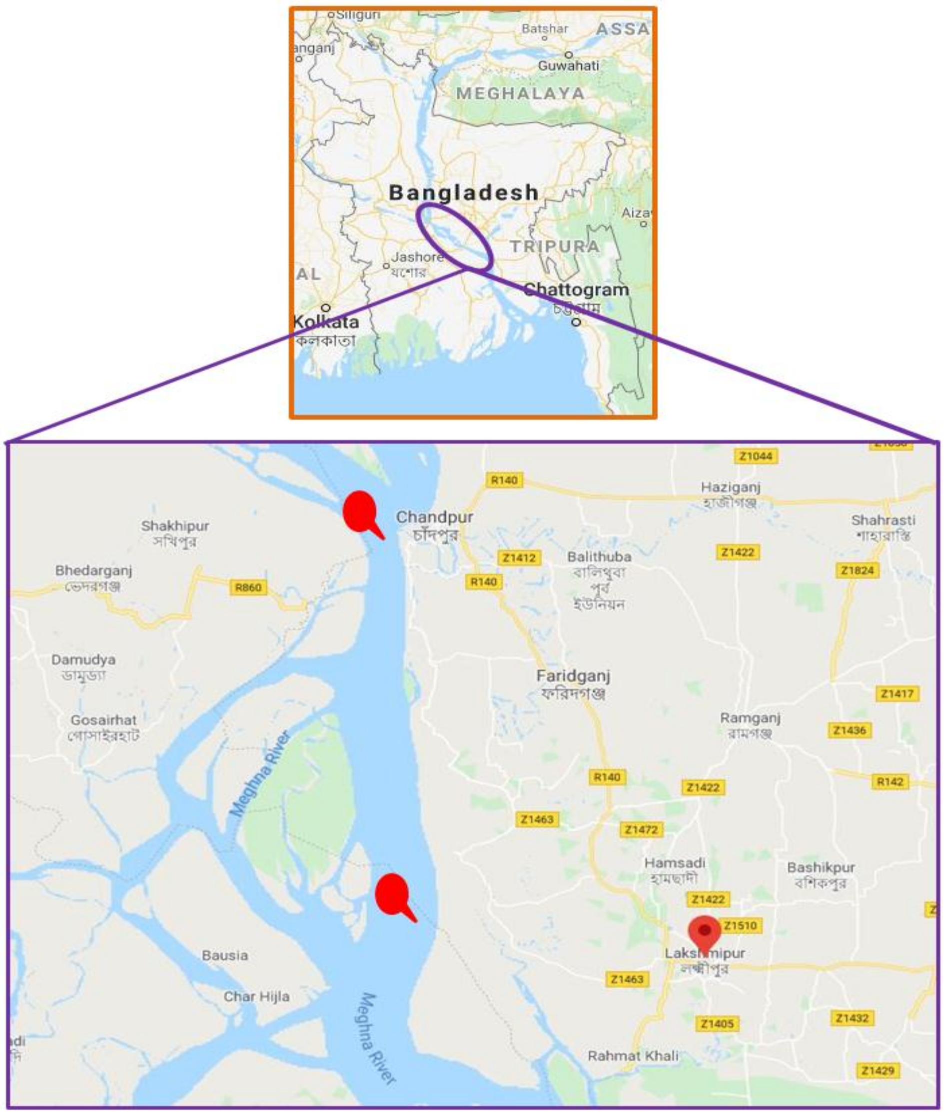

Figure 1. Sampling site [Chandpur (23.23, 90.63) and Laxmipur (22.85, 90.67) region] of *Tenualosa ilisha* in the Meghna River, Southeastern Bangladesh. (Source: https://www.google.com/maps; Accessed: 15 April 2020).

The relative condition factor (K_R) was calculated by the equation of **Le Cren (1951):** $K_R = W/(a \times L^b)$ *where*, W is the body weight (g) and L is the total length (cm) and a & b is the length-weight relationship ($W = a*L^b$) parameters. According to **Le-Cren (1951)**, the value of K_R higher than 1 indicates good health and less than 1 indicates relatively poor condition of the fish.

Statistical analyses were done by GraphPad Prism 6.5 software considered at 5% level of significance ($p < 0.05$) in the study.

RESULTS

During the study, a total of 1433 specimens were collected from the Meghna River. The smallest fish was 15.30 cm in size, while the largest one was 57.80 cm. The BW of *T. ilisha* ranged from 37.17 – 2250.00 g. Monthly variation of TL and BW were showed in Figure 2 and Figure 3, respectively.

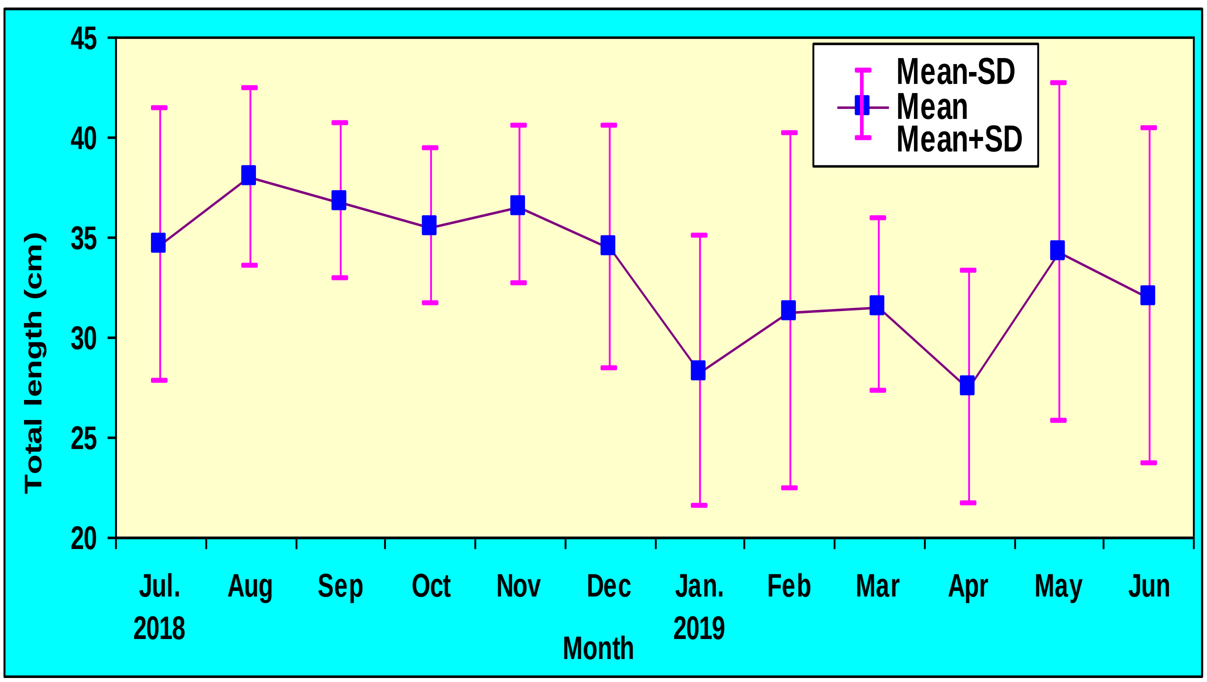

Figure 2. Monthly variations of total length of *Tenualosa ilisha* (Hamilton, 1822) in the Meghna River, Southeastern Bangladesh.

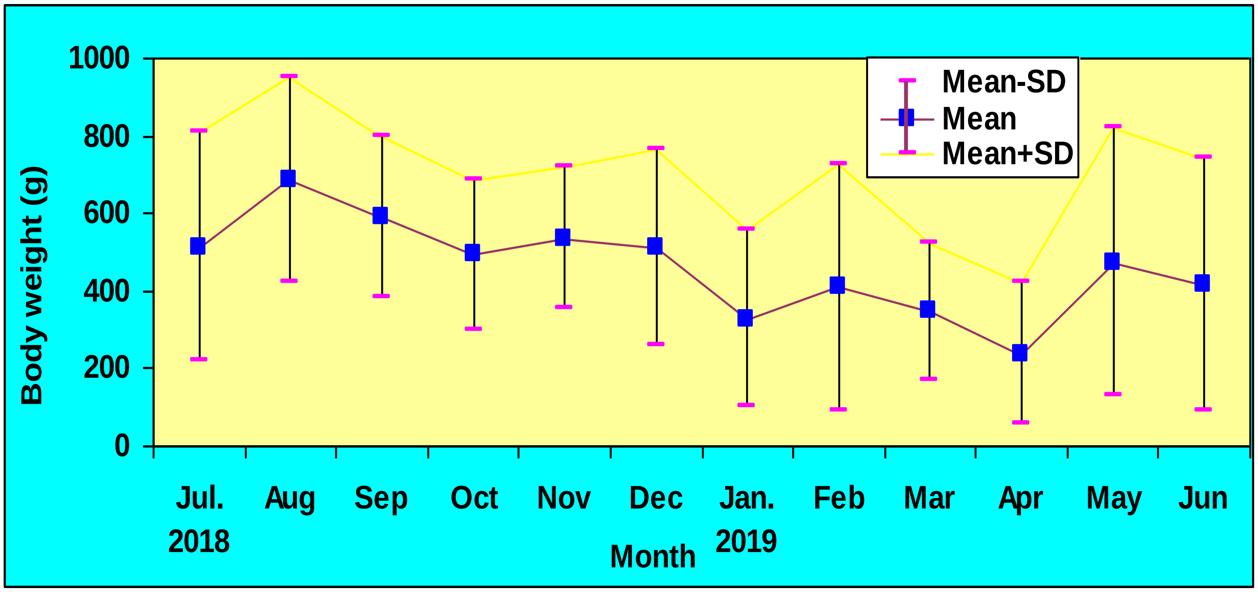

Figure 3. Monthly variations of body weight of *Tenualosa ilisha* (Hamilton, 1822) in the Meghna River, Southeastern Bangladesh.

The minimum value of K_R was 0.65 in January and the maximum value was 1.66 in July. Monthly variations of K_R were showed in Figure 4 and Table 1. Table 2 Showed correlation between TL *vs.* K_R and BW *vs.* K_R.Variations of K_R with TL were showed in Figure 5.

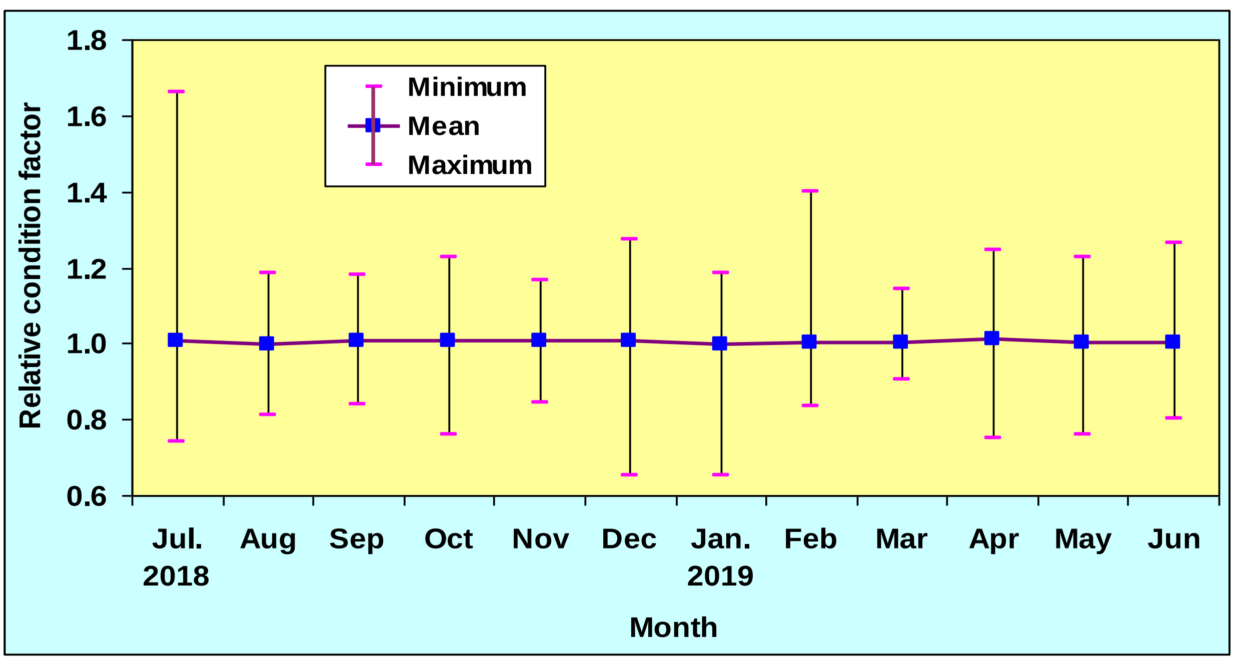

Figure 4. Monthly variations of relative condition factor (K_R) of *Tenualosa ilisha* (Hamilton, 1822) in the Meghna River, Southeastern Bangladesh.

Table 1. Descriptive statistics on Relative condition factor (K_R) measurements and their 95% confidence limits of the *Tenualosa ilisha* (Hamilton, 1822) in the Meghna River, Southeastern Bangladesh

Month	*n*	Relative condition factor (K_R)			
		Min	Max	Mean ± SD	95% CL
Jul. 18	72	0.74	1.66	1.00 ± 0.13	0.98 - 1.03
Aug	103	0.81	1.18	1.00 ± 0.09	0.98 - 1.01
Sep	120	0.84	1.18	1.01 ± 0.08	0.99 - 1.02
Oct	130	0.76	1.23	1.00 ± 0.10	0.98 - 1.02
Nov	124	0.84	1.17	1.01 ± 0.08	0.99 - 1.02
Dec	226	0.65	1.27	1.01 ± 0.13	0.99 - 1.02
Jan. 19	72	0.65	1.18	1.00 ± 0.10	0.97 - 1.02
Feb	76	0.83	1.40	1.00 ± 0.09	0.98 - 1.02
Mar	35	0.90	1.14	1.00 ± 0.06	0.98 - 1.02
Apr	79	0.75	1.24	1.01 ± 0.12	0.99 - 1.04
May	209	0.76	1.22	1.00 ± 0.10	0.99 - 1.01
Jun	187	0.80	1.26	1.00 ± 0.09	0.99 - 1.02
Overall	1433	0.65	1.66	1.00 ± 0.10	0.99 - 1.01

n, Sample Size; Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, Confidence Limit

Table 2. Correlation of relative condition factor (K_R) with total length (TL) and body weight (BW) with 95% confidence limits of the *Tenualosa ilisha* (Hamilton, 1822) in the Meghna River, Southeastern Bangladesh

Correlation	r_s values	95% CL of r_s	*p* value	Level of significance
TL *vs.* K_R	0.0226	-0.0308 to 0.0758	0.3927	ns
BW *vs.* K_R	0.1530	0.1005 to 0.2046	< 0.0001	****

r_s, Spearman rank-correlation values; CL, confidence limit; *p*, shows the level of significance; *ns*, not significant; **** very highly significant

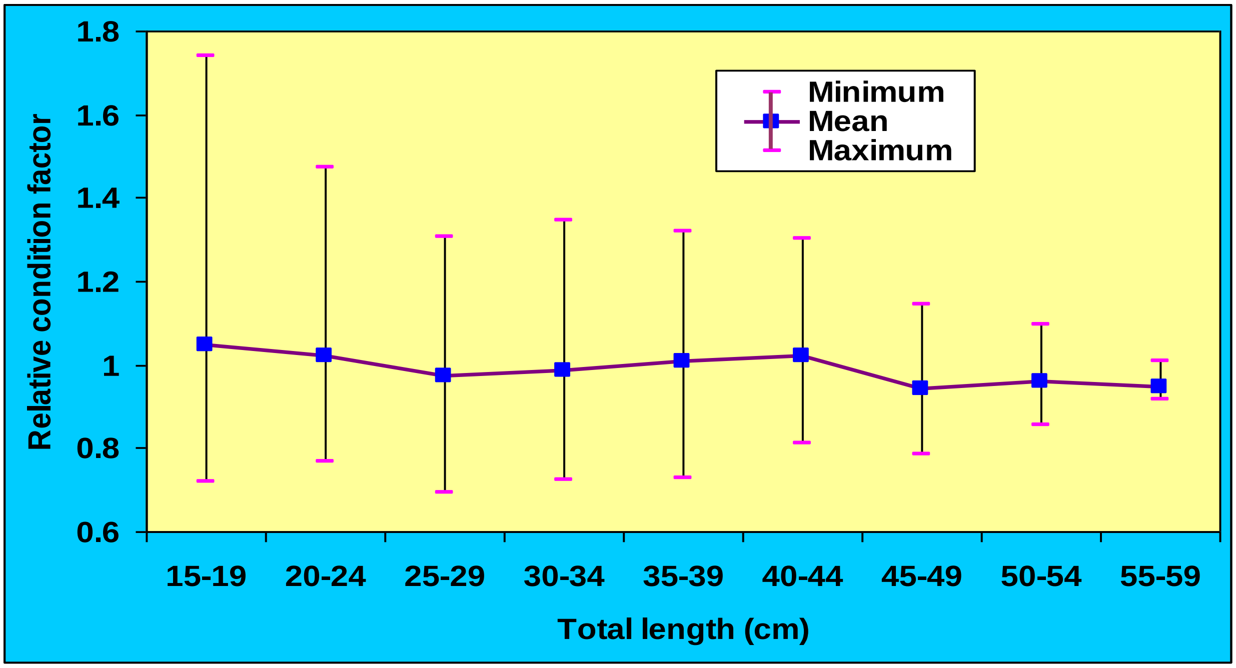

Figure 5. Variations of relative condition factor (K_R) with total length of *Tenualosa ilisha* (Hamilton, 1822) in the Meghna River, Southeastern Bangladesh.

DISCUSSION

Information on condition of *T. ilisha* in the Meghna River is scant. A large number of specimens of various body sizes were collected from commercial catch of the Meghna River in Chandpur and Laxmipur regions throughout the year. However, absence of smaller than 15.3 cm TL during the study may be attributed to the selectivity of fishing gear or low market price **(Rahman *et al.*, 2019a, b; Hossen *et al.*, 2019b; Azad *et al.*, 2018)**.

In the study, we found the maximum length as 57.8 cm TL which was more or less similar to the study (57 cm) of **Rahman *et al.*, (1999)** and **Amin *et al.*, (2002)** in Bangladesh and **Al-Baz & Grove (1995)** in Kuwait but smaller than the study (61 cm) of **Amin *et al.*, (2004)**, though FishBase **(Froese and Pauly, 2020)** showed a maximum length of 60 cm. All other studies **(Flura *et al.*, 2015; Sarkar *et al.*, 2017; Roomiani and Jamili, 2011; Bhakta *et al.*, 2019; Mohanty and Nayak, 2017; Bhaumik *et al.*, 2011)** found the body length were smaller than the current study. Essentially, maximum length is a helpful tool to estimate the growth parameters *i.e.*, asymptotic length, growth coefficient, thereby important for fisheries management and resource planning **(Hossain *et al.*, 2009; 2014)**.

Mean TL and BW were comparatively smaller in January. September-October is the peak spawning season of Hilsa shad **(Hossain *et al.*, 2014)** and in January they recruit in the adult stock. Another small peak was in February **(Mathur, 1964)**. The juvenile recruit in April and thus they are small in size and weight. In August maximum mean length and weight found as presence of much more food in the River.

During the study, relative condition factor (K_R) was studied to evaluate the overall health and productivity of *T. ilisha* in the Meghna River. Mean K_R value throughout the year indicated a balance habitat for hilsa population. The present study found minimum and maximum K_R value in January and July, while **Sarkar *et al*. (2017)** stated in August and June in Hooghly estuarine system, India. K_R value may higher during spawning season **(Khan *et al.*, 2001)**. The difference may be occurred due to maturity of gonads, amount of undigested food in the alimentary canal and changes in amount of fat stored in body tissue **(Hossain *et al.*, 2017)**.

Smaller size specimen indicated the higher value of K_R as they have high feeding density. The value gradually decreased with increasing the length as gonadal development occurs. **Mohanty and Nayak (2017)** also indicated same matter for *T. ilisha* in the Chilika Lake, India. **Reuben (1992)** stated that an early stage of fish has higher K_R value. Though, **Welcome (1979)** reported that condition factor in fish decreases with decreasing in size and is also influenced by the reproductive cycle.

Overall K_R of our study was within 0.99-1.01 while **Mandal *et al.*, (2018)** reported K_R value varied between 0.98-1.04 and **Sarkar *et al.* (2017)** observed it from 0.98 to 1.05 for *T. ilisha* from India.

CONCLUSION

The current study designated temporal variation of length, weight and condition of *T. ilisha* from the Meghna River, SE Bangladesh. This study described on fish health depending on the relative condition factor. The findings of this study will help to improve sustainable management policy of hilsa fishery in the Meghna River ecosystem and other adjacent waterbodies.

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Temporal Variation of Growth Pattern and Physiological Status of Hilsa Shad, *Tenualosa ilisha* (Hamilton, 1822) in the Meghna River (Bangladesh)

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ABSTRACT

The current study was conducted on the temporal variation of the growth pattern and the physiological status of *Tenualosa ilisha* (Hamilton, 1822) from the Meghna River, Bangladesh for the period of July 2018 to June 2019. A sum of 1433 individuals were collected, where its body weight (BW), total length (TL), standard length (SL) and fork length (FL) were measured with 0.01 g and 0.01 cm accuracy. The growth pattern was estimated through length-weight relationship by the equation: $BW = a \times TL^b$, where BW was in g and TL in cm. The parameters *a* and *b* were estimated with linear regression analyses. Physiological status was determined using equation provided as follows: $\bar{a} = W/L^b$. If $\bar{a}$ was close to the *a* value (*a*, LWR parameter) then the fish was in an ideal condition, where $\bar{a} > a$ pointed to fatty fish and $\bar{a} < a$ to lean fish. The TL ranged from 15.3cm to 57.8 cm while the BW was from 37.17–2250 g. The overall growth pattern for *T. ilisha* was positive allometric (b = 3.135) in the Meghna River. The maximum fatty fish was found in the month of December (44%) while the minimum was in October. The highest percentage of lean fish was found in the monthof February (41%) and the lowest was in September (22%). The present findings would add some beneficial data for consumer preference, meanwhile further studies are recommended to achieve a sustainable management of hilsa fishery and other water bodies in the Meghna River.

INTRODUCTION

Tenualosa ilisha is locally known as ilish, ilsha or hilsa **(Shafi & Quddus, 1982)** in Bangladesh. This euryhaline species is found in marine, brackish and freshwater habitats occurring Bay of Bengal, Indian Ocean, Arabian Sea and Persian Gulf **(Amin *et al.*, 2005)** covering the country of Bangladesh, India, Sri Lanka, Iran, Iraq, Kuwait, Malaysia, Oman, Pakistan, Sumatra, Qatar, Saudi Arabia, Thailand, United Arab Emirates and Viet Nam **(Arai & Amalina, 2014; Freyhof, 2014)**. It is a commercially essential target species for large-scale fishers in Bangladesh and elsewhere in Asia. About 76% of the global hilsa production is supported from Bangladesh while Myanmar, India and other country (Including Thailand, Iran, Malaysia, Iraq, Kuwait, Indonesia, and Pakistan) cover only 15%, 4% and 5%, respectively **(Islam *et al*., 2016)**. Tropical anadromous fish hilsa **(Riede, 2004)** often shows schooling behavior **(Hossain *et al*., 2019)** and migrate from the Bay of Bengal into inland freshwater primarily the Meghna, Tetulia and Andermanik rivers to spawn **(Hossain *et al*., 2014)**. After developing into juveniles (locally known as *Jatka*) fish hilsa return to the open sea. The Meghna River ecosystem is a major spawning ground of hilsa from where 18% of the total country hilsa production is introduced **(Hossain *et al*., 2018)**.

Length frequency distribution (LFD) provides information on reproductive potential **(Khatun *et al*., 2018)**, dynamic growth rates, recruitment and mortality **(Neuman and Allen, 2001)** of fish population as well as definite the river health **(Ranjan *et al*., 2005)**. Growth pattern can be identified using morphometric studies *i.e.*, length-weight relationship (LWR) throughout the study period. Growth pattern of fish are used to execute the seasonal deviation of growth and conditions to compare the life history and to assess the unit stock differences **(King, 2007; Hossen *et al*., 2020; Khatun *et al*., 2020; Sabbir *et al*., 2020)**. Physiological status of fish (*i.e*., ideal, fatty or lean) helps to recognize the physiology of an individual fish species **(Sutharshiny *et al*., 2013)** which supports fisheries' management as well as consumer preference.

Several studies have been conducted on *T. ilisha* on the basis of population biology **(Amin *et al*., 2000; Halder *et al*., 2001; Amin *et al*., 2002; Halder & Amin 2005; Ahmed *et al*., 2008)**, exploitation status **(Amin *et al*., 2008)**, stock assessment and management **(Amin *et al*., 2004; Bhaumik, 2016; Rahman *et al*., 2018)**, Jatka fishing and sustainability **(Rahman *et al*., 1995; Miah *et al*., 2000)**, length weight relationship **(Dutta *et al*., 2012; Nima *et al*., 2020)** etc. However, to the best of our consciousness, none of these studies has covered the demographic information of growth pattern or the physiological condition of *T. ilisha*. Therefore, to describe the growth pattern and physiological status of *T. ilisha*, the present investigation was conducted in the Meghna River, southeastern (SE) Bangladesh using a monthly data over one year.

MATERIALS AND METHODS

***Study site and* sampling:** This research was done in the Meghna River in southeastern Bangladesh from July 2018 to June 2019. A total of 1433 individuals of *T. ilisha* were sampled randomly on monthly basis from the commercial catch at several palces in Chandpur region, SE Bangladesh. Fishers used traditional fishing gears seine net (*Ber jal*; mesh size: 2.5-6.5 cm), and gill net (*Chandi* or *ilish jal*; mesh size: 9-12 cm, *Chap jal*; mesh size: 7-15 cm) to catch the fish. After collection, they were immediately preserved in ice at the site.

***Fish* measurement:** In the laboratory, total length (TL) was estimated by a measuring board nearest to the 0.01 cm. For body weight (BW), an electric balance to the precision of 0.01 g accuracy was used for each individual.

***Length-frequency distribution (LFD) and Growth* pattern:** The length-frequency distribution for *T. ilisha* was estimated by using 1 cm intervals of TL. The growth pattern was estimated by length-weight relationship: $BW = a \times TL^b$, where BW was the total body weight (g) and TL was the total length (cm). The parameters *a* and *b* were calculated through: $ln\ (W) = ln\ (a) + b\ ln\ (L)$. Furthermore, 95% confidence limits of *a*, *b* and the coefficient of determination r^2 were assessed. Extreme outliers from the regression analyses were omitted according to **Froese (2006)**. The value of exponent (*b*) provides information on growth pattern of fish. A value of 3 specifies an isometric growth and other than 3 indicates that the growth is allometric **(Beverton & Holt, 1996)**. To validate the growth pattern *i.e.*, isometric or allometric (negative or positive) for significant divergence from the isometric value of *b*, a t-test was applied **(Sokal & Rohlf, 1987)**.

***Physiological* status:** Individual physiological condition (*i.e.*, ideal, lean or fatty) for *T. ilisha* was estimated using equation provided by **King (2007)** as: $\bar{a} = BW/TL^b$. If $\bar{a}$ is near to the *a* value (*a* is the LWR parameter), it point to the fish is in ideal condition, whereas variation from the *a* value is revealing of either fatty or lean fish ($\bar{a} > a$ point to fatty fish and $\bar{a} < a$ to lean fish).

***Statistical analysis*:** All statistical analyses were implemented through GraphPad Prism 6.5 software in this study considering a significance level of 5% ($p < 0.05$). Before analysis, similarity and normality of data were checked.

RESULTS

Length-frequency distribution (LFD)

The LFD for *T. ilisha* exposed that the smallest individual was 15.3 cm in TL while the largest one was 57.8 cm in TL (Table 1). LFDs showed that the 35-42 cm TL size group was numerically dominant in the stock (Figure 1). Additionally, most of the individuals were of 36-37 cm TL size group, that is about (6.62%), while those from 40-41 cm were 6.35% individuals.

Table 1. Descriptive statistics on Total Length (TL) and body weight (BW) measurements and their 95% confidence limits of the *Tenualosa ilisha* (Hamilton, 1822) in the Meghna River of southeastern Bangladesh

Sampling month	*n*	Total length (cm)				Body Weight (g)			
		Min	Max	Mean ±SD	95% CL	Min	Max	Mean±SD	95% CL
Jul. 2018	72	17	53	34.58±6.80	32.98-36.18	78	1458	513.19±294.94	443.89-582.50
Aug.	103	27.5	51	37.95±4.45	37.08-38.82	248	1555	686.47±262.66	635.13-737.80
Sep.	120	27	48	36.77±3.84	36.07-37.46	200	1265	588.93±208.78	551.19-626.66
Oct.	130	25.5	48	35.49±3.89	34.82-36.17	174	1185	493.12±193.91	459.47-526.76
Nov.	124	28.5	47	36.51±3.93	35.81-37.20	225	1056	536.07±182.36	503.66-568.49
Dec.	226	19.7	44.5	34.45±6.09	33.65-35.25	54.98	969	511.55±25158	478.57-544.52
Jan. 2019	72	18	41.6	28.24±6.74	26.66-29.83	54.98	921	328.27±228.43	274.59-381.95
Feb.	76	18.9	46.2	31.26±8.92	29.22-33.30	70.68	1100	408.22±318.76	335.38-481.05
Mar.	35	26	42.5	31.56±4.34	30.07-33.05	173	933	345.63±175.25	285.43-405.83
Apr.	79	15.3	43.6	27.49±5.82	26.18-28.79	37.17	929	238.16±183.75	197.00-279.32
May	209	15.3	55.5	34.2±8.43	33.05-35.35	37.17	1800	473.10±344.44	426.14-520.07
Jun.	187	18.5	57.8	32.05±8.37	30.84-33.26	68	2250	415.87±324.24	369.09-462.65

n, Sample Size; Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, Confidence Limit

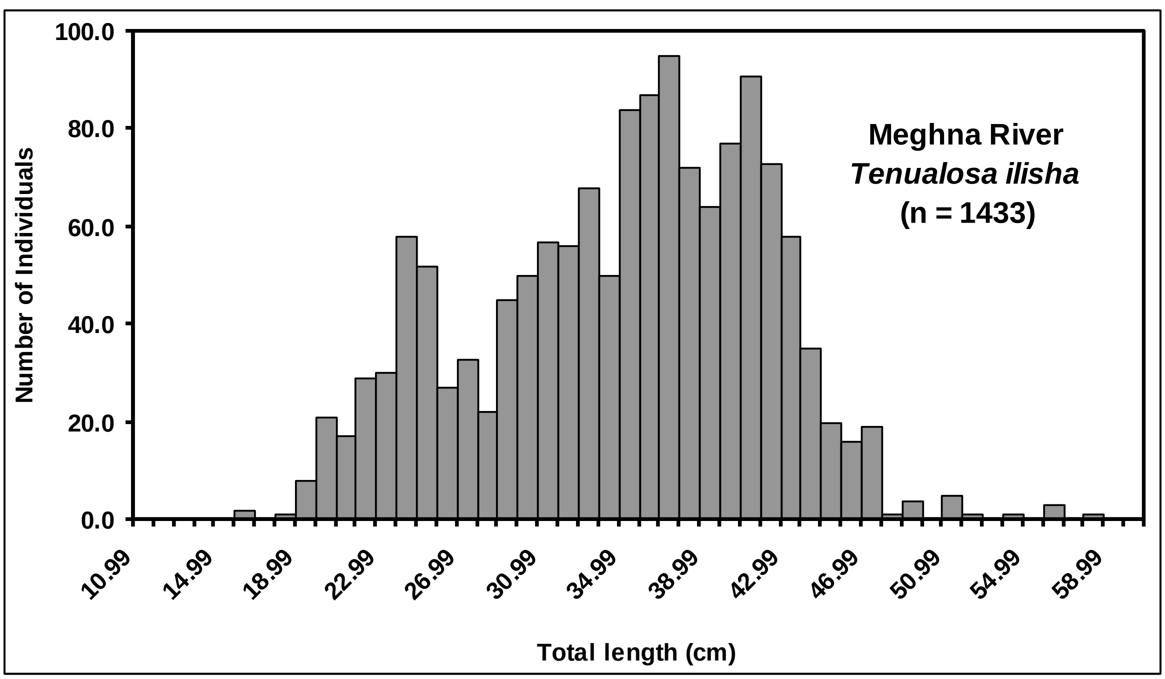

Figure 1. Length frequency distribution of the *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh

Growth pattern

The BW of *T. ilisha* ranged from 37.17–2250 g during the study period from the Meghna River. Monthly descriptive statistics estimated parameters of the LWR of *T. ilisha* in the Meghna River were shortened in Table (2).

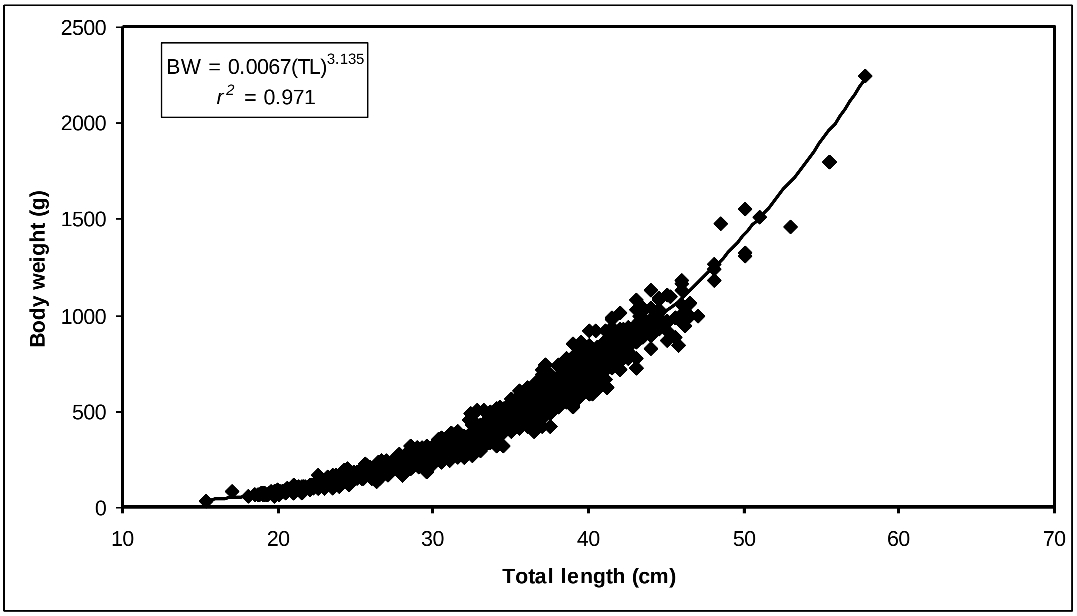

Figure 2. Length weight relationship of the *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh

The allometric coefficient (*b*) for the LWR indicated a positive allometric growth pattern in most cases. Negative allometric growth was found in February while isometric growth showed up in June, July and December. However, the overall *b* value designated a positive allometric growth (b = 3.135) that is shown in Figure (2). Monthly deviations of length for hilsa shad are stated in Figure (3), whereas Figure (4) shows the variation of *b* value. All LWRs were highly significant ($p < 0.0001$), with all r^2 values ≥ 0.950.

Table 2. Descriptive statistics and estimated parameters of the length-weight relationships ($BW = a \times TL^b$) of the *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh

Month	Regression parameters		95% CL of *a*	95% CL of *b*	r^2	GT
	a	***b***				
Jul. 2018	0.0078	3.098	0.0048-0.0126	2.962-3.235	0.967	I
Aug.	0.0058	3.201	0.0034-0.0097	3.057-3.345	0.951	A+
Sep.	0.0048	3.238	0.0030-0.0078	3.106-3.371	0.952	A+
Oct.	0.0018	3.492	0.0010-0.0032	3.332-3.652	0.936	A+
Nov.	0.0066	3.130	0.0042-0.0105	3.001-3.258	0.950	A+
Dec.	0.0095	3.050	0.0069-0.0131	2.959-3.141	0.951	I
Jan. 19	0.0049	3.273	0.0035-0.0067	3.175-3.372	0.984	A+
Feb.	0.0108	2.998	0.0085-0.137	2.928-3.067	0.990	A-
Mar.	0.0051	3.202	0.0030-0.0086	3.052-3.352	0.983	A+
Apr.	0.0053	3.181	0.0035-0.0082	3.051-3.311	0.969	A+
May	0.0068	3.104	0.0056-0.0082	3.050-3.157	0.984	A+
Jun.	0.0078	3.079	0.0066-0.0091	3.033-3.125	0.989	I
Overall	0.0067	3.135	0.0060-0.0074	3.107-3.163	0.971	A+

Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, Confidence Limit; GT, Growth Type

Length-length relationships (LLRs) were also estimated that were greatly correlated with r^2 values ≥ 0.983 and presented in Table (3) and Figure (5). By LLRs one can compare different body length (*i.e.*, TL, FL & SL).

Table 3. The estimated parameters of the length-length relationships ($y = a + b \times x$) of *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh

Equation	Regression parameters		95% CL of *a*	95% CL of *b*	r^2
	a	***B***			
TL = *a* + *b*× FL	1.2800	1.094	1.0872 to 1.4728	1.088 to 1.101	0.988
TL = *a* + *b*× SL	1.9414	1.174	1.7216 to 2.1613	1.182 to 1.166	0.983
SL = *a* + *b*× FL	-0.3366	0.925	-0.498 to -0.176	0.919 to 0.930	0.988

TL, total length; FL, fork length; SL, standard length; *a* and *b* are the regression parameters; CL, confidence intervals; r^2, co-efficient of determination

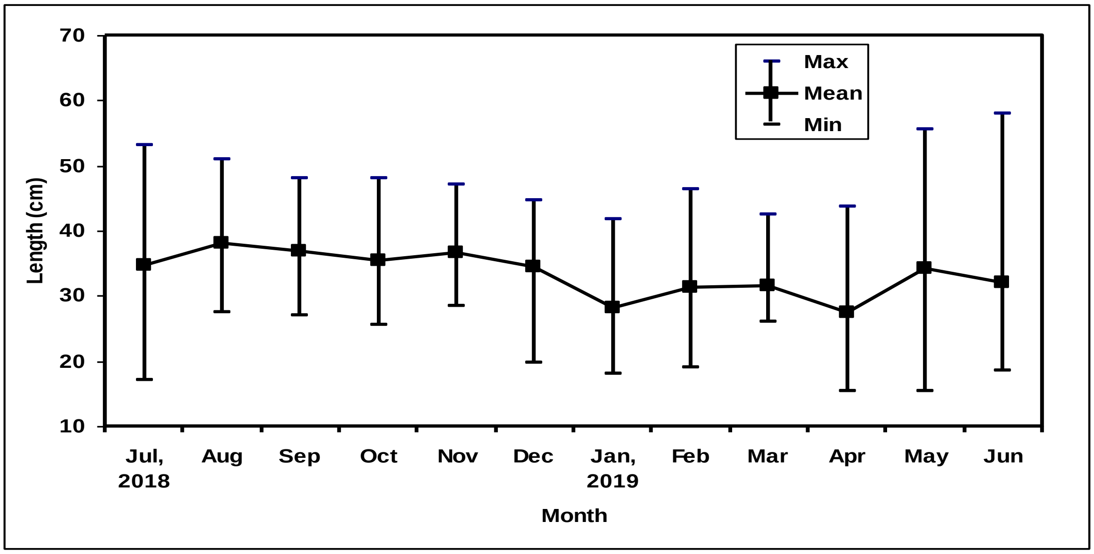

Figure 3. Monthly variation on minimum, mean and maximum length of the *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh

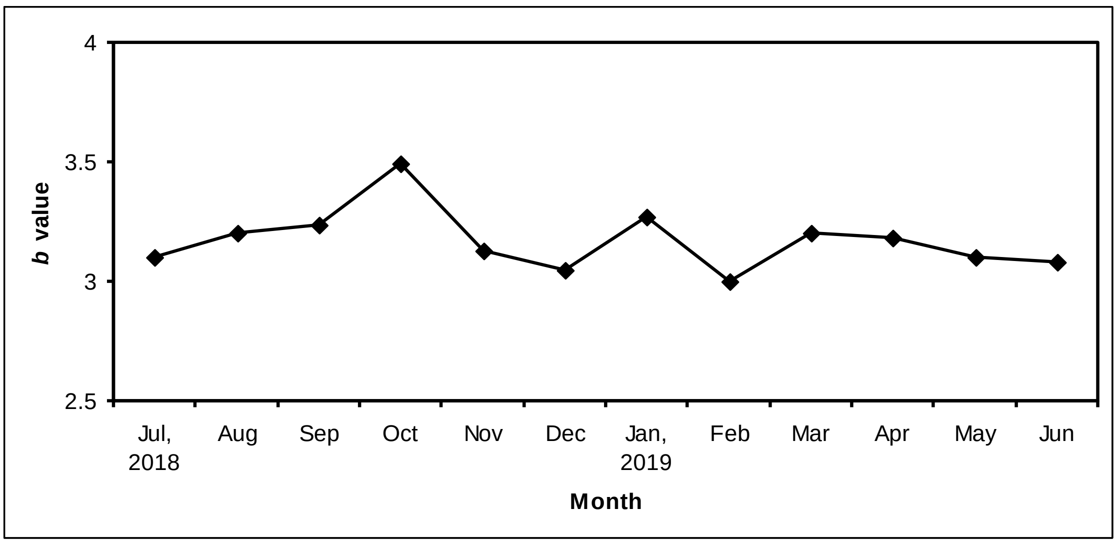

Figure 4. The generalized ln-ln relationships between total length and body weight of the *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh

Physiological status

In the current study, the maximum proportion of fatty fish was found in December (44%). The percentage of fatty fish started to increase in April and continued until July. Beginning from August, fatty fish began to decrease gradually and reached its minimum in October. After November, it gradually increased and continued to increase before February. The maximum percentage of lean fish was found in February (41%) and the lowest was in September (22%). The monthly deviations of physiological condition *i.e.*, ideal, lean or fatty for *T. ilisha* are given in Figure (6).

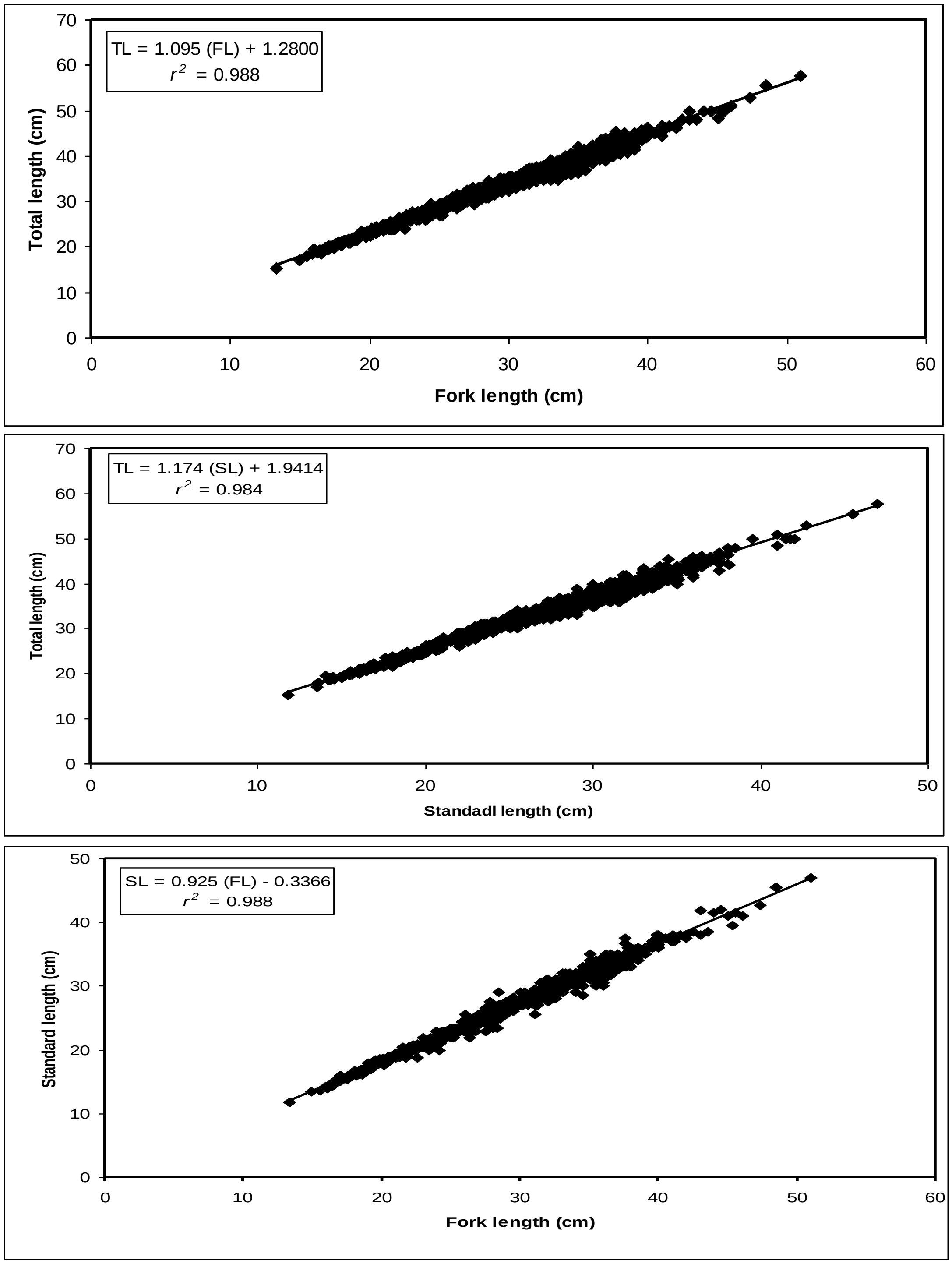

Figure 5. Length-length relationship (TL *vs.* FL, TL *vs.* SL & SL *vs.* FL) of the *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh

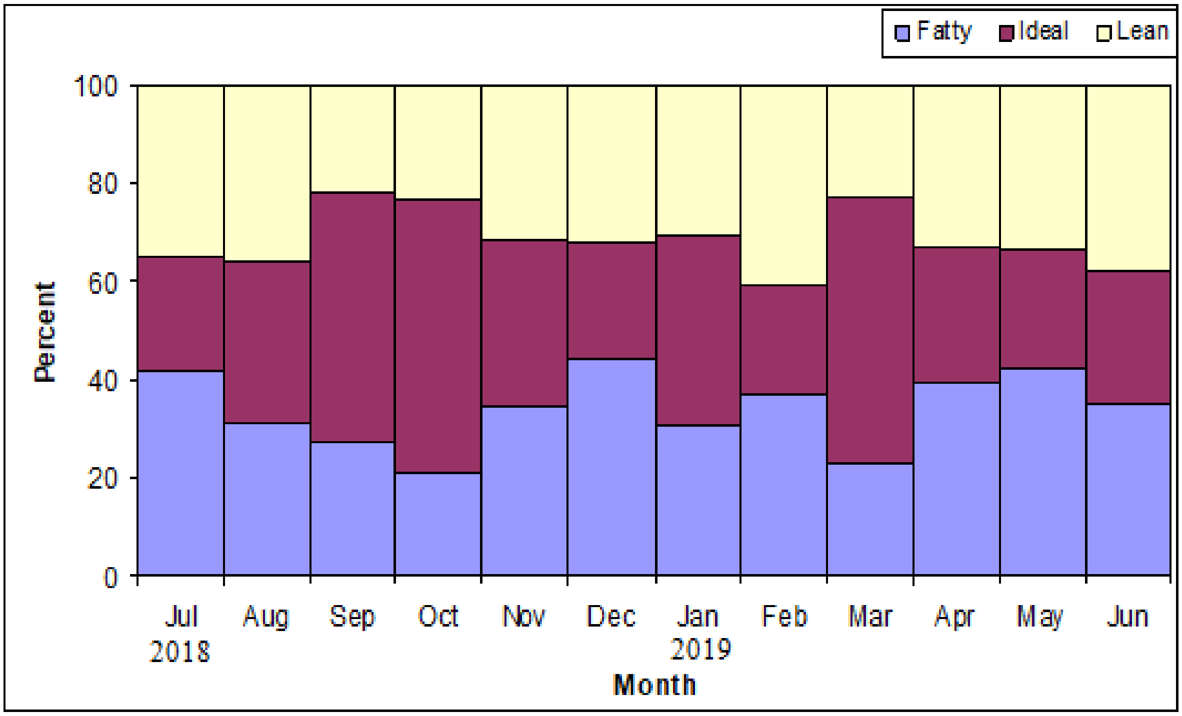

Figure 6. Monthly variation of physiological condition (*i.e.*, ideal, fatty or lean) for *Tenualosa ilisha* in the Meghna River of southeastern Bangladesh

DISCUSSION

A few studies have been presented on several aspects of Hilsa shad *T. ilisha.* However, a study on physiological condition *i.e.*, ideal, lean or fatty of Hilsa has not been conducted so far. To fill the gap, the present investigation was done in the Meghna River, SE Bangladesh by collecting a large number of individuals covering different body length throughout the year. Absence of specimens smaller than 15.3 cm can be accredited to fishing gear selectivity or absence of smaller individuals throughout the sampling **(Azad *et al*., 2020; Islam *et al*., 2020)**. In the present study, 57.8 cm fish was found which was more or less similar to the study (57 cm) of **Rahman *et al*. (1999)**, **Amin *et al*. (2002)** in Bangladesh. Furthermore, **Al-Baz and Grove (1995**) found a 57 cm fish in Kuwait. In comparison, that was smaller than the study (61 cm) of **Amin *et al*. (2004)** though fishbase showed a maximum length of 60 cm **(Forese & Pauly, 2020)**. On the contrary, other researchers **(Bhaumik *et al*., 2011; Roomiani & Jamili, 2011; Sarker *et al*., 2017; Bhakta *et al*., 2019)** have reported that the body lengths were smaller than the current study. However, difference in body length may be ascribed to geographic distribution and influences of environment like water temperature, food availability, etc.. **(Hossain *et al*., 2015; Hassan *et al*., 2020)**.

The value of *b* from the LWRs may vary between 2 and 4 though, values ranging from 2.5-3.5 are also common **(Hassan *et al*., 2020)**. When the value of *b* is close to 3

(b≈3.0) it indicates an isometric growth, but any significant difference from 3 indicates allometric growth pattern. When the value is > 3 would indicate a positive allometric and < 3 gives a negative allometric **(Tesch, 1971)**. The present study remained the value of b within 2.998 to 3.492 which was in the expected range for fish species **(Froese, 2006)**. The overall b value (b = 3.135) of the current study showed positive allometric growth. The present findings are similar to those of **Sujansingani (1957)** and **Bhaumik *et al*. (2011)** from Hoogly estuary (India). Moreover, current results agree with those of **Al-Baz & Grove (1995)** from Kuwait. Isometric growth pattern was stated by **Amin *et al*. (2002)** in Bangladesh, **Bhakta *et al*. (2019)** in Gujarat India and **Mahamed *et al*. (2016)** in Iraq. A negative allometric growth was observed by some other researcher including **Rahman *et al*. (2000), Amin *et al*. (2004),** and **Rahman *et al*. (2018)** in Bangladesh**, Das *et al*. (2019), De & Datta (1990), Sarker *et al*. (2017)** in India, **Roomiani & Jamini (2011)** in Persian Gulf, Iran. However, the variation in growth pattern might be associated with various reasons including fish health, sex, food availability, gonad maturation, nitration, habitat suitability, seasonal environmental effect on habitat, preservation method and differences in the observed length ranges of the captured specimens **(Hossain *et al*., 2013; Hasan *et al*., 2020),** which were not taken into account during this study.

In the present study, minimum number of fatty fish was found in October and the lowest percentage of lean fish was in September due to peak-spawning season **(Rahman *et al*., 2012)**. Percentage of fatty fish started to increase in November and the maximum fatty fish (44%) was found in December attributable to resting phase after peak-spawning season. The maximum percentage of lean fish was found in the month of February (41%). **Hossain *et al*. (2019)** indicated that the abundance of juvenile hilsa was found during January to May in the River Meghna. A minor peak-spawning was also detected throughout February to April by **Mathur (1964)** and **Moula *et al*. (1991)**. The percentage of fatty fish started to increase in April and continued until July. Juvenile fish become nourished in the Meghna River that is the largest nursery ground for hilsa and return to Bay of Bengal with their parents **(Hossain *et al*., 2019)**. Physiological status of fish may also be fluctuating due to environmental effect on habitat, habitat changes, primary productivity, food availability or nutrition etc.

CONCLUSION

The current study designated temporal variation of growth pattern and physiological status of *T. ilisha* from the river Meghna, Bangladesh. The findings would be cooperative for consumer preference as well as support to maintain a sustainable management of hilsa fishery in the Meghna River ecosystem and other adjacent water bodies.

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