Thesis for the Degree of Master of Fisheries Science

Population Dynamic and Stock Assessment of Hilsa (*Tenualosa ilisha*) in the Kuakata Coast of Bangladesh

by

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Population Dynamic and Stock Assessment of Hilsa (*Tenualosa ilisha*) in the Kuakata Coast of Bangladesh

방글라데시 쿠아 카타 연안 힐사(*Tenualosa ilisha*)의 개체군 역학 및 자원 평가

Advisor: Prof. S. M. Nurul Amin

by

Miah Md Sagir

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Population Dynamic and Stock Assessment of Hilsa (*Tenualosa ilisha*) in the Kuakata Coast of Bangladesh

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Abstract

Studied population dynamic and stock assessment of Hilsa (*Tenualosa ilisha*) in the Kuakata Coast of Bangladesh. This study aims to estimate relative growth pattern, mortalities, exploitation and stock status of tropical shad, *Tenualosa ilisha* in Bangladesh. Total number of *T. ilisha* was collected for this study was 2625 from the Kuakata coast of Bangladesh between June 2020 and February 2021. The minimum and maximum total lengths was 9.00 cm and 50.10 cm, while minimum and maximum total weights was 47.76 and 1257.44 gm, respectively. Mean total length and body weight of *T. ilisha* was 30.27 (± 9.37) cm and 386.1 (± 229.1) gm, respectively. Length-weight relationship model of *T. ilisha* was established and the model equation was $W = 0.0104L^{3.0104}$ ($r^2 = 0.9259$). The natural and fishing mortality was 1.53 yr^{-1} and 0.88 yr^{-1}, respectively. The calculated exploitation level (E) was 0.63 which was 26% higher than optimum exploitation (E = 0.50). Current yield-per-recruit (YPR) was 69.50 g. Estimated F_{max}, $F_{0.1}$ and $F_{40\%}$ were 1.25 yr^{-1}, 0.84 yr^{-1} and 0.79 yr^{-1}, respectively. Current fishing mortality was estimated at 0.88 yr^{-1} that was 5% higher than $F_{0.1}$. The maximum sustainable yield (MSY) of Hilsa was estimated as 471,707 tons. The current production (550,000 tons) of hilsa in Bangladesh waters was 16% higher than the MSY. Therefore, it might be concluded that the stock of hilsa fishery is over exploited condition in Bangladesh waters.

CHAPTER 1: INTRODUCTION

1.1 Background of the Study:

The anadromous clupeid fish Hilsa (*Tenualosa ilisha*) (subfamily Alosinae) is the national fish of Bangladesh (Rahman 2007). It is a high-volume and very dominant fish in Bangladesh. Since it contains important micronutrients, minerals, and polyunsaturated fatty acids (i.e. omega-3 fatty acids) in its flesh and other edible part of the body, the fish has tremendous beneficial effects on human health. It is widely distributed in tropical and sub-tropical countries like Bangladesh, India, Myanmar, Pakistan, Iraq, Kuwait, Bahrain, Indonesia, Malaysia, and Thailand. Bangladesh is the world's leading producer of Hilsa, followed by Myanmar and India. The average annual global shares of hilsa have shifted mostly to Bangladesh at 86.7% followed by India, Myanmar, Iran, Iraq, Pakistan, and Kuwait at 8.0, 4.0, 1.1, 0.2, 0.1, and 0.3%, respectively (Rahman et al, 2018). Hilsa accounts for approximately 30% of Bangladesh overall fish output. In this fishery, about 2% of the population is directly involved. It has a major economic effect.

1.2 Problem statement:

Many studies on the population dynamics and stock assessment of the Hilsa fishery in Bangladesh have already been reported, (Alam et al., 2017-2018; Rahman and Cowx 2008; Amin et al., 2002, 2004, 2008; Including Hilsa (Rahman et al., 1999-2000; Glamuzina et al., 2017; Amin et al., 2008; Gayanilo et al., 2005; Venema and van Zalinge 1989; Sparre et al., 1989; BOBP 1987).

Although there has been a lot of research and studied on population dynamic and stock assessment of Hilsa in Bangladesh, no detailed research has been conducted to optimize length at first capture for the highest yield per recruit (YPR) and spawning biomass per recruit (SBPR). Therefore, there is no clear science base evidence about growth and recruitment overfishing of *T. ilisha* in Bangladesh waters. Subsequently, there is a gap of information for management issue of hilsa fishery in Bangladesh.

1.3 Objectives:

1. To estimate the population parameters like as asymptotic length ($L\infty$), growth co-efficient (K), total mortality (Z), natural mortality (M), fishing mortality (F) and exploitation rate (E).
2. To determine the optimum length at first capture (L_c) for the highest yield-per-recruit (YPR) and spawning biomass-per-recruit (SSB/R) of hilsa.
3. To estimate the maximum sustainable yield (MSY).

CHAPTER 2: LETURTURE REVIEW

2.1 Morphology and Taxonomy of Hilsa:

Hilsa has 18-21 dorsal soft rays and anal soft rays but no dorsal spines. There are 30 to 33 skates on the belly. In the upper jaw, there is a distinct median notch. Gill racers are small and numerous, ranging from 100 to 250 on the lower part of the arch, with hyaline fins. In juveniles, a dark blotch appears behind the gill opening, accompanied by a series of small spots along the flank. Life is full of color, silver flecked with gold and purple.

The taxonomy of the species, defined below, is based on the studies of Pillay and Rosa (1963), Whitehead (1985), Shad Foundation (1998), FishBase (2012):

Systemic position:

Kingdom:	**Animalia**
Phylum:	**Chordata**
Class:	**Actinopterygii**
Order:	**Clupeiformes**
Family:	**Clupeidae**
Genus:	***Tenualosa***
Species:	***T. ilisha***

2.2 Habitat and Distribution:

The fish is marine, freshwater, brackish, pelagic-neritic, anadromous, and can be found in depths of up to 200 meters. In both marine and freshwater, the size is 34^0N- 5^0N, 42^0E- 97^0E. 41.5 cm maturity length, 36.0 cm common length (male), 42 cm (female). It can reach a maximum length of 60 cm, weights up to 3 kg, and have a maximum recorded age of 5 years. It can be found in Bangladesh, Pakistan, Myanmar, (also known as Burma), and the Persian Gulf region, where it can be found in the Tigris and Euphrates rivers in and around Iran and southern Iraq.

2.3 Fishery Status and Importance of Hilsa:

For the exclusive economic zone, Bangladesh has 4.7 million hectares of inland water areas and 166,000 square kilometers of marine areas. At the time, Bangladesh’s unusual climate of year-round sunlight and temperature, as well as its abundant water, provided favorable conditions for fish growth and development. Bangladesh are known for their love of fish. In Bangladesh, fish is an important part of people’s diets, livelihoods, and culture. Fish is by far the most common animal-source food among all population groups, averaging 19.71 kg per year. Fish is an essential diet staple since it is high micronutrients and accounts for 60% of the animal protein intake. Bangladesh's fishing industry is an important, accounting for 3.61% of the national GDP. Bangladesh's agricultural sector contributes 14.2% to GDP (Al-Baz et al., 1995), employing 47% of the working population (Talwar et al., 1991) and sustaining 17 million people (1.4 million women) by fishing, farming, fish handling, and processing. In 2018, Bangladesh ranked 3rd in inland fish production, 5th in aquaculture production, and 11th in marine fish production (CIA 2018).

The division's Hilsa production in 2014-2015 was 2 lacks 53 thousand 161 tons, according to the fisheries department. From there, in 2015-2016, it increased to 2 lacks 57 thousand 225 tons. This increased to 3 lacks 24 thousand 298 tons in 2016-2017, 3 lacks 29 thousand 25 tons in 2017-2018, and 3 lacks 41 thousand 119 tons 2018-2019. Officials from the Divisional Fisheries Department said the figures for this year are even better, though they haven't arrived yet. According to the department, the country's Hilsa production increased from 5 lacks 15 thousand tons in 2018-2019 to 5 lacks 33 thousand tons in 2019-2020.

Figure 2.1: Trends of Hilsa production over last two decades in Bangladesh.

2.4 Age and growth of Hilsa:

The asymptotic length ($L\infty$) varies widely between 51.5 and 65.6 cm. Furthermore, the asymptotic length ranged from 51.5 to 57.0 cm in 25% of studies, 57.0 to 61.1 cm in 60% of studies, and 61.1 to 65.9 cm in 15% of studies, respectively (Table 2.1). The asymptotic length ($L\infty$) is 58.50 cm on average.

The growth coefficient (K) is parameters of the von Bertalanffy growth function that indicates how close one is to reaching asymptotic length. The growth factor (K) values of hilsa range from 0.53 to 0.99. K values ranged from 0.53 to 0.63 in 10% of the studies, 0.63 to 0.75 in 40% of the studies, 0.75 to 0.87 in 35% of the studies, and 0.87 to 0.99 in 15% of the studies (Table 2.1). The mean growth coefficient (K) is equal to 0.78 $year^{-1}$, which is a reasonable parameter that corresponds to 80 percent of studies. As a result, further research is required to confirm that the K value of the Hilsa is important for high management.

The growth performance index (ϕ') ranges from 3.14 to 3.55. The ϕ' values ranged from 3.14 to 3.24 in 5% of the studies, 3.44 to 3.34 in 25% of the studies, 3.34 to 3.44 in 25% of the studies, and 3.44 to 3.55 in 45 percent of the studies, respectively. 3.42 is the average growth performance (ϕ').

Table 2.1: Growth parameters (Asymptotic length ($L\infty$), growth coefficient (K), growth performance index (ϕ'), maximum age for Hilsa species previous studies in Bangladesh

Author	$L\infty$ (cm)	K	ϕ'	Age
Sarker et al., (2019)	57.7	0.90	3.47	3.33
Rahman et al., (2018)	58.7	0.90	3.50	6.25
Rahman et al., (2012)	53	0.83	3.37	3.61
Rahman and Coxs. (2008)	58.8	0.82	3.45	4.60
Halder and Amin (2005)	51.5	0.53	3.14	5.66

Halder et al., (2004)	62.5	0.72	3.45	4.16
Amin et al., (2002)	60.0	0.82	3.47	3.65
Rahman et al., (2002)	59.97	0.99	3.55	3.03
Rahamn et al., (2000)	61.5	0.83	3.48	3.70
Rahamn et al., (1999)	60.9	0.66	3.38	4.55
Rahman et al., (1998)	58.3	0.74	3.40	4.05
Miah et al., (1997)	57.0	0.66	3.33	4.54
BFRI/RS (1994)	61.1	0.71	3.44	4.22
Van der Knaap et al., (1987)	58	0.83	3.45	3.61
Average	58.50	0.78	3.42	4.21

2.5 Mortality and Exploitation rate of Hilsa:

The natural mortality rate (M) is the rate at which fish in a population die from natural causes at any given time. The Hilsa natural mortalities are ranged from 0.89 to 1.45 yr^{-1}, which seems to be a reasonable range of variation. 1.17 yr^{-1} is the average natural mortality rate (Table 2.2). Natural mortality ranges from 0.89 to 1.07 yr^{-1}, 1.07 to 1.26 yr^{-1}, and 1.26 to 1.45 yr^{-1} in research involving 25%, 40 %, and 35% of the population, respectively. The average natural mortality was 1.20 yr^{-1}.

Fishing mortality has ranged from 0.62 to 3.45 yr^{-1}, indicating a wide range of variation. The average fishing mortality rate is 1.85 yr^{-1}. Fishing mortality ranges from 0.62 to 1.2 yr^{-1}, 1.2 to 1.95 yr^{-1}, 1.95 to 2.7 yr^{-1}, and 2.7 to 3.45 yr^{-1} based on 15%, 55%, 20% and 10% studies, respectively (Table 2.2).

The total mortality ranges of the Hilsa in various studies ranged from 1.89 to 4.90 yr^{-1}, indicating a broad range of variation. The average total mortality rate is 3.05 yr^{-1} (Table 2.2). Total mortality is an important management parameter for determining the rate of exploitation and maximum sustainable yield. Total mortality ranges between 1.89 and 2.48 yr^{-1}, 2.48 and 3.29 yr^{-1}, 3.29 and 4.09 yr^{-1}, and 4.09 and 4.90 yr^{-1} from 35%, 45%, 10% and 10% studies respectively.

Exploitation rate is the purpose of an age class that is caught during the life span of a population exposed to fishing pressure. Thus the number caught versus the total number of individuals dying due to fishing and other reasons (Pauly et al. 1984). In an optimal exploited stock, fishing mortality should be about equal to natural mortality, resulting in a fixed E-optimum = 0.5 (Gulland, 1971). The exploitation rate varies between 0.33 and 0.70 in different studies (Table 2.2). The average rate of exploitation is 0.59. From 10%, 50%, and 40% research, the abuse rates range from 0.33 to 0.48, 0.48 to 0.59, and 0.59 to 0.70 (Table 2.2).

Table 2.2: Natural mortality (M), fishing mortality (F), total mortality (Z), and exploitation rate (E) for Hilsa species during 1987 to 2019 studies in Bangladesh

Author	M	F	Z	E
Sarker et al., (2019)	1.45	3.45	4.90	0.70
Rahman et al., (2018)	1.36	2.83	4.19	0.67
Rahman et al., (2012)	1.36	1.87	3.23	0.58
Rahman and Coxs. (2008)	0.98	1.32	2.30	0.57
Halder and Amin (2005)	0.92	1.95	2.87	0.68
Halder et al., (2004)	1.17	1.62	2.79	0.58
Amin et al., (2002)	1.28	2.49	3.77	0.68
Rahman et al., (2002)	1.41	1.77	3.18	0.56
Rahamn et al., (2000)	1.28	2.01	3.29	0.61
Rahamn et al., (1999)	1.12	2.16	3.28	0.67
Rahman et al., (1998)	1.18	1.43	2.61	0.55
Miah et al., (1997)	0.89	1.14	2.03	0.56

BFRI/RS (1994)	1.16	1.25	2.41	0.52
Van der Knaap et al., (1987)	1.27	0.62	1.89	0.33
Average	1.20	1.85	3.05	0.59

2.6 Maximum Sustainable Yield (MSY) of Hilsa:

The total production was the lowest at 199,032 metric tons in 2003, while the highest at 394,951 metric tons was recorded in 2016. From 1995 to 2016, the total average catch was 244,876 metric tons, average Z was 3.29 yr^{-1}, average F was 2.006 yr^{-1}, average MSY was 202,823 and then in total catch increased rapidly average 16% overfished. Afterwards, production increased steadily to 517,198 metric tons in 2018, and then sharply increased again to the highest amount 533,000 in 2019 (Figure 2.2).

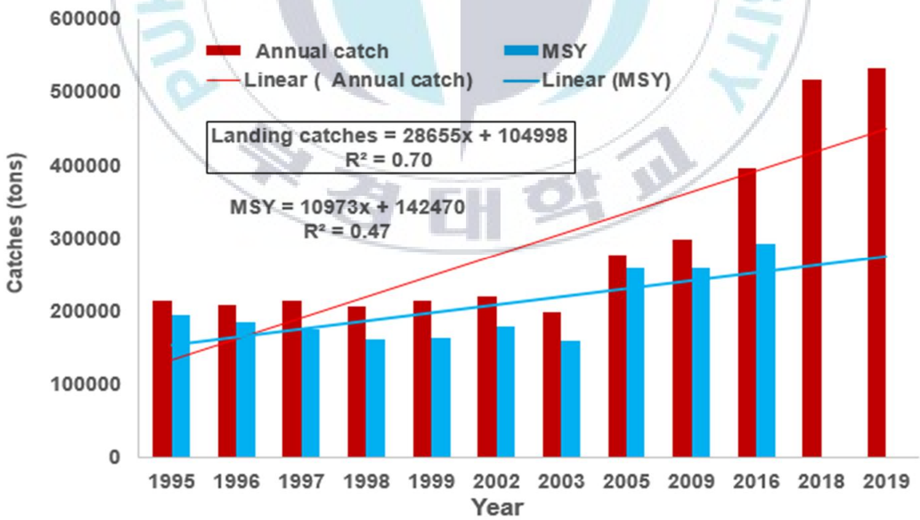

Figure 2.2: Trend of annual production and MSY of Hilsa in Bangladesh during the 1995-2019

Adequate research has been done on population dynamics and stock assessment of Hilsa fish in Bangladesh waters, which has already been discussed. Despite so much research, relative yield per recruit (YPR) and spawning biomass per recruit ($SBPR$) have never been well researched. Although maximum sustainable yield (MSY) and effort at maximum sustainable yield ($fMSY$) were studied simultaneously, only one method was used, but in the present study, a different method has been used which has never been used in the case of Hilsa. Therefore, it is a gap in the study of Hilsa population dynamics and stock assessment research in Bangladesh waters. So the main purpose of the present study was yield per recruit (YPR), spawning biomass per recruit ($SBPR$), maximum sustainable yield (MSY), and effort at maximum sustainable yield ($fMSY$). It is expected that the management of Hilsa fisheries in Bangladesh will be further strengthened through the present study.

CHAPTER 3: MATERIALS AND METHODS

3.1 Collection of data:

Monthly length-frequency samples of Hilsa (*Tenualosa ilisha*) were collected between June 2020 and February 2021 from the two landing stations of Pathargata ($22^{0}03'07''$ N, $89^{0}58'18''$ E) and Kuakata ($21^{0}48'53''$ N, $90^{0}07'23''$ E), southern coast of Bangladesh (Figure 3.1).

These samples of *T. ilisha* were mainly caught by gill net. Total length (TL) of 2625 individuals was measured from the tip of the mouth to the tip of the telson of the nearest 0.1 mm and total weight was taken by an electronic balance of 0.001 g accuracy.

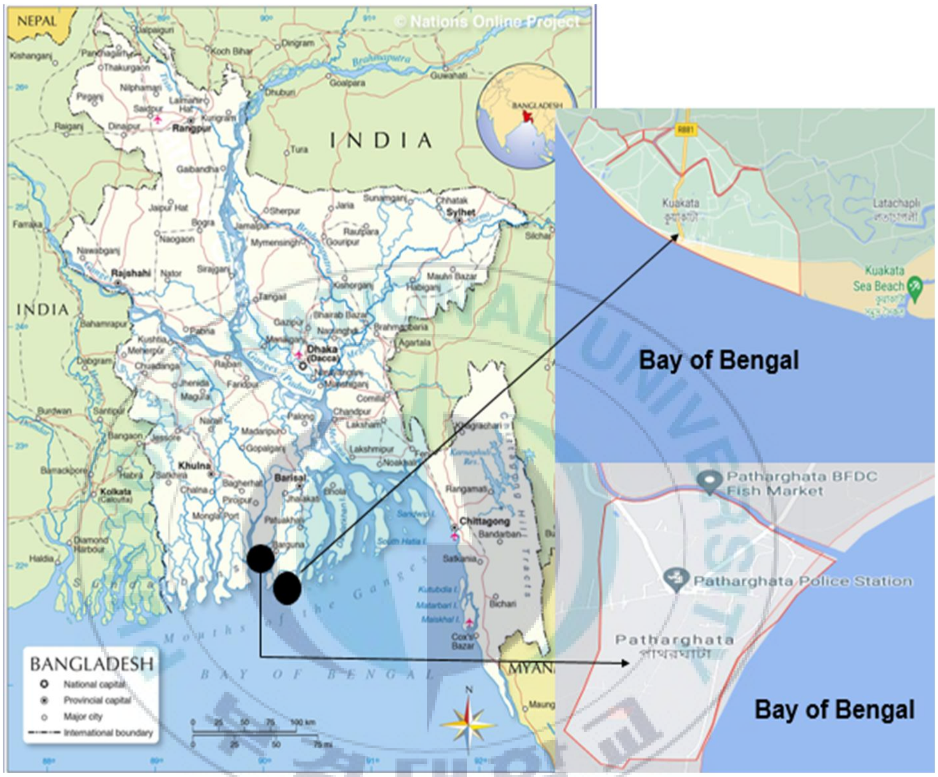

Figure 3.1: Sampling locations (Pathargata, Kuakata) in the southern part of Bangladesh waters.

3.2 Data analysis:

To estimate the population structure, the length-frequency data of *T. ilisha* were analyzed by using the MINITAB Version 14. The data were pooled monthly and subsequent grouped into two-centimeter interval (Table 3.1). Then the data were analyzed using FiSAT (FAO-ICLARM Stock Assessment Tools) program explained in detail by (Gayanilo et al., 1996).

Table 3.1: Monthly length frequency distribution for *T. ilisha* from Patharghata, Kuakata southern part of Bangladesh

Mid-length	Jun-2020	Jul-2020	Aug-2020	Sep-2020	Oct-2020	Nov-2020	Dec-2020	Jan-2021	Feb-2021	Total (N)
9.0				12	15					27
11.0				61	59					120
13.0				56	71					127
15.0				54	62					116
17.0				39	44					83
19.0				21	23					44
21.0			1	1	1			5		8
23.0	1					1	1	8	3	14
25.0	6	17	15		17	7	7	13	4	86
27.0	4	15	11		15	15	7	14	7	88
29.0	2	7	6		8	4	5	11	29	72
31.0	7	10	7	6	6	8	18	20	69	151
33.0	34	28	31	15	10	46	37	32	83	316
35.0	81	78	67	16	19	52	69	53	45	480
37.0	46	46	48	8	28	39	58	49	26	348
39.0	26	32	31	11	28	36	69	34	12	279
41.0	7	13	12	4	10	15	35	17	7	120
43.0	1	3	6		4	5	16	12	1	48
45.0			5	1	4	6	4		3	23
47.0							2	1	1	4
49.0						1				1
51.0					1					1

Total (N)	**215**	**249**	**240**	**305**	**425**	**235**	**328**	**269**	**290**	**2625**

3.3 Length-Weight Relationship model:

To establish the length-weight relationship model, $W = a L^{b}$ was applied (Ricker, 1975; Quinn II and Deriso, 1989), where W is the weight (mg), L is the total length (mm), 'a' is the intercept (condition factor) and 'b' is the slope (relative growth rate).

3.4 Growth parameters:

An estimate of maximum length (L_{max}) was obtained using the data described above and the extreme value theory (Gumbel, 1954; Formacion et al., 1991) as implemented in the FiSAT software. The parameters of the von Bertalanffy Growth Function (VBGF), asymptotic length (L_{∞}) and growth co-efficient (K) were estimated by means of ELEFAN-I (Pauly and David, 1981). Estimated of L_{∞} and K was used to calculate the growth performance index (φ') (Pauly and Munro, 1984) using the equation:

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

Potential longevity (t_{max}) of the species was calculated from Pauly (1984) formula: $t_{max} = 3/K$. The inverse von Bertalanffy growth equation (Sparre and Venema, 1992) was used to determine lengths of *T. ilisha* at various ages. The VBGF is defined by the equation:

$$L_t = L_{\infty}[1 - e^{-k(t - t_0)}]$$

where L_t = mean length at age t, L_∞ = asymptotic length, K = growth co-efficient, t = age of the *T. ilisha* and t_0 = the hypothetical age at which the length is zero (Pauly and David, 1981, Dulcic and Kraljevic, 1995).

3.5 Mortality parameters:

Once the growth parameters of VBGF were obtained, a linearized length-converted catch curve (Pauly, 1984) was constructed using the following formula to estimate total mortality (Z):

In $(N_t/\triangle_t) = a + bt$, where N is the number of individuals of relative age (t) and $\triangle_t$ is the time needed for the Hilsa to grow through a length class. The slope (b) of the curve with its sign changed gives Z.

The annual rate of natural mortality (M) was estimated using four different methods

1) The empirical relationship (Pauly, 1984 and Moreau et al., 1947): $Log10\,M = -0.0066 - 0.279 Log10 L\infty + 0.6543\,Log10 K + 0.4634\,Log T.$

Where, L_∞ the asymptotic length, K the growth co-efficient of the VBGF and T the mean annual habitat water temperature ^{0}C (here it was 29.7 ^{0}C).

2) Zhang and Megrey (2006) method, the equation is; $M = \beta k / eK(Ci.tmax - t0) - 1$

Where, Ci is 0.302 for pelagics and 0.440 for demersals; K and $t0$ are von Bertalanffy growth parameters; $tmax$ is the maximum age; β is the length-weight relationship coefficient.

3) Alagaraza method (1984); M = $\frac{-ln[0.01]}{tmax}$

Where, Tm is the maximum age (lifespan)

4) Alverson and Carney method (1975); $M = \frac{3K}{e^{K(0.38.tmax)}-1}$

Where, K is the von Bertalanffy growth coefficient and $tmax$ is the maximum age.

Once Z and M were obtained, fishing mortality (F) was estimated using the relationship:

F = Z – M; where Z is the total mortality and M, natural mortality. The exploitation level (E) was obtained from E = F/Z = F/ (F+M).

3.6 **Length at first capture:**

Ascending left arm of the length-converted catch curve was used to estimate the probability of capture (Pauly, 1987). By plotting the cumulative probability of capture against mid-length of class interval, we obtain a resultant curve from which the length at first capture L_c was taken as corresponding to the cumulative probability at 50%.

3.7 **Recruitment pattern:**

The recruitment pattern was obtained by projecting the length-frequency data backwards on the time axis using growth parameters (Moreau and Cuende, 1991). Normal distribution of the recruitment pattern was determined by NORMSEP (Pauly and Caddy, 1985) in FiSAT.

3.8 **Steady state biomass (SSB):**

The estimated length standardized VPA and cohort analysis were performed using the FiSAT routine. L, K, M, F, a (constant), and b (exponent) values for the species were used as inputs to a VPA analysis by the FiSAT routine. The value of t_0 was zeroed out. Fry (1949) published the procedure, which was later updated by a number of authors (Pauly, 1984 and Jones, 1984).

3.9 **Yield and Spawning Biomass per recruit:**

The relative yield per recruit was calculated by means of Zhang and Megrey model (Zhang & Megrey, 2010) which has the equation:

$$\frac{Y_l}{R} = F \cdot \left(\alpha L_\infty{}^{\beta}\right) \left(\frac{L_\infty - l_c}{L_\infty - l_r}\right)^{\frac{M}{K}} \cdot \sum_{n=0}^{3} \frac{U_n \left(\frac{L_\infty - l_c}{L_\infty}\right)^n}{F + M + nK}$$

Where a is the length-weight coefficient, β is the length-weight power coefficient, $L\infty$ is the von Bertalanffy maximum length, F is the fishing mortality, M is the natural mortality, K is the von Bertalanffy growth rate, lc is the length at first capture, lr is the length at recruitment and Un integration coefficient, $U_0 = 1$, $U_1 = -3$, $U_2 = 3$ and $U_3 = -1$. The biological management reference points, $Fmax$ and $F0.1$ were calculated based on the Yield per recruit (YPR). The $Fmax$ is the fishing mortality that accounts for the highest YPR and $F_{0.1}$ is the corresponding fishing mortality to 10% of the maximum slope in the YPR curve.

The spawning biomass per recruit (SSPR) was estimate by means of the length-based spawning biomass per recruit model (Zhang, 2016). It contains the form:

$$\frac{SB}{R} = m_{l_c}\left(\alpha L_\infty^{\beta}\right)\left[\frac{L_\infty - l_c}{L_\infty}\right]^{\frac{M}{K}}\left[\frac{L_\infty - l_r}{L_\infty}\right]^{-\frac{M}{K}}\sum_{n=0}^{3}\frac{U_n\left[\frac{L_\infty - l_c}{L_\infty}\right]^n}{F+M+nK}$$

Where, mlc is the maturity ratio of length class, a is the length-weight coefficient, β is the length-weight power coefficient, $L\infty$ is the von Bertalanffy maximum length, F is the fishing mortality, M is the natural mortality, K is the von Bertalanffy growth rate, lc is the length at first capture, lr is the length at recruitment and Un is integration coefficient, $U_0 = 1$, $U_1 = -3$, $U_2 = 3$, $U_3 = -1$. The management reference point, $F40\%$ which indicates the fishing mortality at 40% of the maximum spawning biomass per recruit was calculated in accordance with the SBPR x% fishing mortality ($Fx\%$) that maintains the spawning biomass at x% of the virgin spawning biomass (that is if there is no fishing mortality), at the length at first capture was computed using the follow equation (Zhang and Megrey, unpublished manuscript):

$$x\%_{l_c} = \frac{m_{l_c}\left(\alpha L_\infty^{\beta}\right)\left[\frac{L_\infty - l_c}{L_\infty}\right]^{\frac{M}{K}}\left[\frac{L_\infty - l_r}{L_\infty}\right]^{-\frac{M}{K}}\sum_{n=0}^{3}\frac{U_n\left[\frac{L_\infty - l_c}{L_\infty}\right]^n}{F_{x\%}+M+nK}}{m_{l_c}\left(\alpha L_\infty^{\beta}\right)\left[\frac{L_\infty - l_c}{L_\infty}\right]^{\frac{M}{K}}\left[\frac{L_\infty - l_r}{L_\infty}\right]^{-\frac{M}{K}}\sum_{n=0}^{3}\frac{U_n\left[\frac{L_\infty - l_c}{L_\infty}\right]^n}{M+nK}}$$

Where, mlc is the maturity ratio of length class, a is the length-weight coefficient, β is the length-weight power coefficient, $L\infty$ is the von Bertalanffy maximum length, F is the fishing mortality, M is the natural mortality, K is the von

Bertalanffy growth rate, lc is the length at first capture, lr is the length at recruitment and Un is integration coefficient, $U_0 = 1$, $U_1 = -3$, $U_2 = 3$.

3.10 Estimation Maximum Sustainable Yield (MSY):

The catch per unit effort ($CPUE$) was obtained by distributing the total catch ($Yield$) by the effort of each year; $CPUE = Y/f$, where Y is the catch or yield, and f is the number of fishing boats. The estimate the MSY, the $CPUE$ and effort was applied to the Schafer Surplus model as outlined by Zhang (2020) in the equation $CPUE = a + bf$; where a and b are the intercept and slope which are the constant multiplying by the fishing effort (f) and knowing that yield. $Y = f(CPUE)$ gives: $Y = af + bf2$ which is the parabolic yield equation of the Schafer surplus model, (Schafer, 1954). Thus the effort required to reach the maximum sustainable yield ($fMSY$) and MSY were calculated by the equation:

$$fMSY = -a/2b \text{ and } MSY = -a\hat{}2/4b \text{ (Zhang, 2020)}$$

CHAPTER 4: RESULTS

4.1 Population Structure:

The total number of individuals of *T. ilisha* collected for this study was 2625. The minimum and maximum total lengths was 9.00 and 50.10 cm, while minimum and maximum total weights was 47.76 and 1257.44 gm, respectively. The mean total length and body weight of the *T. ilisha* was 30.27 (± 9.37) cm (Figure 4.1) and 386.1 (± 229.1) g (Figure 3.2), respectively.

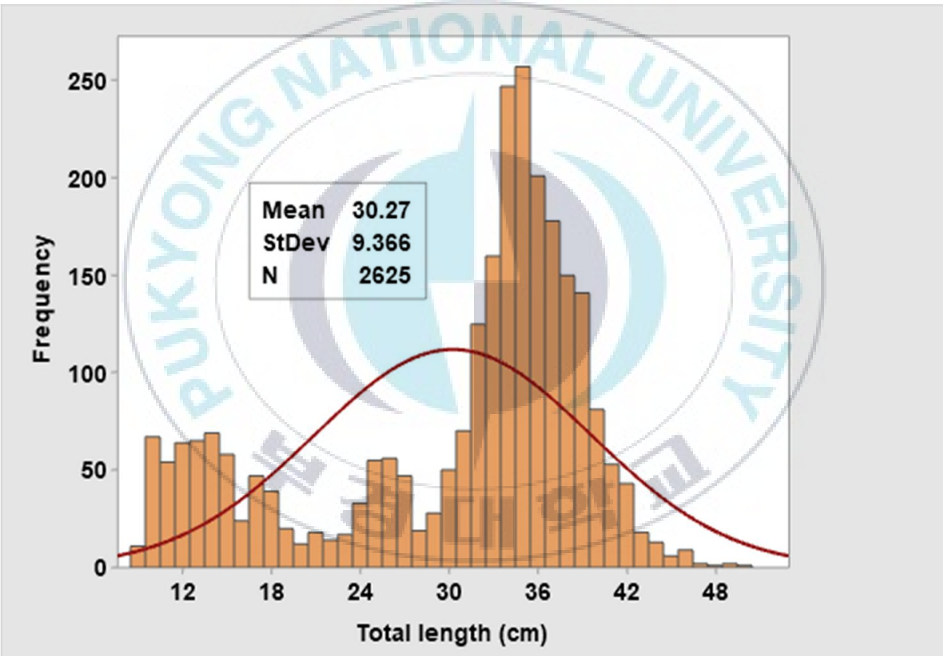

Figure 4.1. Size frequency distribution of *T. ilisha* in Kuakata, Patharghata southern part of Bangladesh during June 2020 to February, 2021

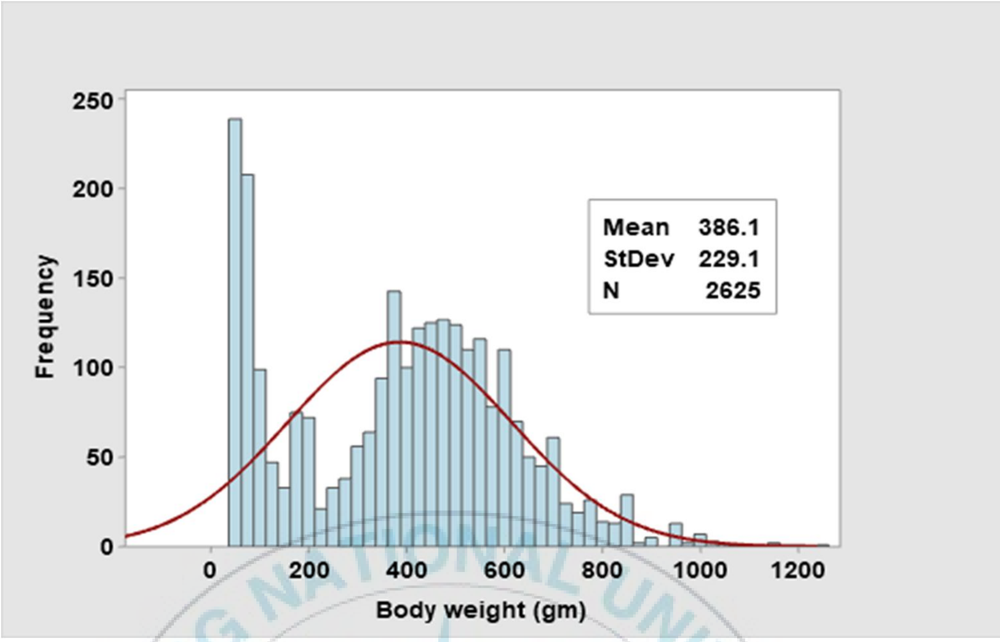

Figure 4.2. Weight frequency distribution of *T. ilisha* in Kuakata, Patharghata, southern part of Bangladesh during June 2020 to February, 2021

4.2 Length-weight relationship model:

Length-weight relationship model of *T. ilisha* was established in exponential form and the model equation was $W = 0.0104L^{3.0104}$ ($r^2 = 0.9259$). The calculated relative growth coefficient (b) was 3.0104 and the growth constant (a) was 0.0104. The b value was very close to isometric value (3) and it was not significantly ($p < 0.05$) differing from 3. Therefore, it is revealed that the growth pattern of *T. ilisha* was isometric in the investigated area during study period (Figure 3.3).

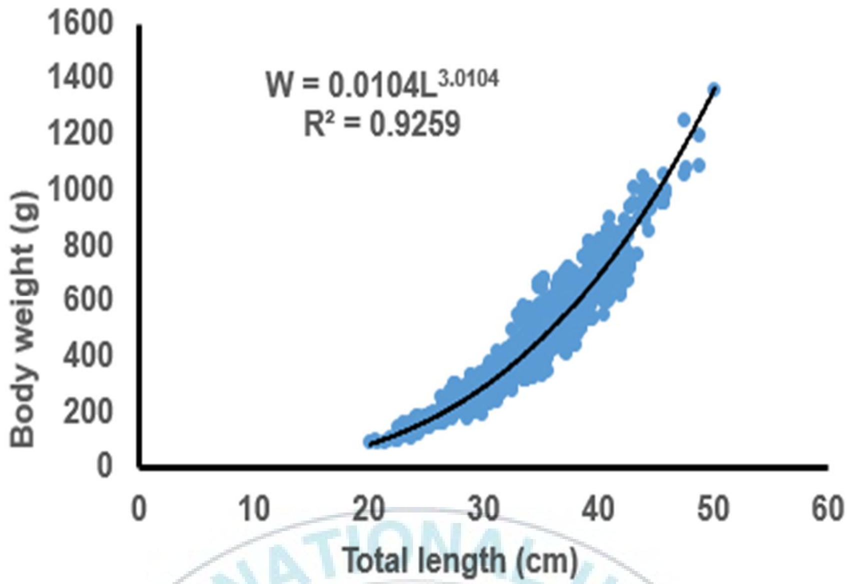

Figure 4.3: Length-weight relationship model of *T. ilisha* in Kuakata, Patharghata, (southern part) of Bangladesh in 2020

4.3 Growth parameters:

Von Bertalanffy growth parameters for *T. ilisha* were calculated to be $L\infty = 53.85$ cm and $K = 0.97$ $year^{-1}$. The response surface (R_n) for the curve in these ELEFAN estimates was 0.181. The restructured length distribution in shown over the computed growth curves generated with those parameters (Figure 3.4).

Table 4.1 Population factors of *T. ilisha* in Bangladesh, 2020.

Population parameters	*Tenualosa ilisha*
Asymptotic length(L_∞) in cm	53.85
Growth coefficient (K) (yr^{-1})	0.97
Response surface (R_n)	0.181

Life span (t_{max}) in year	3.09
Growth performance index (φ′)	3.45
Natural mortality (M) (yr^{-1})	1.53
Fishing mortality (F) (yr^{-1})	0.88
Total mortality (Z) (yr^{-1})	2.41
Length at first capture (L_c) in cm	10.42
Optimum length (L_{opt})	32 cm
L_C/L_∞	0.19
M/K	1.57
Exploitation rate (E)	0.63
Maximum sustainable yield (MSY) (tons)	471707

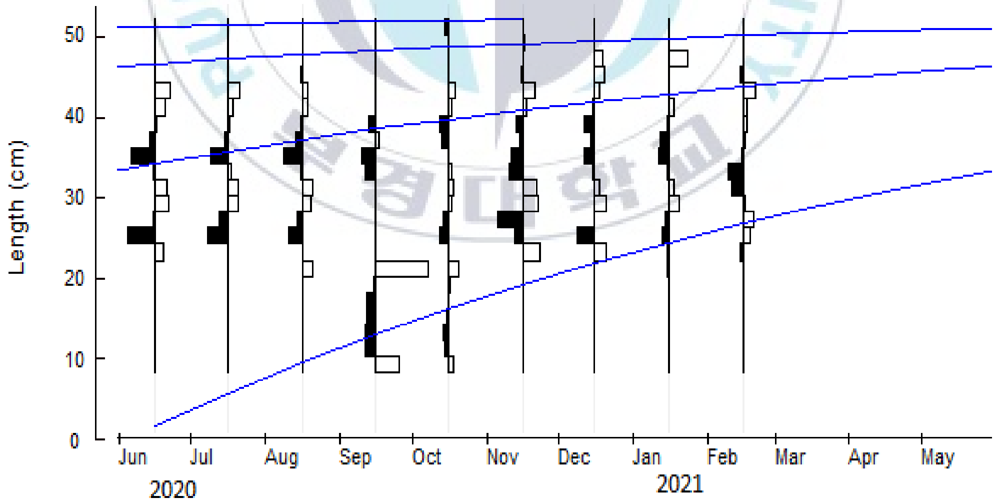

Figure 4.4. The von Bertalanffy growth curves superimposed on the length-frequency distribution of *T. ilisha* in the Kuakata, Patharghata, (southern Bangladesh) in 2020. ($L\infty = 53.85$ cm, $K = 0.97\ yr^{-1}$, $R_n = 0.181$)

4.4 Mortality:

Natural mortality (M) and total mortality (Z) computed were 1.53 yr^{-1} and 2.41 yr^{-1}, respectively. The capture curve used to estimate Z is depicted in (Figure 3.5). The least square linear regression was used to calculate the value of Z using the darkened circles. The points that are not totally recruited or are very similar to L∞ are shown by the blank circles. A good match to the capture curve's descending right limits was found. By subtracting natural mortality (M) from total mortality (Z), the fishing mortality (F) was found to be 0.88 yr^{-1}.

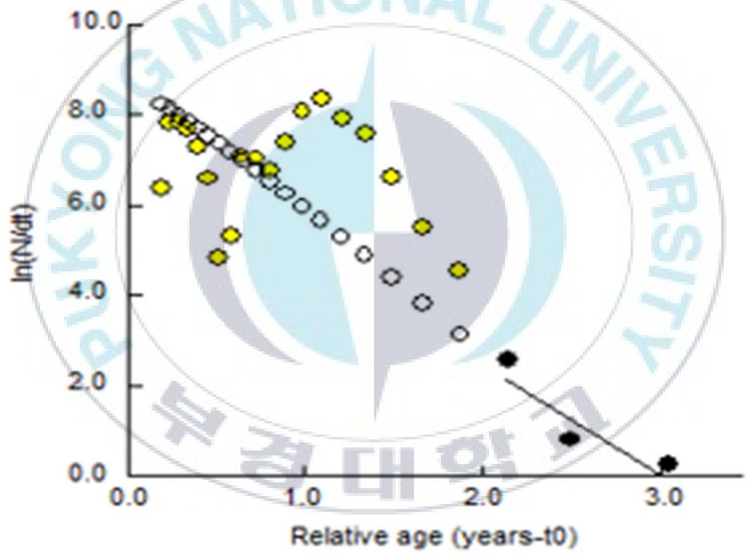

Figure 4.5. Length-converted catch curve analysis to estimate total mortality Z, from the length-frequency distribution of *T. ilisha* in Patharghata, Kuakata (southern Bangladesh) in 2020

In addition to Pauly (1980) methods, other methods were for natural mortality. It turned out that all the methods have different values, but the values are very close.

And an average value was determined from the all values. The average value was 1.59 yr^{-1} (Table 3.2)

Table 4.2: The value of natural mortality (M) using different methods:

No	Methods	Value
1.	Pauly (1980);	1.53
2.	Zhang & Megrey (2006);	1.98
3.	Alverson & Carney (1975);	1.37
4.	Alagaraza (1984)	1.49
Average		1.59

4.5 Exploitation rate:

The exploitation rate (E) was calculated as 0.63. The medium high values of E indicate that there was a variety of fishing going on during that period. This observation is founded on Gulland's findings (1971). He claims that when F = M, i, e., when E is greater than 0.50, the stock is considered over fished.

4.6 Length at first capture (L_C):

The length at first capture (L_c) for *T. ilisha* in the southern part of Bangladesh waters was 10.42 cm (Figure 3.6). L_{25}, and L_{75} were determined to be 8.60 cm, and 12.45 cm, respectively. The optimum length at first capture was 32 cm.

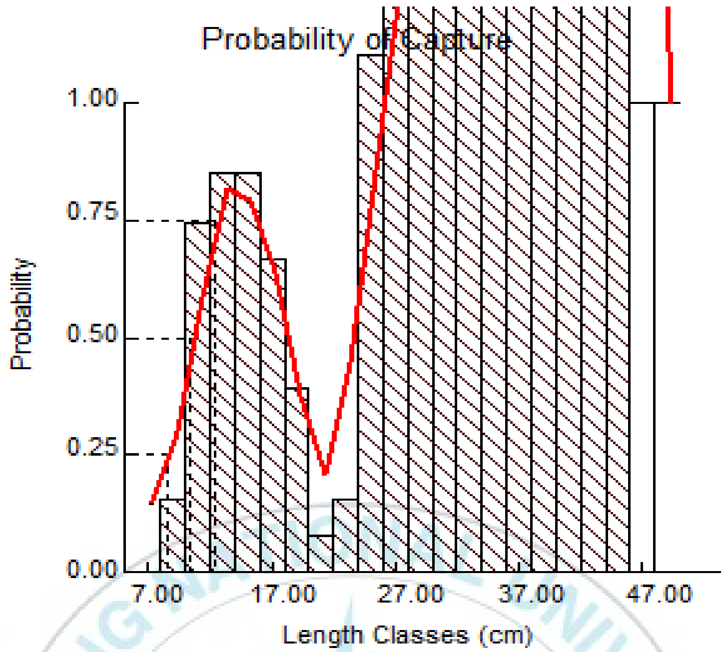

Figure 4.6: Length at first capture of ($L_c = L_{50} = 10.42$ cm) *T. ilisha* in the Kuakata, Patharghata (southern Bangladesh) in 2020

4.7 Recruitment pattern:

The recruitment pattern of *T. ilisha* was continuous throughout the year with one major peak in August-September (Figure 3.7). The percent recruitment varied from 0.13 to 31.44 during the study period. The highest recruitment peak occurred between August and September. The highest (31.44%) and lowest (0.13%) percent recruitment was observed in the months of September and April (Figure 3.7).

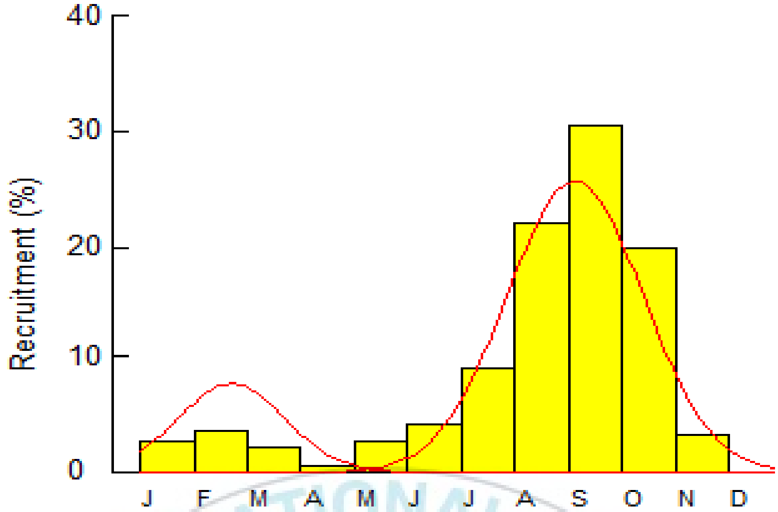

Figure 4.7: Recruitment pattern of *T. ilihsa* in Patharghata, Kuakata, (southern Bangladesh) in 2020

4.8 Steady state biomass (SSB):

Virtual population analysis (VPA) performed on *T. ilihsa* revealed that the minimum fishing mortalities were recorded as 0.02 yr^{-1} and 4.47 yr^{-1} for the mid-lengths of 9 cm and 51 cm, respectively (Figure 3.8). The fishing mortality (F) was relatively high over the mid-lengths from 35 to 45 cm. The total steady state biomass was found to be 1318591425 tons. In the table below, the total population, capture (in number), fishing mortality, and steady-state biomass (tons) per length class are shown (Table 3.2). At present, the target of Hilsa in Bangladesh is 1 x 10^6 but this year total landing catch is 5,50,000 tons (1 x 10^5). However, this study shows that the steady-state biomass was 1318591425 tons. Therefore, if the government wants, it will be able to total landing catch four times as many Hilsa because there is that amount of Hilsa in stock. However, it can be double increase very easily, if it is more than four times so that there will be no loss of Hilsa stock biomass.

Table 4.3: Estimated steady state biomass of *T. ilihsa* in Bangladesh waters

	Mid-Length	Catch (in numbers)	Population (N)	Fishing Mortality (F)	Steady-state Biomass (tons)
1	9.0	27000000512	9966320615424	0.0611	6940697
2	11.0	120000004096	9263230484480	0.2811	12219052
3	13.0	127000002560	8490022076416	0.3103	19324471
4	15.0	115999997952	7736788516864	0.2964	28389222
5	17.0	83000000512	7021916585984	0.2217	39535681
6	19.0	44000002048	6366172282880	0.1226	52944967
7	21.0	8000000000	5773034782720	0.0232	68821276
8	23.0	14000000000	5236650934272	0.0421	87060480
9	25.0	86000001024	4714168057856	0.2719	106448726
10	27.0	88000004096	4144318906368	0.2962	126038130
11	29.0	71999995904	3601799315456	0.2591	146158106
12	31.0	151000006656	3104663142400	0.5919	163998376
13	33.0	316000010240	2563346530304	1.4375	170562127
14	35.0	480000016384	1911007870976	2.8945	153585077
15	37.0	347999993856	1177285820416	3.1746	120002376
16	39.0	278999990272	661565472768	4.4726	80009075
17	41.0	120000004096	287122227200	3.8962	45919126
18	43.0	48000000000	119997718528	3.1801	25971581
19	45.0	23000000512	48903794688	3.3816	13419131
20	47.0	4000000000	15497163776	1.2619	7128024
21	49.0	1000000000	6647449088	0.5260	4846579

22	51.0	1000000000	2738636288	0.8800	3267521
Total steady-state biomass					**1318591425**

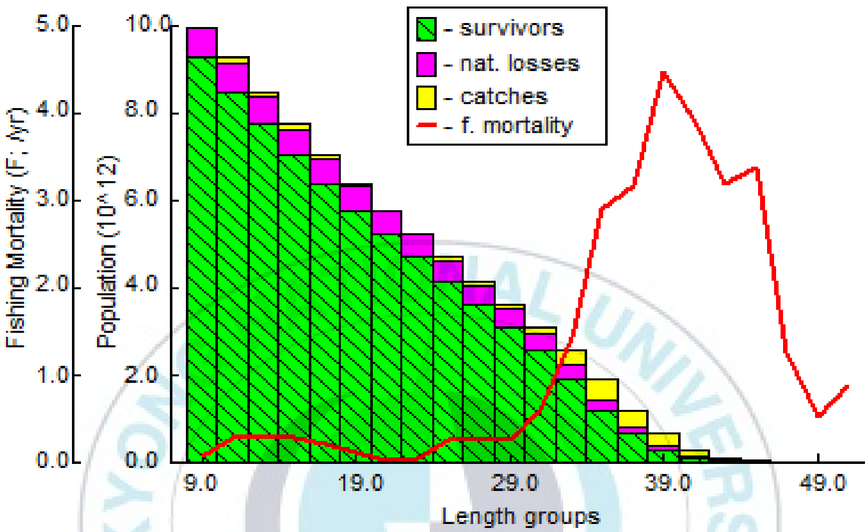

Figure 4.8: Fishing mortality of *T. ilisha* on different size class of southern part of Bangladesh, 2020

4.9 Yield and spawning Biomass per recruit:

Hilsa (*T. ilisha*), the yield and biomass per recruit are calculated as a function of the fishing mortality rate (F). From a derived exploitation pattern, F_{max} is the value of F that gives the maximum possible yield per recruit from a cohort during its duration. The current fishing mortality (F), 0.88 year^{-1} determined the current Yield per recruit 69.50 g. The fishing mortality ($Fmax$) that maximum yield per recruit was computed as 1.25 year^{-1} and the maximum yield per recruit was 71.87 g. The biological management reference point ($F_{0.1}$) was computed to be 0.84 year^{-1} and its corresponding Yield per recruit was 68.83 g. The current spawning biomass per recruit was computed to be 43.44 g at the current fishing mortality of 0.88 year^{-1} as shown in (Figure 3.9). The percent of spawning biomass of the virgin spawning biomass at the current fishing mortality and length at first capture was established to be F 33%. Based on the spawning biomass per recruit, $F_{40\%}$ was estimated as 0.79 year^{-1} and 47.23 g (Figure 3.10). (Figure 3.11) shows yield per recruit and spawning biomass per recruit against different reference point (Fmax, Fcur, F0.1%, and F40%) of fishing mortality.

Table 4.4: Fishing mortality and reference point of *T. ilisha* in southern part of Bangladesh waters, 2020

Parameters	F_{cur}	F_{max}	$F_{0.1}$	$F_{40\%}$
F (year^{-1})	0.88	1.25	0.84	0.79
Y/R (gr/r)	69.50	71.87	68.83	67.85
B/R (gr/r)	43.44	31.62	45.07	47.23

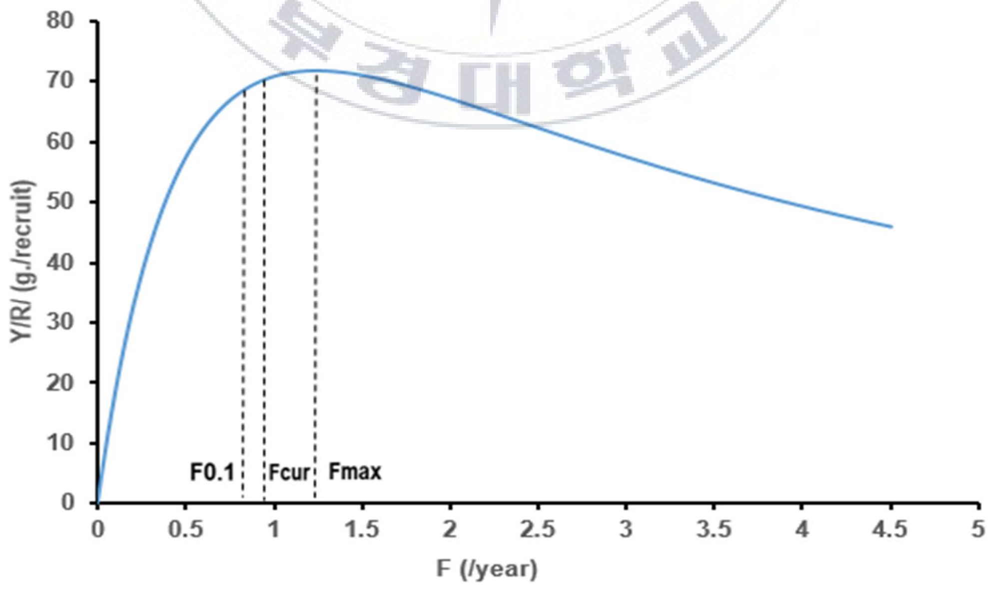

Figure 4.9: Yield per recruit percent against fishing mortality indicating F current reference point and F maximum yield per recruit percent of *T. ilisha* in the waters of southern part, Bangladesh

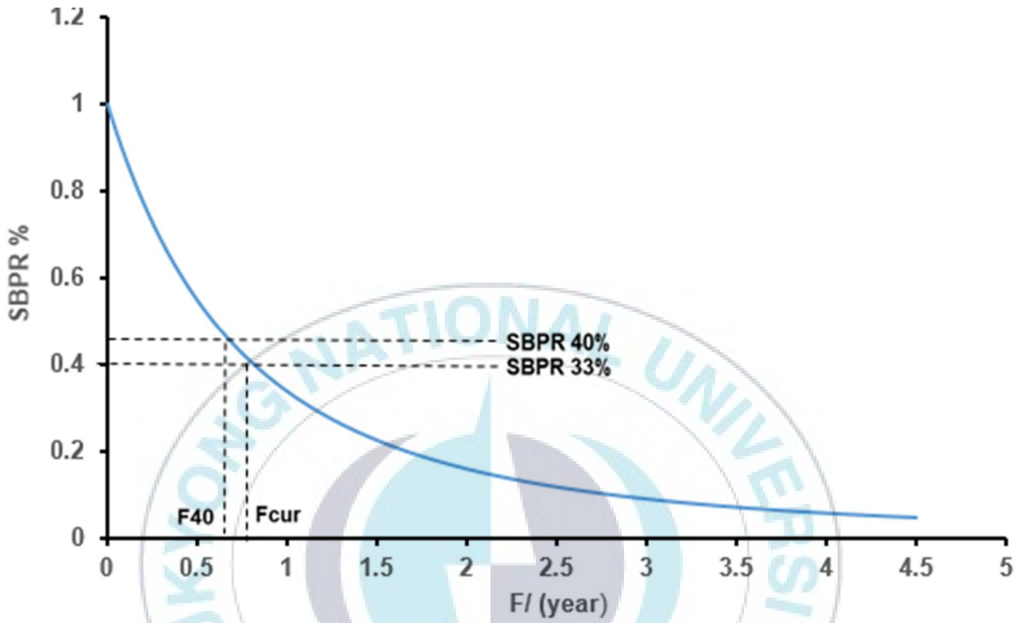

Figure 4.10: Spawning biomass per recruit percent against fishing mortality indicating 40% reference point and current spawning biomass per recruit percent of *T. iisha* in the waters of southern part, Bangladesh

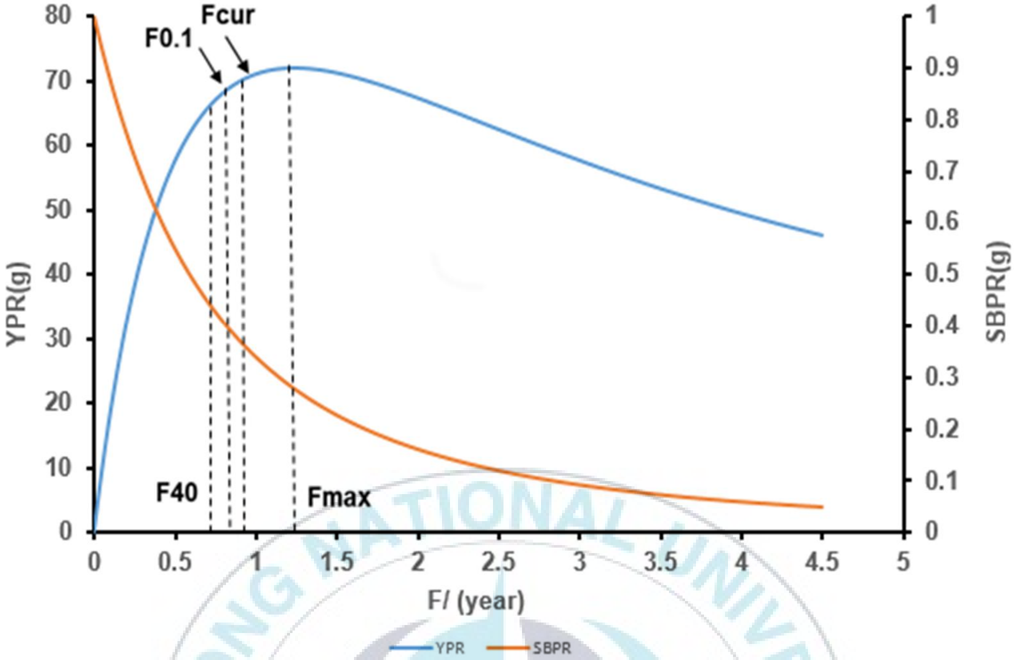

Figure 4.11: Yield-per-recruit (YPR) and Spawning-biomass-per-recruit against different reference points of fishing mortality of *T. ilisha* in the southern part of Bangladesh waters

4.10 Maximum sustainable yield (MSY):

Consuming the time series catch and effort data for *T. ilisha* in (Table 3.5) to obtain the value pf the parameters a (10.64) and b (-0.00006) respectively as given in (Fig. 3.12). Using the Schafer surplus production equilibrium model, The MSY of *T. ilisha* was estimated as 471,707 tons and the current landing was 550,000 tons that was 16% higher than MSY of hilsa and the corresponding optimum effort ($fMSY$) was established to be 88667 fishing boats as described in the diagram below (Figure 3.13).

Table 4.5: Time series catch and effort data of *T. ilisha* from 2011 to 2020

Year	Catch (mt)	Fishing effort (Boats)	CPUE
2011	339845	36,472	9.32
2012	346512	61,175	5.66
2013	351223	56,363	6.23
2014	385140	58,195	6.62
2015	387211	60,215	6.43
2016	394951	39,782	9.93
2017	466343	84,593	5.51
2018	517198	90,209	5.73
2019	533000	92,447	5.77
2020	550000	95,200	5.78
Average	427142	67,465	6.70

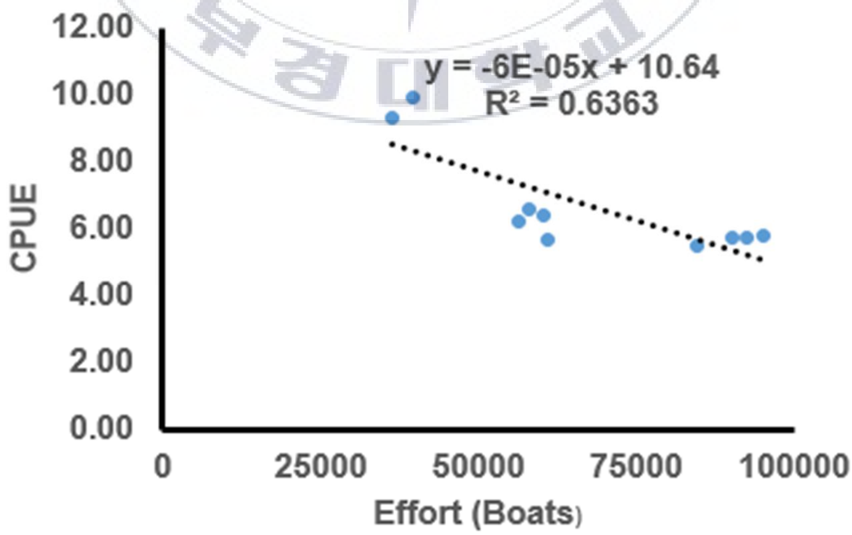

Figure 4.12: Linear regression of CPUE against effort of Hilsa in Bangladesh waters

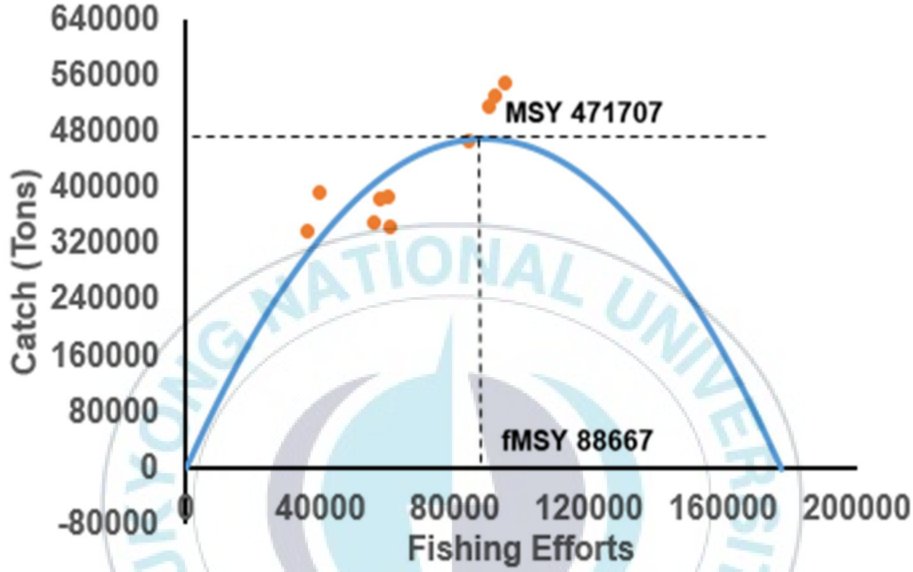

Figure 4.13: Schafer equilibrium model showing the stock status and MSY of *T. ilisha* in the Bangladesh waters

CHAPTER 5: DISCUSSION

5.1 Length-Weight Relationship model:

The isometric growth (b) value for aquatic species is between 2.5 and 4.0 (Le Cren, 1951). The currently study was calculated relative growth coefficient (b) was 3.0104 and the constant (a) was 0.0104. The b value was very close to isometric value (3) and it was not significantly ($p < 0.05$ differed from isometric value 3.

Observing at the values of a and b from 1998 to the present study 2020, it is seen that the value of research is close to the value of isometric value 3 (Table 5.1). Environmental conditions, diet, different environments, fishing condition, physiology, and fishing condition during sampling could all be contributing factors to the lower b value or negative isometry development.

Table 5.1 The value of length-weight relationship model a and b of *T. ilisha* of different years in Bangladesh waters

Year	Author's	*a*	*b*
2020	Present study*	0.0104	3.0104
2018	Rahman & Wahab	0.0368	2.7170
2015	Flura et al.,	0.0100	3.0402
2002	S.M Nurul Amin et al.,	0.0135	3.0770
2000	S.M Nurul Amin et al.,	0.0736	3.0920
2000	Rahman et al.,	0.0135	2.9740
1999	Rahman et al.,	0.0160	2.9110
1998	Md. Sagir et al.,	0.0224	2.9800

5.2 Growth Parameters:

The current findings $L\infty$ = 53.85 cm TL and K = 0.97 $year^{-1}$ (Table 2.1), but other studies in Bangladesh waters found that the growth parameters of Hilsa populations varied greatly (Alam et al., 2018; Amin et al., 2008; Rahman and Cowx 2006; Rahman et al., 1999, 2000; Miah et al., 1997; BOBP 1987). The asymptotic length ($L\infty$) ranged from 52.0 to 61.5 cm, the K ranged from 0.6 to 1.1 $year^{-1}$. Munro's phi prime test (Pauly and Munro 1984; Munro and Pauly 1883) is another test that is estimated from length-frequency data (ϕ' = 3.28), and values were found to be well within those for clupeid fishes (Pauly and Munro 1984; Munro and Pauly 1983). The growth performance index (ϕ′) had a low level of variability and fell within the range of clupeid species (Munro and Pauly 1983). This means the calculated parameters are accurate, and it is the first time length-frequency data have been collected from fish in all major habitat types by Pathorgata, Kuakata (southern part), Bangladesh waters. Nonetheless, length-frequency data that is sexually segregated may provide more accurate information, and this field should be investigated further.

5.3 Mortality Parameters and Exploitation Rate:

The calculated total mortality (Z) was 2.41 $year^{-1}$, natural mortality (M) was 1.53 $year^{-1}$ and fishing mortality (F) was found to be 0.88 $year^{-1}$ respectively for *T. ilisha* in the southern part of Bangladesh waters (Table 4.1). The calculated fishing exploitation level (E) was 0.63 which is 26% higher than optimum level of exploitation (E = 0.50). However, fishing pressure was 26% higher, that reveal the fisherman did not stop their fishing activities during study period in the investigated region. These results showed an over fishing pressure on the stock of *T. ilisha* in the southern part of Bangladesh waters. This is based on the assumption of Gulland (J. Gulland, 1987) which say the fish stock is at optimal when F = M or when exploitation rate (E) = 0.50. when the exploitation rate (E) is the greater ($E > 0.50$), the fish stock is to be over-exploited but when exploitation rate is less ($E < 0.50$), the fish stock is said to be under-exploited. However, studies in the past have shown that there is not much difference in the mortality standards, similar to current studies (Figure 2.2). However, although the exploitation rate is the over exploitation comparable the current study in all previous research, (Van der Knaap, 1987) research has shown that exploitation rate (E) is 0.33 which means under exploitation (Figure 2.2).

5.4 Length at first Capture (L_c):

The current study established the length at first capture in the southern part of Bangladesh waters to be 10.42 cm (Figure 4.6). The current length at first capture (10.42 cm TL) is less than the ones estimated for 27 cm TL (Amin et al., 2018) and 20.11 cm TL (Halder and Amin, 2005) in the Bangladesh waters.

The length at first capture is the length at which 50% of fish encountering the fishing gear can be retained (Zhang, 2020). Fisheries, Fish stocks, and ecosystems are adversely affected by the harvesting of immature fish (Froese, 2004). Growth overfishing is the result of harvesting immature fish (Pauly, 1979). There are negative economic impacts created on the fisheries sector by growth overfishing. Harvested immature fishes are sold at lower prices, usually as fish feeds, than matured fishes thereby making the fisheries sector unprofitable (Jennings et al., 1999).

5.5 Yield and Spawning Biomass-Per-Recruit:

Yield-per-recruit (YPR) is a biological management reference point use to establish fishing mortality and length at first capture to achieve optimum yield per recruit to the information in determining optimum mesh size and number of fishing vessels for effective fisheries resource management (Zhang and Megrey, 2010). $F_{0.1}$ is the fishing mortality when the yield per recruit is equal to 10% of the unfished biomass. F_{max} is the maximum fishing mortality that produces the highest yield per recruit (Tirtadanu and Chordrijah, 2019).

Yield-per-recruit for *T. ilisha* in the marine water of the southern part of Bangladesh gradually increased along with the fishing intensity until the fishing mortality reached 1.25 year^{-1} (Figure 4.9). The yield per recruit of *T. ilisha* gradually kept declining when the fishing mortality (Fmax) was greater than 1.25 year^{-1}. The study showed (Figure 4.9) that the current fishing mortality (Fcurrent) = 0.88) is less than the maximum fishing mortality (Fmax = 1.25) and the management fishing mortality reference point ($F_{0.1}$ = 0.84) indicating the presence of overfishing taking for *T. ilisha* stock in the marine waters of the southern part of Bangladesh. In case of yield per recruit (YPR) 5% overfishing is taking place at the southern part (Kuakata, Patharghata) coast of Bangladesh.

The spawning-biomass-per-recruit (SBPR) measures the intensity and impact of fishing on the stock productivity. The indication ranges from 0% (fully exploited) to 100% (Virgin state) (Tirtadanu and Chodrijah, 2019). The current percent of spawning biomass of *T. ilisha* virgin spawning biomass in the nearshore waters of southern part of Bangladesh was estimated as F 33% (Figure 4.10). The level at which a spawning biomass can reach to be a matter of concern is 20% (Froese, 2004). The current SBPR (33%) is higher than 20% indicating a presence of recruitment overfishing. Furthermore, spawning biomass per recruit (SBPR) 11% overfishing in taking place at the southern part (Kuakata, Patharghata) of Bangladesh.

5.6 Maximum Sustainable Yield (MSY) and Steady State Biomass (SSB):

The maximum sustainable yield is the average annual catch that can be sustained over time by keeping the stock at the level of producing maximum growth (Sparre and Venema, 1998). The current study estimated the annual average landing of *T. ilisha* to be 427142 mt and the maximum sustainable yield (MSY) as 471707 mt (Figure 4.13). This indicates that the annual average landing is 16% less than the current maximum sustainable yield (MSY). Therefore, there is a need to increase the fishing intensity to reach the maximum sustainable yield.

Table 5.2: Instantaneous of the MSY of the Hilsa in the waters Bangladesh estimated by different authors

Studies	Methods	Year	Data Type	MSY (Tons)
Rahman et al. (2018)	Gulland Method	2015-2016	Length-frequency	526,000
Amin et al. (2002)	Gulland Method	1999	Length-frequency	162,396
Halder & Amin (2005)	Gulland Method	2002	Length-frequency	235,130
Amin et al. (2008)	Gulland Method	1980-2000	Length-frequency	210,125
Alam et al. (2021)	BSM	2017-2018	Catch and Effort	263,000
Present Study*	Schafer Method	2020	Catch and Effort	471,707

(Gulland method is MSY = Z × B × 0.5 Or MSY = Z × SSB × 0.5, where, Z is the total annual mortality, B is the Biomass, SSB is the steady state biomass, respectively).

Although several studies have proposed the MSY for Hilsa stock in Bangladesh's water using Gulland methods (Table 5.2), a discrepancy exists between those and present study. The method used in the previous studies using length-frequency data may not produce robust estimates of MSY when the fishery is characterized by a simultaneous increasing trend in the catch and CPUE indices. On the other hand, the Monte Carlo catch-only method (CMSY) has shown its robustness in previous study and reviews. Therefore, to save the stock, immediate protective management measures are required.

The estimated steady state biomass (SSB) and population number (N) were found to have a strong relationship with fish size (Table 4.3). However, the number of larger-sized fish was significantly reduced, likely due to high fishing pressure, and no substantial contribution was obtained from fish larger than 51 cm TL (Table 4.3). This should be taken as a red flag in terms of ensuring the long-term viability of the Hilsa fishery, and further efforts should be made to preserve Hilsa brood fish. In reality, due to the increased conservation a brood fish Hilsa in recent years, larger sized Hilsa (> 1 kg and > 44 cm TL) resurfaced in Bangladesh waters (southern part) in significant numbers, increasing by about 15% on average from 2015 to 2016 (Wahab 2016).

CHAPTER 6: CONCLUTIONS

6.1 Conclusion:

The estimated exploitation level was at 0.63 that was 26% higher than optimum level of exploitation (E = 0.50). The current length at first capture (L_C =10.42 cm) was much lower than optimum length at first capture (Lc = 32.0 cm), that indicated growth overfishing of *T. ilisha*. The current SBPR ($F_{33\%}$ = 39.01 g) was recorded at fishing mortality of 1.25 yr^{-1} which was lower than SBPR ($F_{40\%}$= 47.23 g) at fishing mortality of 0.79 yr^{-1} that indicated recruitment overfishing. Additionally, the MSY of *T. ilisha* was estimated as 471,707 tons and the current landing was 550,000 tons that was 16% higher than MSY of hilsa. To overcome the growth and recruitment overfishing, it is recommended to increase 11% length at first capture from the current length at first capture for sustainable yield of hilsa.

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