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Fishing Enclosure as a Simple Approach to Stimulate Spawning Success of *Tenualosa ilisha* (Hamilton, 1822) in Bangladesh

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ABSTRACT

The study was intended to assess the impact of fishing enclosure during the peak breeding time of hilsa, *Tenualosa ilisha* on its breeding success. During the last peak breeding season of hilsa (October 4-25, 2021) a comprehensive investigation was attempt to evaluate the impact of fishing enclosure by "MV Rupali Ilish" research vessel, speedboat and experimental fishing net were deployed to demeanor a rigorous investigation in and around the spawning grounds areas (about 7,000 sq km, including Moulvirchar, Monpura, Dhalchar and Kalirchar). Additionally, data were also assumed from landing stations (via terrestrial cruises) near the spawning ground areas and other hilsa prone region of Bangladesh. The percentage of spent hilsa (locally called pite) and oozing hilsa were monitored following a standard protocol. Among all the hilsa captured in and around the spawning grounds, the proportion of male and female were 16-41% and 85-97%, respectively of the total catch, suggesting a male and female sex ratio (1:2.3). The rate of breeding success in 2021 was 51.76% i.e., 51.7% hilsa successfully participated in the breeding process which was 103.52% higher than the base year (2001-02). The approximate number of fertilized eggs in 2021 was 7,86,314 kg. Increased production of hilsa eggs and *jatka* indicated a positive impact of twenty-two days fishing enclosure. Percentages of gravid and oozing hilsa were also found higher compared to previous years. Due to the prohibition of all types of fishing, the percentage of female hilsa in the breeding areas increased up to 83.96%. Overall, twenty-two days fishing enclosure was found very effective for successful spawning of hilsa.

INTRODUCTION

The national fish hilsa (*Tenualosa ilisha*, Hamilton, 1822) is Bangladesh's most important open-water species, contributing significantly to the country's economy, income, poverty alleviation, employment, and food security. The global average yearly production of the 11 hilsa fishing nations is >0.72 million tons (Hossain *et al*., 2019), of which Bangladesh contributes about 80%, India 15%, Myanmar 4%, and other nations (such as Iraq, Kuwait, Malaysia, Thailand, and Pakistan) 1% (DoF, 2022). In last 12 years, hilsa production in Bangladesh has increased about 81% that reached 5.65 lakh MT in 2020-21 and annual growth increment in hilsa sector was 3.31% (DoF, 2022). Currently, hilsa contributes about 12.2% to overall fish production and about 1% to the country's GDP (DoF, 2022). Hilsa has also wraps sociocultural and religious values and its non-consumptive value estimated approximately US$0.36 billion per annum (Mohammed *et al*., 2016). In the country, around 2.5 million individuals are directly or indirectly involved in the catching and trading of hilsa fish (DoF, 2022).

Hilsa is a typical anadromous shad (Jones, 1951; Pillay, 1955; Pillay and Rao, 1962, 1963) with a complex life cycle. Hilsa reproduces in upstream rivers, where the larvae hatch from free-floating eggs. The larvae vary in size between 2.3 and 3.1 mm and are drifted by wave action and tidal currents to the nursery grounds (Rahman, 2006). Immature early stages develop in river channels, then migrate to the sea to feed and grow before returning to the rivers as mature gravid hilsa to complete the life cycle (BOBP, 1987; Milton and Chenery, 2003; Hossain *et al*., 2016). Juvenile hilsa remain in the downstream of river, albeit they have been found to occur in the upper and lower estuaries, and even further down to the coastal areas that are far from both their spawning and nursery grounds (Hossain *et al*., 2016). The juvenile hilsa known as *jatka* remain around the nursery grounds for the next 5-6 months and attain a maximum size of 10-16 cm (Raja, 1985; BFRI/RS, 1994) in 8542 km2 suitable riverine and nearshore coastal waters in Bangladesh (Hossain *et al*.,2016). As the *jatka* grows bigger with an ability to adapt to salinity, they start migrating from brackish-freshwater habitats to the offshore or seawards and at 10-16 cm total length, all the hilsa complete their migration (BOBP, 1987; BFRI/RS, 1994). As the hilsa become sexually mature at nearly a year of age, they start their spawning migration into freshwaters (Hossain *et al*., 2014b).

Hilsa is a high fecund fish that can lay up to 2 million eggs (Qureshi, 1968, Shafi *et al*., 1977, Quddus, 1982, Moula, 1992, Rahman *et al*., 1998, Blaber *et al*., 2001, Haldar, 2004, BFRI, 2006-07, Rahman *et al*., 2017, Rahman *et al*., 2012). Albeit hilsa spawn all the year round, the full moon phase in Bengali month Ashwin-Kartik (September-October) (Rahman *et al*., 2012; Saifullah *et al*., 2004) coincides with the peak spawning season. The spawning cycle is closely synchronized with the lunar cycle, and intense spawning is observed during three-days before and after the new moon and the full moon (Miah *et al*., 1999). During the major spawning season, mature gravid hilsa are captured in large numbers from the major spawning areas. During

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their seaward migration, juvenile hilsa known as *jatka* have also been caught in some of the major rivers of the country (Ahmed *et al.*, 2010; Rahman *et al.*, 2011, 2012, Jaher *et al.*, 2013). During this onward and backward migration, widespread unregulated capture of mature and juvenile hilsa can have a serious negative impact on hilsa population and affect sustainable production of the country.

In light of the foregoing, the hilsa Fishery Management Action Plan (HFMAP) was developed for the management, and conservation of hilsa, with the goals of safeguarding nursery and spawning sites and prohibiting indiscriminate killing of illegal sized hilsa. Under the "Fish Protection and Conservation Act-1950", so far six hilsa sanctuaries and four major spawning grounds have been established in the country's coastal and freshwater zones for the successful conservation of *jatka* and brood hilsa (Figures 3; Tables 3 and 4). The results of BFRI, RS research showed that a high number of matured gravid hilsa congregate at the spawning grounds for breeding during the peak spawning time, which coincides with the lunar periodicity, and more especially the full moon phase (Reuben *et al.*, 1992; Rahman and Cowx, 2008, Rahman *et al.*, 2017). At this time, matured gravid hilsa are indiscriminately captured, which has a negative impact on spawning and hilsa population BoBLME (2012). As a result, in accordance with HFMAP recommendations, fishing closure has been imposed to ensure the safe and successful spawning of hilsa. This enclosure last for 22 days, from 4th-25th October in 2021, and included a new moon and full moon day (Bengali month Ashwin,1427), (Table 1 and Figure 1). During this time, all types of commercial trawlers fishing in the sea, coastal regions, and rivers were restricted under the Marine Fisheries Ordinance 1983, Section 55, Sub-section 2 (D) for safe hilsa migration and spawning.

Fisheries enclosures may be temporary or ongoing and have a variety of justifications. For instance, fishing restrictions have been employed extensively in fisheries management to prevent overfishing and the collapse of a fishery, restore depleted stocks, and limit bycatch of protected species (National Oceanic and Atmospheric Administration (NOAA), 1985; Gell and Roberts, 2002; Farmer *et al.*, 2016; Agar *et al.*, 2019). Fishing enclosures have occasionally been implemented during a species' breeding or spawning season in an effort to directly minimize fishing mortality and to increase the number of eggs produced annually (Murawski *et al.*, 2000; Arendse *et al.*, 2007). There are many examples of fishing enclosures around the world, for example; it has been implemented in the Gulf of Mexico shrimp fishery and Florida lobster fishery [National Oceanic and Atmospheric Administration (NOAA), 1985; Beets and Manuel, 2007], United States Virgin Islands grouper fishery (Beets and Friedlander, 1999) and coral reefs in Kenya (McClanahan, 2010).

In Bangladesh, the Department of Fisheries (DoF) enacted the fishing enclosure in collaboration with law enforcement organizations such as the Navy, Coast Guards, River Police, and Air Force based on the findings of BFRI, RS. The impact of fishing enclosure seems to have a positive impact on the overall hilsa product of the country.

Table 1: Management interventions for *jatka* and brood hilsa conservation in the major spawning and nursery grounds of hilsa in Bangladesh.

Year	Management system	Considering issues
2001-02	Conventional	Without any management
2002-03	Conventional	Traditional (improved) management
2003-04	*Jatka* conservation	Protection system
2004-05	*Jatka* conservation	Protection system
2005-06	*Jatka* conservation+sanctuary	Full Moon basis
2006-10	*Jatka* conservation+sanctuary+10 days hilsa fishing enclosure	Full Moon basis
2011-12	*Jatka* conservation+sanctuary+11 days hilsa fishing enclosure	Full Moon basis
2012-13	*Jatka* conservation+sanctuary+11 days hilsa fishing enclosure	Full Moon basis
2013-14	*Jatka* conservation+sanctuary+11 days hilsa fishing enclosure	Full Moon basis
2014-15	*Jatka* conservation+sanctuary+15 days hilsa fishing enclosure	Full Moon basis
2015-16	*Jatka* conservation+sanctuary+15 days hilsa fishing enclosure	Full Moon basis

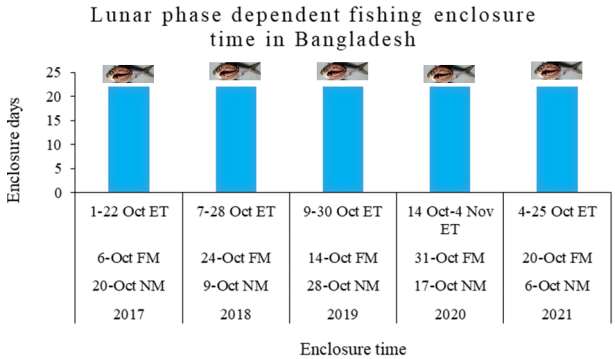

Figure 1: New moon and full moon dependent fishing enclosure time in Bangladesh.
** ET= Enclosure time, FM= Full moon day, NM= New moon day*

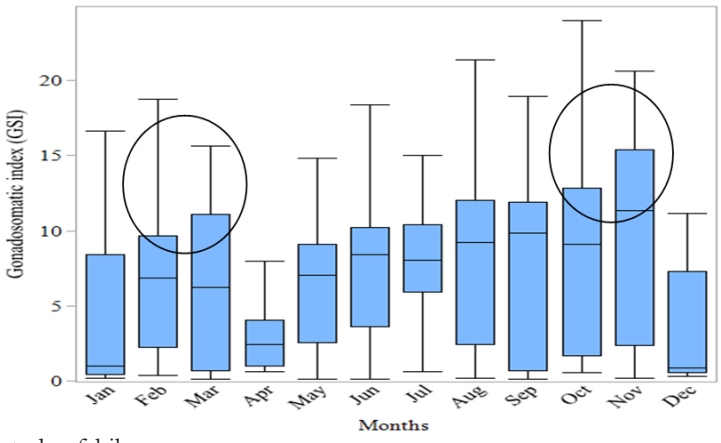

Figure 2: Monthly GSI study of hilsa

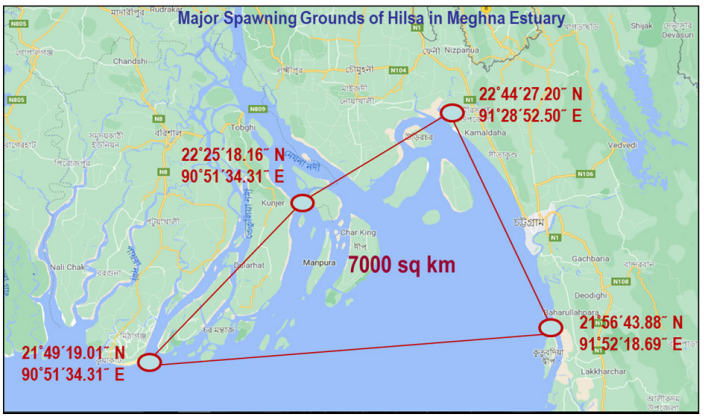

Figure 3: Major spawning grounds of hilsa in the Meghna River estuary with approximate GPS point (Source: BFRI and GEF studies).

Table 2: Areas of spawning grounds in Bangladesh.

Sl No.	Directions	Contour	Areas (sq km)	District
1	East-North	Mayani-Mirarsorai	125	Chittagong
2	West-North	Paschim Syed Aowlia-Tojumuddin	80	Bhola
3	East-South	Gondamara-Bashkhali	120	Cox's Bazar
4	West-South	Latachapali-Kolapara	194	Patuakhali

Source: Bangladesh gazette 28 May, 2014, MoFL

METHODOLOGY

Preparation of Hilsa Research Team

The Hilsa Research Team of BFRI, RS, Chandpur carried out all the investigations. Two ways were selected for sampling and data collection such as:

a. Research vessel (*M.V. Rupali Ilish* with speed boat) trip (Figure 4) and

b. Research trip with necessary research equipment's by using local transport system

Five research teams were formed to conduct a comprehensive investigation in the designated hilsa spawning and sanctuary areas (Table 2 and 3). The nursery grounds were chosen as sampling sites because: (a) hilsa shed their eggs in almost all major river systems across the country during the breeding season, but the spawning grounds (Figure 3) grasp 80-90% of them; (b) hilsa eggs and larvae begin drifting and shifting to upstream rivers shortly after spawning; and (c) hilsa is a migratory fish that may travel a long distance after spawning and be captured there. As a result, a large sampling area was chosen to provide precise information on the percentage of spent, oozing, and gravid hilsa.

Figure 4: Hilsa research vessel 'MV Rupali Ilish

Table 3: Six established sanctuary areas of *T. ilisha*.

Sl. No.	Sanctuary area	Length	River	Enclosure period	District
1.	Shatnol-Char Alexander	100 km	Lower Meghna estuary	March-April	Chandpur-Laxmipur
2.	Char Ilisha-Char Pial	90 km	Stretch of Shahbajpur Channel, tributary of the Meghna River	March-April	Bhola
3.	Bheduria-Char Rustam	100 km	Stretch of Tetulia river	March-April	Bhola-Patuakhali
4.	Kalapara Golbunia-Confluence of Bay of Bengal and Andharmanik river	40 km	Andharmanik river	November-January	Patuakhali
5.	Tarabunia-Vomkora	20 km	Lower Padma River	March-April	Shariatpur
6.	Habinagar, Barisal Sadar-Hizla- Mehendigonj	82 Km	Meghna River	March-April	Barisal

Source: Bangladesh gazette 28 May, 2014 and 17 April, 2018, MoFL

Standard Formula (Rahman *et al*., 2009 and Rahman *et al*., 2017)

The number of hilsa rescued and total fertilized eggs as a result of the fishing enclosure were determined using the following formula:

No. of hilsa saved due to fishing enclosure (TN) = Nos. of fishing boat*Nos. of haul/day*Nos. of fish captured/ Nos. of haul* 1

Nos. of days TN*FF*SF*EF/1000.....(2)

Where,

TN = Total No. of hilsa excluded due to fishing enclosure;

EF = % of female fishes in the study areas;

SF = % of spent/oozing fish, and

EF = Average egg (g) per fish

Site Selection

The major hilsa spawning grounds, nursery grounds and fish landing sites (13 districts) in Bangladesh were selected for investigation (Table 5 and Figure 5). These sites account for the majority of spawning hilsa during the peak spawning season, through which the country's major river systems are flowing including the river Padma and Meghna. Furthermore, samples were collected from Chattagram and Cox's Bazar, where the majority of marine hilsa are gathered for vending.

Table 4: Selected sites for sampling

SL. No.	Sites	District	River/Sea
1.	Chandpur, Katakhali, Horinaghat, Haimchar and Charvoirobi	Chandpur	Meghna
2.	Hizla, Mehendiganj, Ulania	Barishal	Meghna
3.	Ramgoti, Char Alexandar	Laxmipur	Meghna
4.	Tanki Bazar, Chairman ghat, Hatia	Noakhali	Meghna estuary
5.	Dhalchar, Moulovirchar, Daulatkhan, Monpura	Bhola	Meghna estuary
6.	Kalirchar, Patharghata	Barguna	Meghna estuary
7.	Mohipur, Galachipa, Kalapara	Patuakhali	Andharmanik
8.	Tarabunia	Shariatpur	Padma
9.	Godagari	Rajshahi	Padma
10.	Mawa	Munshigonj	Padma
11.	Fishery Ghat	Chattagram	Sea
12.	BFDC Ghat	Cox's Bazar	Sea
13.	BFDC Ghat	Khulna	Sea

Data collection time frame

Three sequential time frames were selected for sampling and data acquisition by the Hilsa Research Team such as:

i) Before the enclosure period (05 days)

ii) Whole enclosure period (22 days)

iii) After the enclosure period (05 days)

Determination of size, sex and percent composition of gravid/berried hilsa

The length (cm) and weight (g) of collected hilsa samples were measured at different sampling locations (Table 4). The length was measured using a wooden scale and weight with a digital balance, respectively. External observation and steady light pressure from the tip of the ventral squat to the anus of the belly were used to identify the sex of hilsa fish.

The fish exhaling liquid cream while stripping was considered as male; on the contrary, the fish extruding eggs and a light reddish substance were considered as a female hilsa. Female hilsa were also detected with a potbellied reddish and larger anus. If neither of this milk/ eggs come out, the fish were considered as immature

Figure 5: Thirteen districts on the map of Bangladesh from where data were collected during fishing enclosure.

(*jatka*) or partly mature. Female hilsa were often found larger in length than male hilsa.

Identification of Spent (pite 'in local language) and Oozing (*spawning*) hilsa

The spent hilsa were characterized by some external features like skinny, squeezed stomach, and an extended slender body. If watery liquid or blood emerges with the alienated and malformed egg after light pressure on the abdomen, it was labeled as the spent hilsa ('pite' in the local language). After being captured from the river, spent hilsa were quite feeble. Usually fishers keep spent hilsa for their own household consumption and don't bring them to the market because they diminish the market value of other fish. Oozing hilsa were recognized by studying their egg-laying state, which is characterized by ripe eggs erupting spontaneously without any pressure on the abdomen (Figure 6).

Gonadosomatic index of hilsa

During the investigation, the sex of at least 30 individual specimens were observed by abdominal incision and ocular examination of the gonad. The gonads were meticulously stripped of all fat, connective tissue, and blood vessels, and their gonadal weight (GW) was calculated to the nearest 0.001 g. The gonadosomatic index (GSI) was determined using the following formula: GSI = GW × 100/BW (Nikolsky, 1963)

Determining the (%) of Spent (*pite*) hilsa

The Hilsa Research Team of BFRI determined the number and rate of spent hilsa primarily from hilsa captured using experimental nets in the breeding grounds and surveillance of commercial fish landing sites around the breeding grounds.

Figure 6: Pictorial views of spent and oozing hilsa.

Calculation of Fertilized Eggs

During the fishing enclosure, the approximate number of fertilized eggs (Figure 7) released by hilsa in the spawning grounds were estimated using the following formula:

The plausible amount of egg production due to the fishing enclosure was:

Approximate Egg Production = {(54*22*15500*75/100) *(51.76/100*110)}/1000 = 7,86,314kg

Where, No. of matured hilsa captured in per unit effort = 27 (Two haul/day; = 54); Total nos. of enclosure days = 22 days; Approximate number of fishing boats = 15500; Total area of spawning ground =7000sq km, on an average 2 fishing boats are operated in per sq. km; Average percentage of matured female during the fishing enclosure = 75%; Average percentage of spent hilsa during the fishing enclosure = 51.76%; Average weight of gonad of matured female = 110g; One kilogram = 1000g.

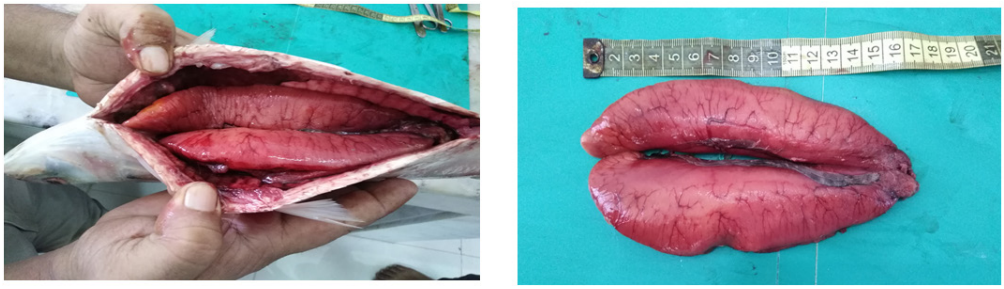

Figure 7: Pictorial views of hilsa eggs.

Calculation of *jatka* Production

The number of fry and *jatka* production were calculated based on 50% hatching rate of fertilized eggs and 10% survival rate of hatched larvae.

Size, Weight, Age and CPUE Calculation of hilsa fry and *jatka*

Hilsa larvae were collected from the spawning grounds and adjacent sites by means of BFRI experimental fishing net (made of glass nylon fiber) (Figure 8). A measuring scale and a digital balance were used to determine the length and weight of hilsa larvae and *jatka*. The amount of *jatka* (kg) captured in a 100 m net per hour per boat was delineated as the catch per unit effort (CPUE).

Observations of Other Impacts of Fishing Enclosure

To observe the additional benefit of the 22-day fishing enclosure, larvae and juveniles of other fish species were collected from the spawning grounds and adjacent sites using a BFRI experimental fishing net (made of glass nylon fiber: mouth diameter - 15 ft, length from the mouth to the end - 25 ft, loop size - zero, and fishing time was 30 minutes) (Figure 8).

Figure 8: Experimental fishing net for collecting juvenile hilsa.

Data Analysis

The data were compiled and processed using Microsoft Excel (version 2016). Graphical representation of data was also prepared by Microsoft Excel.

Result and Discussion

Size and Sex Ratio of hilsa

The majority of the hilsa captured in the upstream rivers were smaller than 35 cm (50% in Chandpur), whereas the majority of the hilsa captured in the downstream rivers were greater than 35 cm (>74% in Bhola and Barishal) (Figure 9). Furthermore, most of the hilsa (80-90%) captured at the down stretches of the Meghna estuaries were gravid female. Ahmed *et al.* (2010) found 77-84% of hilsa at Ramgoti and 86-92% of hilsa at Hatia under the size class of 36-52 cm whereas smaller sized (18-36 cm) hilsa ranged between 8-23%. On the contrary, Rahman *et al.* (2009, 2013, 2015 and 2017) investigated the influence of fishing enclosure on hilsa spawning grounds and revealed larger percentage (90%, 95% and 85%, respectively) of hilsa comprising length groups greater than 30-35 cm in the Monpura and Hatia areas. Almukhtar *et al.* (2016) also found size discrepancies in T. ilisha migrating in the Shatt Al Arab River and Southern Al Hammar Marsh, Basra, Iraq. Rahman *et al.* (2012) categorized hilsa into four size groups, small (<30 cm), medium (30–39 cm), large (40–49) cm and extra-large (>50 cm) and found more than 90% hilsa within the range of 30–40 cm during their investigation. The data from a recent survey by phone to fish vendors (2013–14) conducted under the ESPA-Deltas project in some of the largest hilsa landing centers and markets of the Bangladesh coast showed that 90% of the hilsa ranged from 25–75 cm (Fernandes *et al.*, 2016). However, Dutta *et al.* (2012) found the maximum length of hilsa 45.5 cm in their studies. In general, commercial catches in both Bangladesh and Indian waters showed a general size range of about 15–52 cm (Azad *et al.*, 1987; Gupta, 1989; Rahman, 2006).

Aside from the spatial variation of L-F, an apparent temporal variation in the length class of hilsa was also noticed. Normally, 30-35 cm length class predominated before and after the enclosure period, whereas mature hilsa (egg bearing female, >40 cm) predominated during the spawning time (Figure 10). Ahmed *et al.*, 2010; Rahman *et al.*, 2011, 2012, Jaher *et al.*, 2013 and Rahman *et al.* (2017) Alam *et al.* (2019) also found an alteration of the hilsa length class before and after the spawning time. The proportion of male and female hilsa also varied significantly before and after the prohibition period, indicating an uneven hilsa sex ratio. Before and during the prohibition, the average proportion of male hilsa was 3-14%, rising to 16-41% during the enclosure period (October 4-October 25). However, before and during the restriction period, the average proportion of female hilsa was 56-89%, raised up to 85-97% during the enclosure period (October 4- October 25). These findings differed

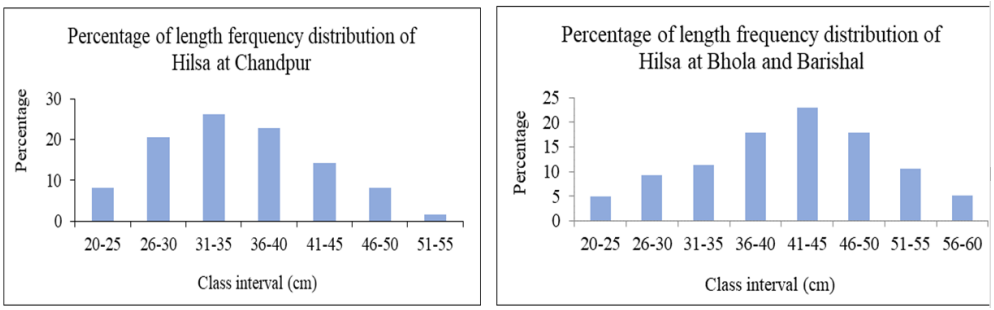

Figure 9: Percentage of different length-classes of hilsa at upstream and downstream of rivers in Bangladesh.

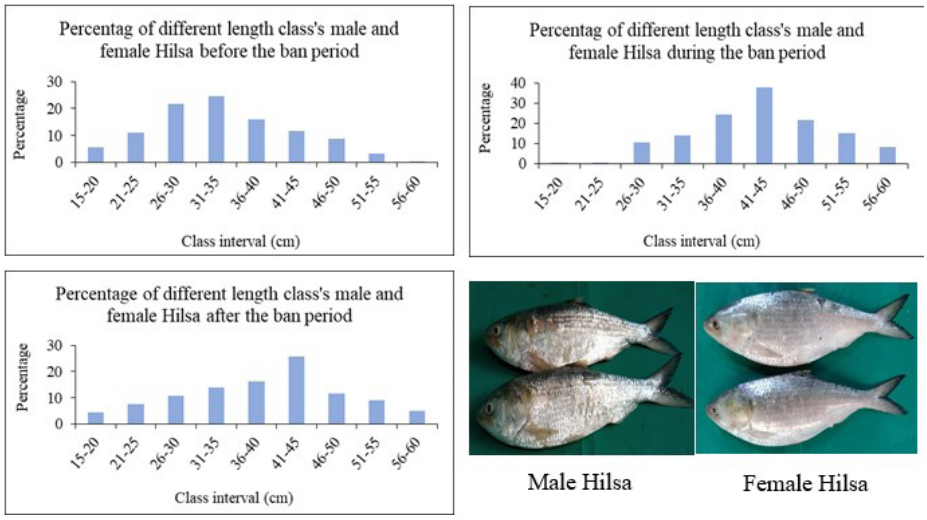

Figure 10: Percentage of different length class's male and female hilsa before, after and during the ban period in the major spawning grounds of hilsa in Bangladesh

to some extent from those of Haldar *et al.* (2004), who observed a male-female sex ratio of 1:2 in the main spawning sites of hilsa. In a separate study, Islam *et al.* (1987) found a male-female sex ratio of hilsa 1:1.08 in the upper stretches of Meghna River (Chandpur). In previous BFRI conducted investigation, Rahman *et al.* (2009) noticed 35% male and 65% female, whereas Ahmad *et al.* (2010) found almost 4.2% male and 95.8% female in and around the spawning grounds among all the captured hilsa. During the monsoon, Quereshi (1968) observed a male-female sex ratio of 1:1, although the female was dominating in October. According to Blaber *et al.* (2001) males are more abundant among smaller fish. The bias in the sex ratio of T. ilisha suggests that males may not live as long as females (Mahmud, 2020).

Percent composition of spent and oozing hilsa

Approximately, 2100 hilsa were examined throughout this study where a substantial number of spent and oozing hilsa were found during the study period. The overall fraction of oozing and spent hilsa were 32.4% and 51.7%, respectively (about 84%, combing both). The results indicated that fishing enclosure ensured successful breeding as also found by Ahmed *et al.* (2010); Rahman *et al.* (2011 and 2012); Jaher *et al.* (2013) and Rahman *et al.* (2017) during their studies.

In 2001-02, the percentage of spent hilsa was >1%. The percentage of spent hilsa has steadily increased until recent years (103% higher in 2020-21 than in 2009-10), due to the successful deployment of a fishing closure during the peak spawning season (Figure 11).

Rahman *et al.* (2009) found 1.51% oozing and 5% spent hilsa during the fishing ban period in the spawning grounds and it was about 2.80-3.57 times higher than the Global Environment Facility (GEF) and Bangladesh Fisheries Research institute (BFRI) studies of 2002 and 2003. The occurrence of spent hilsa ranged between 5-39% in 2007-09 which was estimated 76% higher than the previous studies (Ahmed *et al.*, 2010). The percentage of spent hilsa was about 34% in 2010; 36% in 2011 and

Table 5: Percent composition of spent and oozing hilsa during the enclosure period.

Status of hilsa breeding	Sampling points					
	Cox's Bazar	**Ramgoti**	**Chandpur**	**Potuakhali**	**Monpura**	**Average**
Oozing	98 (31%)	950(62%)	72 (13%)	16 (17%)	19 (39%)	32.4%
Spent	147 (52%)	455 (31%)	287 (42%)	32 (71%)	16 (63%)	51.76%
Total Number	**245**	**1405**	**359**	**48**	**35**	**2092**

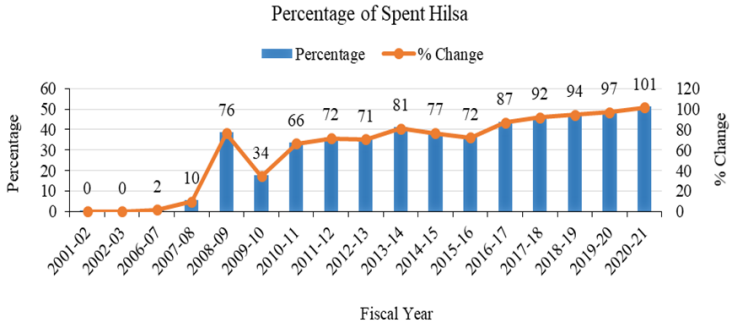

Figure 11: Percentage and change of spent hilsa in different years in Bangladesh.

2012; 41% in 2013; 39% in 2014; 37% in 2015; 44% in 2016 (Rahman *et al*., 2017).

Production of fertilized eggs and *jatka* during the fishing enclosure period and spawning success

The total egg production of hilsa was determined using the BFRI's standard formula. Due to the fishing prohibition, approximately 7,86,314 kg of hilsa eggs (Figure 12) were produced in 2021-22. If 50% of the eggs produced are fertilized and hatched, and 10% of them survive, then approximately 7,86,314 crores of hilsa fry and 39.31 crores of *jatka* (Figure 12) were recruited into the hilsa population. These studies suggested that increasing the number of enclosure days (10 days from 2007-08 to 2010-11; 11days from 2011-12 to 2013-14; 15 days from 2014-15 to 2015-16; and 22 days from 2016-17 to 2020-21) had a positive impact on egg and *jatka* production. In the current year (2020-21), egg production augmented about 17 times, while fry and *jatka* production increased approximately 16.2 times than the year 2007-08 when fishing enclosure during the peak spawning time started to be implemented. Each year, the recruitment of this significant number of *jatka* to the hilsa population as a result of the fishing restriction resulted in a consistent and increased production of hilsa in Bangladesh (Figure 14). Haldar (2004) and Ahmed *et al*., 2010; Rahman *et al*., 2011, 2012, Jaher *et al*., 2013 Rahman *et al*. (2017), Mahmud *et al*. (2020) stated that a total fishing prohibition has a significant positive impact on *jatka* abundance as well as the country's overall hilsa production. Seasonal closure during the breeding or spawning period of species directly reduces fishing mortality and thereby achieving greater annual reproductive output (Murawski *et al*., 2000; Arendse *et al*., 2007).

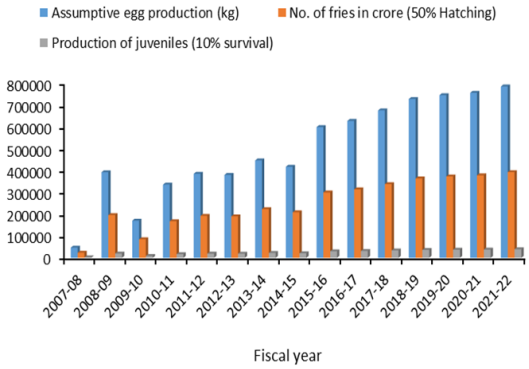

Figure 12: Approximate number of eggs, fry and *jatka* production in the major spawning grounds.

CPUE of hilsa fry and *jatka*

The CPUE of *jatka* (19.94 kg/100 m net/boat/hr) of the current year (2021-22) demonstrated 18 times increment compared to the base year, and it was roughly 1.8 times higher in amount than the previous year (2019-20) (Figure 13). Nevertheless, current CPUE is about four times greater than the study conducted by Rahman *et al*. (2017). Successful spawning of higher percentage of hilsa due to fishing closure resulted in increased CPUE of *jatka* in the country (Alam *et al*., 2019a, 2019b and Mahmud *et al*. (2020). Kamal *et al*. (2015) found significantly higher CPUE while studying the effects of seasonal closure in a multispecies fishery.

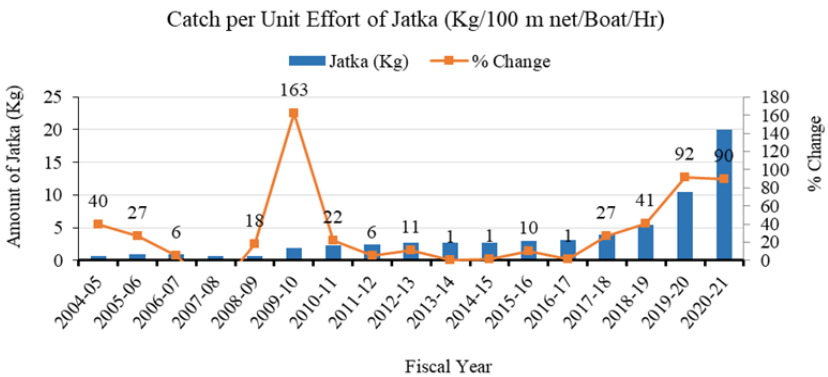

Figure 13: CPUE of *jatka* in the selected sampling sites.

Total hilsa production of the country

The hilsa production in the country was 1,99,032 MT in 2002-03, 2,79,189 MT in 2006-07, and in last year (2020-21) it reached at 5,65,183 MT (DoF, 2021). The overall hilsa production of the country has increased roughly 2.77 times since 2002-03 and about 2.0 times since 2006-07 through implementation of fishing closure by all relevant government agencies (Figure 14). All previous investigators of BFRI (Ahmed *et al*., 2010; Rahman *et al*., 2011 and 2012; Jaher *et al*., 2013 and Rahman *et al*., 2017) concluded that hilsa production is gradually increasing in the country due to the stricter implementation of management interventions especially fishing closure during the peak spawning time of hilsa. Beets and

Manuel (2007) noted that, the temporal and seasonal closures used in fisheries management in tropical and subtropical regions have been useful and beneficial based on perceived benefits and annual production (Beets and Manuel, 2007).

Availability of hilsa and other fish's larvae in experimental nets (indicator of breeding success)

In the breeding grounds, a glass nylon fiber net was used to gather larvae at high and low tide (Figure 8). During low tide, around 29% of hilsa larvae were detected in the experimental net, whereas 71% were other fish's larvae. During high tide, however, hilsa larvae were 56%, whereas other fish's larvae were 44%. Overall, 85% of hilsa larvae were found during high and low tide (Figure 15). The total number of larvae gathered during high and low tides varied significantly; at high tide, the number of larvae was greater than at low tide (Figure 16). Shrimp, chewa, poa, shillong, kakila, baim, chanda, kuchia, bele, and other fish larvae were found with the other fish's larvae. According to the International Union for Conservation of Nature's (IUCN, 2015) biodiversity status of Bangladesh and global biodiversity, many of these species are threatened (vulnerable, endangered, or least concern) (Table 6). After the breeding season, hilsa larvae (Figure 17) begin to migrate to the primary nursery grounds, where they develop into juveniles and then *jatka*.

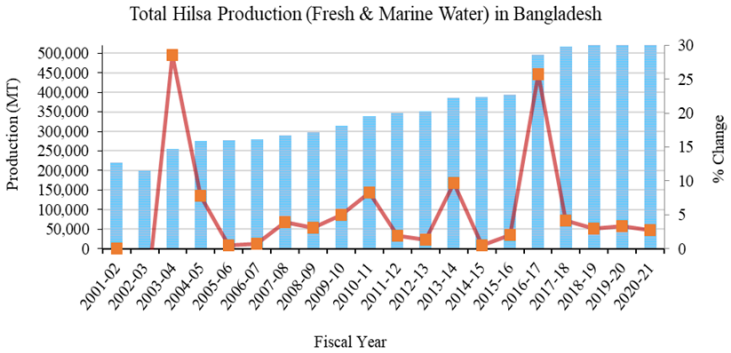

Figure 14: Total hilsa production of the country (Freshwater and Marine)

In a month, hilsa larvae develop from 2 to 2.5 cm (Haldar, 2004). The spawning success of hilsa is indicated by the presence of hilsa juveniles (Figure 17) in various nursery grounds/sanctuary areas. During BFRI's experimental fishing, a large number of hilsa juveniles were found in the nursery grounds (Figure 17), with an estimated age of 30-45 days. Rahman *et al.* (2017) found the similar positive impact of fishing closure on abundance of hilsa and other fish's larvae. In another study, Kincaid and Rose (2017) found that biological community assemblages changed significantly before–after and inside–outside the closing time and area. Kamal *et al.* (2015) studied the effects of seasonal closures in a multi-specific fishery and found that depending on its timing, the closure would highlight some positive biological effects on some target species.

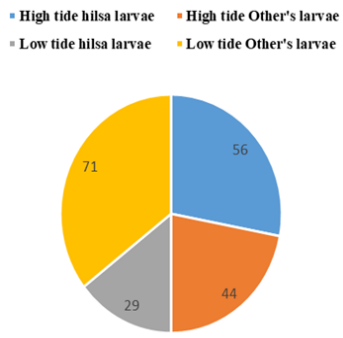

Figure 15: Percentage of hilsa and other's fish larvae during high and low tide

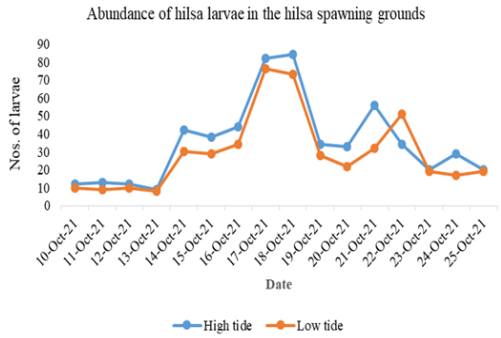

Figure 16: Abundance of hilsa larvae in the spawning grounds.

Figure 17: Observations of hilsa juveniles.

Table 6: Identified fish species list with Bengali name, scientific name and conservation status.

Sl. No.	Local name	Group name	Scientific name	IUCN (2015) BD status*	IUCN (2015) GB status*
1.	Bele	Mudskippers	*Glossogobius giuris*	LC	LC
2.	Chela	Barbs and Minnows	*Salmostoma acinace*	LC	LC
3.	Cuchia	Eels	*Monopterus cuchia*	VU	LC
4.	Red Chewa	Mudskippers	*Odontamblyopus rubicundus*	LC	NE
5.	Vacha	Catfishes	*Eutropiichthys vacha*	LC	LC
6.	Sada Chewa	Mudskippers	*Trypauchen vagina*	LC	NE
7.	Kakila	Gars	*Xenentodon cancila*	LC	LC
8.	Baim	Eels	*Mastacembelus armatus*	EN	LC
9.	Pangus	Catfishes	*Pangasius pangasius*	EN	LC
10.	Poa	Flatheads	*Otolithoides pama*	LC	NE
11.	Silong	Catfishes	*Silonia silondia*	LC	LC
12.	Khorsula	Mullets	*Rhinomugil corsula*	LC	LC
13.	Kholisa	Labyrinth fishes	*Trichogaster fasciata*	LC	NE

**BD = Bangladesh; GB = Global; En = Endangered; Vu = Vulnerable; Lc = Least Concern; NE = Not endangered*

CONCLUSION

The result obtained in this study is an approximation that may be adjusted for a variety of criteria such as the number of fishing boats, those who did not fish, the number of specimens used in the calculation of spent hilsa, and the weight of the female hilsa's ovaries. Furthermore, a variety of biotic and abiotic factors such as (plankton composition, temperature, dissolved oxygen, pH, carbon dioxide, alkalinity, hardness, turbidity, transparency, conductivity, rainfall, and river discharge, among others) may play a significant role in hilsa larvae egg production and hatching in different years, as well as overall breeding success. Furthermore, it is impossible to identify which elements are most relevant for hilsa breeding success and increased output without a controlled laboratory trial (successful implementation of different management interventions or ecological suitability of biotic or abiotic factors). However, because hilsa production is steadily growing with the implementation of management measures, it is possible that this will have some beneficial effects.

RECOMMENDATIONS

The fishing closure should be continued to safeguard mature gravid hilsa and to protect *jatka*. Fishing enclosure should be implemented in combination with other management interventions like gear restrictions, area closure. The existing spawning grounds and nursery grounds should be protected and managed effectively. Additional research is needed to identify new hilsa nursery and breeding sites. The logistic support should be increased to conduct comprehensive on the impact of fishing closure.

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