Evaluating the size at sexual maturity for 20 fish species (Actinopterygii) in wetland (Gajner Beel) ecosystem, north-western Bangladesh through multi-model approach: A key for sound management

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Abstract

Effective fisheries management depend on having an exact assessment of biological parameters, including growth parameters, reproduction, size at sexual maturity (\(L_m\)), and stock assessment. The purpose of this research was to estimate the size at sexual maturity (\(L_m\)) for 20 fish species belongs to 14 families from a wetland (Gajner Beel) ecosystem in the north-western (NW) Bangladesh through multi-models such as length (\(L_{\text{max}}\)) based empirical model, gonadosomatic index (GSI)-based model, and logistic model using commercial catches from January to December 2018. Also, we assessed the \(L_m\) in other water-bodies worldwide. Specimens’ total length (TL) was noted up to 0.1 cm using measuring board body weight (BW) and gonad weight (GW) weighed by digital electronic balance with 0.01 g accuracy. To assess the \(L_m\), maximum body length (\(L_{\text{max}}\)) based empirical model; the relation between TL (total length in cm) vs. GSI (gonadosomatic index in %); and a logistic model were considered. The minimum \(L_m\) was 4.64, 3.90, and 4.15 cm for Chanda nama Hamilton, 1822 and the maximum was 25.33, 24.50, and 24.70 cm for Channa striata (Bloch, 1793) through \(L_{\text{max}}\), GSI, and logistic-based models, respectively. From these three models, the minimum mean \(L_m\) was 4.23 cm for \(C. nama\) and the maximum was 24.84 cm for \(C. striata\). The \(L_m\) with 50.0% species was in 8.80 cm TL. We also calculated the \(L_m\) from different bodies of water based on \(L_{\text{max}}\). This study was generated data of 17 new \(L_m\) among 20 species, which are globally absent. Therefore, the study will help develop sustainable management strategies, conservation through the implementation of mesh size based on the size at sexual maturity (\(L_m\)).

Keywords

Bangladesh, logistic models, fish species, size at first sexual maturity, Gajner Beel

Introduction

In Bangladesh, fishes are the most affluent organisms, which secure livelihood, contribute food, generate employment, and are used to develop the nation’s economy (Hamilton 1971; Godfray et al. 2010; Costello et al. 2012; FAO 2012). The fisheries sector plays a key role in the national economy, contributing 3.50% to the GDP (Gross Domestic Product) of the country and 25.71% in agricultural GDP (DoF 2019). A large variety of aquatic animals...
is found in the inland, estuarine, and marine waters of Bangladesh (Rahman 1989).

Bangladesh is fortunate to have vast aquatic resources and rich fish genetic diversity. It has a lot of inland water bodies that host 267 freshwater fish species. Biodiversity of fishes is very essential for nutrition and livelihoods for the rural people in Bangladesh (Thilsted 2013). Fishes, which spend their life in freshwater, (rivers and lakes), where the salinity is below 1.05‰ are considered freshwater fishes. Fishes require a range of physiological modification to live in the freshwater environment (Rohalin et al. 2019).

A land, which is inundated by water, annually or seasonally, permanently or temporarily that is called a wetland (Keddy 2010). Water purification, processing of carbon and other nutrients, maintenance of shorelines, water storage, and assistance of animals and plants are the important functions of a wetland (Butler 2010). Marsh, swamp, pen, and bog are the main types of wetlands (Keddy 2010). The wetlands can be freshwater, brackish, or saltwater (Ramsar Conservation 1971). The Pantanal in South America, the Amazon River basin, the West Siberian Plain (Fraser and Keddy 2005), and the Sundarbans in the Ganges–Brahmaputra delta (Giri et al. 2007) are the largest wetlands on the Earth. Rivers and streams, Haors, Baors, Beels, lakes and marshes, reservoirs, ponds, cultivated fields flooded by water, and estuarine systems are considered wetlands in Bangladesh (See Table 1). The freshwater wetlands are Haors, Baors, Beels, and Jheels. The man-made wetlands are dighis, lakes, ponds, and borrow pits (Banglapedia 2004).

Gajner Beel is situated at Sujanagar, Pabna in north-western (NW) Bangladesh. This Beel is used as an imperative feeding and spawning ground by many freshwater fish species. Near about 0.5 million people of surrounding villages of this Beel are directly or indirectly reliant on this wetland for their livelihood (Mazid et al. 2005; Hasan et al. 2020).

Effective fisheries management depends on having an exact assessment of biological parameters, including growth parameters, reproduction, size at sexual maturity ($L_m$), and stock assessment (Tracey et al. 2007). The $L_m$ in fish species is a fundamental requirement to find out the reasons on behalf of modifications of the length of maturity (Templeman 1987). Subsequently, it is habitually castoff as a sign of least-acceptable capture dimensions (Lucifora et al. 1999).

Scanning of the literature shows non-availability of species-specific data on size at sexual maturity ($L_m$) of these 20 species except Channa striata (Bloch, 1793) (see Herre 1924; Makmur et al. 2003), Gudusia chapra (Hamilton, 1822) (see Hossain et al. 2010), and Puntius sophore (Hamilton, 1822) (see Hossain et al. 2012a) from the Gajner Beel, Bangladesh. The objective of our research is to estimate the $L_m$ for 20 species from the Gajner Beel in Bangladesh that will be helpful for the management strategies of these species in Gajner Beel in Bangladesh and adjacent aquatic ecosystems.

### Table 1. Types and area of wetlands in Bangladesh.

| Types                      | Wetland                        | Area [km²] |
|----------------------------|--------------------------------|------------|
| Open waters                | Rivers                         | 7497       |
|                            | Estuaries and mangrove swamps  | 6102       |
|                            | Beels and haors                | 1142       |
|                            | Inundable floodplains          | 54 866     |
|                            | Kaptai Lake                    | 688        |
| Closed water               | Ponds                          | 1469       |
|                            | Baors (Oxbow Lakes)            | 55         |
|                            | Brackish-water farms           | 1080       |
|                            | Total                          | 72 899     |

Figure 1. Sampling sites in a wetland ecosystem (Gajner Beel) (indicated by red circle), northwestern Bangladesh.
Materials and methods

The presently reported study was conducted in Gajner Beel (23°55′N, 89°33′E), which is located at Sujanagar, Pabna, NW Bangladesh (Fig. 1). Sampling was done from January to December 2018. Fishes were caught by several types of net (gill nets, long seine) and then preserved in 10% formalin for the further process. Species identification was done by observation of morphometric characters and reviews the various pieces of literature. Each individual was measured by measuring board (0.1 cm) and weighed by digital weight balance (0.01 g). After dissection the fishes, gonads have been removed and weighed. Sexing was determined under the microscopic view, and then only female specimens were used for this analysis. The gonadosomatic index was estimated based on Nikolsky (1963)

\[
\text{GSI} (\%) = \frac{\text{GW}}{\text{BW}} \times 100
\]

where, GW referred to the gonad weight (g) and BW were body weight (g). The length of 50% maturity (50% \(L_m\)) of the 20 fish species was estimated using three models, which were shown in Table 2.

| Model name | Equations | Reference |
|------------|-----------|-----------|
| Empirical model | \(\log (L_m) = -0.1189 + 0.9157 \times \log (L_{\text{max}})\) | Binohlan and Froese 2009 |
| GSI based model | \(L_m = \text{TL vs. GSI}\) | Hossain et al. 2010 |
| Logistic model | \(\text{PMI} = \frac{100}{1 + \exp\left(-\frac{f(TL_m - TL_{50})}{\text{TL}_{50}}\right)}\) | King 2007 |

Analysis of \(L_m\), a logistic curve following King (2007) was applied for the data by plotting the percentage of mature individuals (PMI) against TL class. TL = total length (cm), GSI = Gonadosomatic index (%) and \(L_m\) = Size at sexual maturity.

Results

Altogether 3040 specimens of 20 fish species were considered in the presently reported study and a list of fish species is given in Table 3. The minimum length was 2.40 cm in TL for \(C.\) nama and the maximum length was 46.00 cm for \(C.\) striata. The estimated minimum \(L_m\) was 4.64, 3.90, and 4.15 cm for \(C.\) nama and the maximum was 25.33, 24.50, and 24.70 cm for \(C.\) striata through \(L_{\text{max}},\) TL vs. GSI, and logistic-based models, respectively, and the mean value was 10.04 cm for the 20 species of Gajner Beel, Bangladesh. The maximum length, minimum length, and \(L_m\) with 95% CL are given in Table 4. We also calculated the \(L_m\) from the different water bodies (Table 5) based on \(L_{\text{max}}\) which are collected from the previous works on these species by previous workers. As an example of TL vs. GSI and logistic models and figures are presented in Fig. 2. \(L_m\) shows that 50% of mature fishes are below 8.80 cm, so the selection of this net-mesh size would protect half the adults in the Gajner Beel ecosystem. On the other hand, 80% of mature fishes are below 12.10 cm, so such a larger, more-conservative mesh size might play a vital role for sustainable fish production in wetland ecosystems (Fig. 3).

Table 3. List of total 20 fish species in a wetland ecosystem (Gajner Beel), NW Bangladesh.

| Sl. No | Family | Scientific name | Common name |
|--------|--------|-----------------|-------------|
| 01 | Ambassidae | Chanda nama | Chanda |
| 02 | Anabantidae | Anabas testudineus | Koi |
| 03 | Bagridae | Mystus cavasius | Gudia |
| 04 | Mystus tengara | Tengra |
| 05 | Belonidae | Xenentodon cancela | Kakila |
| 06 | Channidae | Channa orientalis | Cheng |
| 07 | Channa punctata | Taki |
| 08 | Channa striata | Shol |
| 09 | Clupeidae | Gudasia chapa | Chapila |
| 10 | Cobitidae | Lepidocephalichthys guntia | Guntum |
| 11 | Cyprinidae | Amblypharyngodon mola | Moa |
| 12 | Puntius sophore | Jat puni |
| 13 | Salmontomina bacala | Chela |
| 14 | Gobiidae | Glossogobius giuris | Bele |
| 15 | Heteropneustidae | Heteropneustes fossilis | Shingi |
| 16 | Mastacembelidae | Macragnostus aculeatus | Shal baim |
| 17 | Macragnostus panchus | Guchi |
| 18 | Nandidae | Nandus nandus | Bheda |
| 19 | Osphronemidae | Trichogaster fasciata | Kholisa |
| 20 | Siluridae | Ompok pabo | Pabda |

Figure 2. An example figure of size at sexual maturity which produced by TL vs. GSI (A) and logistic model (B) for the 20 species in wetland ecosystem (Gajner Beel) northwestern Bangladesh.

Figure 3. Relation between the maximum total length attained by a species and the number of species attaining that length in a wetland ecosystem (Gajner Beel) northwestern Bangladesh.
Table 4. Size at first sexual maturity ($L_{m}$) of 20 fish species in a wetland ecosystem (Gajner Beel), NW Bangladesh.

| Scientific name | $n$ | Minimum length [cm] | Maximum length [cm] | Maximum length based on (95% CL) | Size at sexual maturity ($L_{m}$) |
|----------------|-----|---------------------|---------------------|----------------------------------|----------------------------------|
| Channa nama    | 196 | 2.40                | 7.20                | 4.64 (3.81–5.68)                | 3.90                            |
| Mystus cavatus | 124 | 5.30                | 16.90               | 10.13 (8.05–12.75)              | 9.80                            |
| Mystus tengara | 139 | 4.80                | 12.60               | 7.74 (6.23–9.65)                | 7.00                            |
| Xenentodon cancila | 118 | 8.50                | 24.00               | 13.96 (10.95–17.77)             | 12.98                           |
| Channa orientalis | 152 | 8.10                | 19.00               | 11.27 (8.92–14.24)              | 12.48                           |
| Channa punctata | 178 | 5.30                | 19.40               | 11.49 (9.09–14.55)              | 12.20                           |
| Channa striata | 128 | 9.50                | 46.00               | 25.33 (19.35–32.89)             | 24.50                           |
| Gadusia chapra | 126 | 4.40                | 14.60               | 7.18 (5.79–8.93)                | 6.90                            |
| Lepidocephalichthys guenthe | 117 | 5.00                | 10.30               | 6.44 (5.22–7.98)                | 6.50                            |
| Amblypharyngodon mola | 193 | 3.90                | 7.80                | 4.99 (4.09–6.13)                | 4.90                            |
| Puntius sophore | 191 | 4.20                | 11.00               | 6.83 (5.53–8.49)                | 7.00                            |
| Salmus situna | 114 | 4.20                | 10.00               | 6.26 (5.09–7.76)                | 6.50                            |
| Glossogobius giuris | 189 | 3.90                | 14.70               | 8.91 (7.13–11.17)               | 8.10                            |
| Heteropneustes fossilis | 180 | 6.30                | 24.10               | 14.02 (10.99–17.84)             | 12.20                           |
| Macropodus maculatus | 115 | 8.70                | 27.00               | 15.55 (12.14–19.86)             | 16.18                           |
| Macropodus maculatus | 190 | 6.90                | 15.70               | 9.47 (7.55–11.89)               | 9.80                            |
| Nandus nandes | 168 | 6.50                | 17.20               | 10.29 (8.18–12.96)              | 10.40                           |
| Trichogaster fasciata | 170 | 3.30                | 9.30                | 5.86 (4.77–7.24)                | 6.00                            |
| Ompok pabu | 122 | 4.80                | 17.80               | 10.62 (8.43–13.39)              | 9.85                            |

Table 5. Calculate the size at sexual maturity based on maximum length from the different water bodies in world wide.

| Species name | Sex | Habitat | $L_{m}$ [cm] | $L_{m}$ (95% CL) |
|--------------|-----|---------|--------------|-----------------|
| Channa nama  | C   | Brahmaputra River tributary, Bangladesh | 6.40 | 4.16 (3.44–5.08) |
|              | C   | Deepor beel, Assam, India | 7.00 | 4.52 (3.72–5.33) |
|              | C   | Hirakud Reservoir, India | 10.10 | 6.32 (5.13–7.83) |
|              | C   | Brahmaputra River, Bangladesh | 7.40 | 4.75 (3.91–5.83) |
|              | C   | Ganges River, Rajshahi, Bangladesh | 7.20 | 4.64 (3.81–5.68) |
|              | C   | India | 11.00 | 6.83 (5.53–8.49) |
| Mystus cavatus | C   | Chi River, Thailand | 16.50 | 9.91 (7.89–12.46) |
|              | C   | Pampanga River, Candaba, Philippines | 11.70 (SL) | 7.23 (5.84–9.00) |
|              | C   | Agusan Marsh, Philippines | 17.00 | 10.18 (8.09–12.82) |
|              | C   | Terulia River, Bangladesh | 16.10 | 9.69 (7.72–12.18) |
|              | C   | India | 25.00 | 14.49 (11.35–18.47) |
| Mystus tengara | C   | Brahmaputra River, Bangladesh | 11.20 | 6.95 (5.62–8.64) |
|              | C   | Ganges River, Bangladesh | 11.60 | 7.18 (5.79–8.93) |
|              | C   | India | 18.00 | 10.73 (8.51–13.53) |
| Xenentodon cancila | C   | Atri River, Bangladesh | 18.10 | 10.78 (8.55–13.60) |
|              | C   | Hirakud reservoir, India | 18.60 | 11.06 (8.76–13.96) |
|              | C   | Chi River, Thailand | 23.00 | 13.43 (10.55–17.07) |
|              | C   | India | 40.00 | 22.29 (17.12–28.81) |
| Channa orientalis | C   | Basantar River, India | 19.60 | 11.60 (9.17–14.67) |
|              | C   | Gajner beel floodplain, Pabna, Bangladesh | 18.40 | 10.95 (8.68–13.82) |
|              | C   | India | 33.00 | 18.69 (14.47–24.02) |
| Channa punctata | F   | Siruvani River, Tamil Nadu, India | 24.40 | 14.18 (11.11–18.05) |
|              | M   | Vellar River, Tamil Nadu, India | 25.00 | 14.49 (11.35–18.47) |
|              | M   | Valam River, Tamil Nadu, India | 24.50 | 14.23 (11.15–18.12) |
|              | M   | Cauvery River, Tamil Nadu, India | 27.90 | 16.63 (12.49–20.94) |
|              | M   | Cauvery River, Tamil Nadu, India | 25.90 | 14.97 (11.70–19.10) |
|              | M   | Tamirabarani River, Tamil Nadu, India | 27.40 | 15.76 (12.30–20.14) |
|              | M   | India | 26.80 | 15.45 (12.06–19.72) |
|              | M   | Ganges River, Bangladesh | 19.20 | 11.38 (9.01–14.38) |
|              | M   | Mathabhanga River, Bangladesh | 18.90 | 11.22 (8.88–14.17) |
|              | M   | Chamarajendra River, Karnataka | 31.00 | 17.65 (13.70–22.64) |
| Channa striata | F   | North Kerian rice agroecosystem, Malaysia | 54.00 | 29.34 (22.27–38.28) |
|              | M   | Vellar River, Tamil Nadu, India | 45.20 | 24.93 (19.06–32.35) |
|              | M   | Agusan Marsh, Philippines | 61.0 | 32.80 (24.78–42.96) |
|              | M   | Chi River, Thailand | 51.00 | 277.84 (21.18–36.26) |
|              | M   | Cappar River, Candaba, Philippines | 41.40 (SL) | 23.0 (17.65–29.77) |

Table 5 continues on next page.
| Species name                              | Sex | Habitat                        | $L_{\text{sex}}$ [cm] | $L_{95\% \text{ CL}}$          |
|-------------------------------------------|-----|--------------------------------|-----------------------|---------------------------------|
| *Channa striata*                          | C   | Pearl River, China             | 39.30                 | 21.93 (16.86-28.34)             |
|                                          | C   | 100.00                         | 51.38 (28.20-68.60)   |                                 |
| *Gudusia chapra*                          | F   | Lake, Mymensingh, Bangladesh   | 13.70 (SL)            | 8.56 (6.70-10.45)               |
|                                          | M   | 12.60 (SL)                     | 7.74 (6.23-9.65)      |                                 |
|                                          | C   | Lower Brahmaputra, India       | 13.80                 | 8.41 (6.74-10.52)               |
|                                          | C   | Betwa River, India             | 15.00                 | 9.08 (7.25-11.39)               |
|                                          | C   | Hirukud Reservoir, India       | 11.60                 | 7.18 (5.79-8.93)                |
|                                          | C   | Ganges Lower region, Bangladesh| 13.40                | 8.19 (6.87-10.23)               |
|                                          | C   | 20.00                          | 11.82 (9.33-14.95)    |                                 |
| *Lepidocephalichthys guenthe*             | C   | Atrai River, Bangladesh        | 8.70                  | 5.51 (4.50-6.80)                |
|                                          | C   | Ganges Lower region, Bangladesh| 9.60 (SL)            | 6.03 (4.91-7.46)                |
|                                          | C   | 15.00                          | 9.08 (7.25-11.39)     |                                 |
| *Amblypharyngodon mola*                   | F   | Wetlands of Dishoi and Neamatighat, Assam, India | 9.00 | 5.69 (4.64-7.02) |
|                                          | M   | 6.60                           | 4.28 (3.53-5.23)      |                                 |
|                                          | C   | Hirukud Reservoir, India       | 7.20                  | 4.64 (3.81-5.68)                |
|                                          | F   | Payra River, Bangladesh        | 5.80 (SL)            | 3.80 (3.16-4.63)                |
|                                          | M   | 5.40 (SL)                      | 3.56 (2.97-4.33)      |                                 |
|                                          | C   | Atrai River, Bangladesh        | 6.20                  | 4.04 (3.35-4.93)                |
|                                          | C   | Ganges River, Bangladesh       | 8.10                  | 5.16 (4.23-6.35)                |
|                                          | M   | 7.60                           | 4.73 (4.00-5.98)      |                                 |
|                                          | C   | Ganges lower region, Bangladesh| 5.9 (SL)             | 3.86 (3.20-4.71)                |
|                                          | C   | Mathabhanga River, Bangladesh  | 7.00                  | 4.52 (3.72-5.53)                |
|                                          | U   | South 24 Parganas, India       | 8.70                  | 5.51 (4.50-6.80)                |
|                                          | C   | India                          | 20.00                 | 11.82 (9.33-14.95)              |
| *Puntius sophore*                         | F   | Ganga basin tributaries, India | 18.50                 | 11.00 (8.72-13.89)              |
|                                          | M   | 6.60                           | 4.28 (3.53-5.23)      |                                 |
|                                          | C   | Mathabhanga River, Bangladesh  | 10.20                 | 6.38 (5.18-7.90)                |
|                                          | C   | Hirukud Reservoir, India       | 10.80                 | 6.72 (5.44-8.34)                |
|                                          | C   | Brahmaputra River basin, India | 7.40 (SL)            | 4.75 (3.91-5.83)                |
|                                          | C   | 20.00                          | 11.82 (9.33-14.95)    |                                 |
| *Salmostoma baccala*                      | C   | Atrai River, Bangladesh        | 10.50                 | 6.55 (5.31-8.12)                |
|                                          | C   | Hinkud Reservoir, India        | 14.70                 | 8.91 (7.13-11.17)               |
|                                          | C   | 18.00                          | 10.73 (8.51-13.53)    |                                 |
| *Glossogobius giuris*                     | C   | Brahmaputra River, Bangladesh  | 9.70                  | 6.09 (4.95-7.54)                |
|                                          | C   | Hirukud Reservoir, India       | 22.50                 | 13.16 (10.35-16.71)             |
|                                          | C   | Hongshui River, China          | 17.50                 | 10.46 (8.30-13.18)              |
|                                          | C   | Agusun Marsh, Philippines      | 19.50                 | 11.54 (9.13-14.60)              |
|                                          | C   | Ganges lower region, Bangladesh| 23.60                | 13.75 (14.79-17.49)             |
|                                          | F   | 22.80                          | 13.32 (10.47-16.92)   |                                 |
|                                          | M   | 23.60                          | 13.75 (14.79-17.49)   |                                 |
|                                          | C   | 17.90 (SL)                     | 10.67 (8.47-13.46)    |                                 |
|                                          | C   | Estuaries, South Africa        | 11.90 (SL)            | 7.34 (5.92-9.15)                |
|                                          | C   | 50.00 (SL)                     | 27.34 (20.82-35.59)   |                                 |
| *Heteropneustes fossilis*                 | C   | Atrai River, Bangladesh        | 13.70                 | 8.36 (6.70-10.45)               |
|                                          | C   | Gajner beel floodplain, Pabna, Bangladesh | 16.50 | 9.91 (7.89-12.46) |
|                                          | C   | Ganga River, India             | 31.00                 | 17.65 (13.70-22.64)             |
|                                          | C   | Gajner beel floodplain, Pabna, Bangladesh | 26.80 | 15.45 (12.06-19.72) |
|                                          | C   | 24.10                          | 14.02 (10.99-17.84)   |                                 |
| *Macrogastinus aculeatus*                 | C   | Ganges River, NW Bangladesh    | 23.40                 | 13.64 (10.71-17.35)             |
|                                          | C   | Thailand                       | 38.00                 | 21.27 (16.37-27.45)             |
| *Macrogastinus panculus*                  | C   | Atrai River, Bangladesh        | 12.60                 | 7.74 (6.23-9.65)                |
|                                          | C   | Mathabhanga River, Bangladesh  | 16.20                 | 9.74 (7.76-12.25)               |
|                                          | C   | Gajner beel floodplain, Pabna, Bangladesh | 14.40 | 8.75 (7.00-10.95) |
|                                          | C   | Hirukud Reservoir, India       | 16.60                 | 9.96 (7.93-12.53)               |
|                                          | C   | 18.00                          | 10.73 (8.51-13.53)    |                                 |
| *Nandus nandus*                           | F   | Ganges River, NW Bangladesh    | 13.60                 | 8.50 (6.66-10.38)               |
|                                          | M   | 12.60                          | 7.74 (6.23-9.65)      |                                 |
|                                          | C   | Brahma River, Bangladesh       | 14.00                 | 8.52 (6.83-10.67)               |
|                                          | C   | Mathabhanga River, Bangladesh  | 14.20                 | 8.63 (6.91-10.81)               |
|                                          | C   | Gajner beel floodplain, Pabna, Bangladesh | 14.10 | 8.58 (8.87-10.74) |
|                                          | C   | 20.00                          | 11.82 (9.33-14.95)    |                                 |
| *Trichogaster fasciata*                   | C   | Deepor beel, Assam, India      | 8.10                  | 5.16 (4.23-6.35)                |
|                                          | C   | Gajner beel floodplain, Pabna, Bangladesh | 9.40  | 5.92 (4.82-7.32) |
|                                          | C   | 12.50                          | 7.68 (6.18-9.58)      |                                 |
| *Ompok pabo*                              | C   | 25.00                          | 14.49 (11.35-18.47)   |                                 |
|                                          | F   | Feni and Gomati River, Tripura, India | 19.00 | 11.27 (8.92-14.24) |
|                                          | M   | 20.70                          | 12.19 (9.62-15.45)    |                                 |
|                                          | C   | Payra River, southern Bangladesh| 22.30                | 13.05 (10.27-16.57)             |

FishBase: Froese and Pauly (2020).
Discussion

This study referred to the first strive to evaluate the size at sexual maturity of 20 fishes through multiple models in the Gajner Beel wetland ecosystem. The selection of permissible capture size at first maturity is broadly used and it is also used as an important tool in fisheries management (Lucifora et al. 1999; Hossain et al. 2012b) in open waters. Available information on size at sexual maturity of fishes from plots of percentage occurrence of mature females against length class can be obtained from the resulting logistic equation (King 2007). Some studies have narrated low exactness in the estimation of \( L_m \) of fishes using this logistic equation (Hossain and Ohtomi 2008; Hossain et al. 2013) but its accuracy for short life cycle organisms is addressed. Garcia (1985) also reported that using the proportion of mature females as an index of population reproduction was highly biased.

Nevertheless, the \( L_m \) was estimated by several models including brooding of eggs over time (especially for crustaceans), the appearance of the ovary and maturation stages over time (King 2007), the relative weight of gonad (TL vs. gonadosomatic index, modified gonadosomatic index, and Dobriyal index) over time (Hossain et al. 2017; Ahamed et al. 2018; Khatun et al. 2019), and histological studies (Chelemal et al. 2009; Jan and Ahmed 2019; Lucano-Ramirez et al. 2019). These methods differ with processing time, precision, accuracy, or suitability when we used these singly (De Martini and Lau 1999). To prevent this problem, we used three models (\( L_m \), TL vs. GSI, and logistic-based models) and their mean value was used to calculate their size at sexual maturity.

Among the 20 fishes, \( C. \) nama was the smallest and \( C. \) striata the largest in TL. Information on \( L_m \) was available only for three species (\( C. \) striata, \( G. \) chapra, and \( P. \) sophore) in FishBase (Froese and Pauly 2020). In our study \( L_m \) (mean \( L_m \)) was 24.84 cm for \( C. \) striata whereas Makmur et al. (2003) recorded 15.40 and 18.00 cm in the Musi River, south Sumatera, and 25.00 cm was found in Indonesia (Herre 1924). For the \( G. \) chapra \( L_m \) was 7.00 cm in this study, Hossain et al. (2010) narrated 8.00 cm in the Ganges River. We found 6.78 cm \( L_m \) for \( P. \) sophore. Halls et al. (1999), Halls (2005), and Hossain et al. (2012a) reported that \( L_m \) was 6.10, 4.50, and 5.00 for the \( P. \) sophore in the Talinnagar sluicegate, Lohajang River, and Padma River, respectively. The \( L_m \) of fish specimens might differ due to several factors like feeding rate, sex and gonadal development, behavior, season, the flow of water, populations density, water temperature, and food (Hossain et al. 2006, 2012a, b; Tarkan et al. 2006; Muchlisin et al. 2010). Most importantly it was the first attempt on \( L_m \) for 20 species in Gajner Beel wetland ecosystem so it can be used as baseline information for the future studies and essential for the selection of the permissible mesh size of nets which will be helpful for the sustainable management strategies of these 20 fish species from Gajner Beel in Bangladesh and contiguous ecosystems. Optimum catchable length (\( L_{opt} \)) is the length where the biomass of an unexploited cohort would be maximum (Froese et al. 2016). We also observed the \( L_{opt} \) which is essential for the management of these 20 fish species (Table 6).

| Scientific name | \( n \) | Minimum length [cm] | Maximum length [cm] | Optimum catchable length of individuals (\( L_{opt} \)) |
|-----------------|------|---------------------|---------------------|-----------------------------------------------|
| Chanda nama     | 196  | 2.40                | 7.20                | 4.80                                           |
| Anabas testudineus | 130  | 7.50                | 16.40               | 10.93                                          |
| Mystus cavatius | 124  | 5.30                | 16.90               | 11.27                                          |
| Mystus tengara  | 139  | 4.80                | 12.60               | 8.40                                           |
| Xenentodon cancila | 118  | 8.50                | 24.00               | 16.00                                          |
| Channa orientalis | 152  | 8.10                | 19.00               | 12.67                                          |
| Channa punctata  | 178  | 5.30                | 19.40               | 12.93                                          |
| Channa striata  | 128  | 9.50                | 46.00               | 30.67                                          |
| Gudusia chapra  | 126  | 4.40                | 14.60               | 9.73                                           |
| Lepidocephalichthys guntea | 117  | 5.00                | 10.30               | 6.87                                           |
| Amblypharyngodon mola | 193  | 3.90                | 7.80                | 5.20                                           |
| Puntius sophore | 191  | 4.20                | 11.00               | 7.33                                           |
| Salmistoma bacaila | 114  | 4.20                | 10.00               | 6.67                                           |
| Glossogobius giuris | 189  | 3.90                | 14.70               | 9.80                                           |
| Heteropneustes fossilis | 180  | 6.30                | 24.10               | 16.07                                          |
| Macrognathus aculeatus | 115  | 8.70                | 27.00               | 18.00                                          |
| Macrognathus paniculatus | 190  | 6.90                | 15.70               | 10.47                                          |
| Nandus nandus   | 168  | 6.50                | 17.20               | 11.47                                          |
| Trichogaster fasciata | 170  | 3.30                | 9.30                | 6.20                                           |
| Ompok pabo      | 122  | 4.80                | 17.80               | 11.87                                          |

Fish diversity of Gajner Beel wetland ecosystem is declining at a faster rate because of many factors; damage of habitat, aquatic pollution, fishing pressure, natural disaster, extreme floodplain siltation, and reclamation of wetland (Dudgeon 1992; Hossain et al. 2014; Rahman et al. 2016). Therefore, to conserve the wild stock of wetlands, more population surveys and stock assessments are urgently needed. Identification of the causative factors for declining of the species, the establishment of suitable sanctuaries, conservation of habitats, and protection of adult species during the spawning — and/ or peak spawning season is highly recommended. Besides this, the mesh size of harvesting nets based on size at sexual maturity should be confirmed throughout the year for sustainable conservation and management. Furthermore, public awareness is most important for the conservation of this species.

The presently reported study concludes that around 50.0% of species were sexually matured in 8.80 cm TL. So, we strongly suggest that \( \leq 8.80 \) cm TL fishes cannot be recommended for harvesting. As a result, at least 50% of species survive in the wetland ecosystem.

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