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# Stock Status of a Few Small Indigenous Fish Species Exploited in the River Ganga, India

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**Abstract:** The River Ganga produces a substantial amount of its fish from small native species, defined here as those with a maximum length of 25 cm. The FiSAT program was utilized to estimate stock assessments of four important small indigenous species from the River Ganga: *Johnius coitor*, *Cabdio morar*, *Salmostoma bacaila*, and *Gudusia chapra*. Fish samples were collected monthly for a year (April 2020–May 2021) from four predetermined sampling sites along the River Ganga (Farakka, Berhampore, Balagarh, and Tribeni) in West Bengal, India. The estimated exploitation rate for *Johnius coitor*, *Salmostoma bacaila*, and *Gudusia chapra* was relatively lower than the optimum level of 0.5 and considerably lower than $E_{max}$ values, indicating that their stocks are experiencing low fishing pressure in the region. The FiSAT results indicated that the species *Cabdio morar* was found to be heavily exploited. The total mortality ($Z$), natural mortality ($M$), and fishing mortality ($F$) rates for all four of the SIF species were examined, and they were contrasted with data from previous studies. On the lower stretch of the River Ganga, all of the fish stocks are optimally exploited ($E_{opt}$), except for the species *Cabdio morar*. The population dynamics of all of the species have been described for the first time on the lower stretch of the River Ganga. According to the findings, all of the fish stocks throughout the lower stretch of River Ganga are optimally exploited ($E_{\mathrm{opt}}$), except for *Cabdio morar*. The study also emphasizes the importance of increasing sustainable fishing efforts, focusing on SIFs throughout the lower stretch of the River Ganga in order to safeguard the livelihood and nutritional status of fishermen.

**Keywords:** growth parameters; population dynamics; SIFs; fisheries livelihood; sustainability; River Ganga

**Key Contribution:** The River Ganga is a major source of diverse fish, including small native species. The FiSAT program was used to estimate the present stock status, growth, and mortality of four important small indigenous species: *Johnius coitor*, *Cabdio morar*, *Salmostoma bacaila*, and *Gudusia chapra*. The estimated exploitation rate for these species was observed to be lower than the optimum level of 0.5 and $E_{\mathrm{max}}$ values, indicating low fishing pressure in the studied stretch of River Ganga. However, among the four species, *Cabdio morar* was found to be heavily exploited. The study highlights the importance of increasing sustainable fishing efforts, focusing on small indigenous species to safeguard the livelihoods of fishermen and nutritional status.



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## 1. Introduction

The River Ganga is the world's fifth largest river and India's longest, and it is home to a vast array of fish species [1,2]. A total of 190 fish species have recently been documented in the River Ganga by Das et al. (2021) [2], of which 42 are commercially important species with high market prices. Of these, 61% are food fish, 36% are ornamental fish, and 3.0%

are sport fish. The river is home to a diverse range of ichthyofauna, and it is regarded as the habitat of a few highly prized Gangetic carps, shads, minnows, barbs, catfish, etc. A combination of anthropogenic and natural stresses has been revealed in recent research, which poses considerable threats to the river's freshwater biodiversity [2–5]. The current fish catch trend from the middle and lower stretch of the River Ganga shows that these stresses have also affected the river's overall biotic integrity [2]. The management of inland fisheries, particularly those in rivers, marshes, and lakes, is sometimes disregarded, but it is crucial for supporting aspects of nutrition and subsistence. Studies have also indicated that the activity of small-scale fisheries has accounted for the major share of nutrition and subsistence after the dominance of catfish in the River Ganga [2], thus providing a major source of income generation. This is likely due to the year-round availability of such commercially important small indigenous fishes (SIFs), which, in turn, is due to their wide range of environmental tolerance limits. On the other hand, SIFs serve as a viable alternative source of dietary proteins, and they are therefore essential for preventing nutrient deficiencies in humans.

The mathematical relationship between fish length and weight is a useful indicator for assessing their overall health, growth, maturity, and reproduction. Fishery biologists can also use length-weight relationships as additional tools to evaluate the population's health [6]. According to King [7], this can be characterized as a method that overcomes the effects of the mortality, recruitment, growth, and reproduction of specific fish populations. Estimating population factors can help to establish the best method for utilizing and managing aquatic life resources like fish and shrimp [8]. It employs a range of statistical and mathematical models in order to generate quantitative predictions about how fish populations will respond to different management approaches [8]. Understanding population dynamics rates requires the computation of the growth, death, and recruitment pattern, which is made achievable by the study of population dynamics in fin and shellfish [9,10]. Since these variables have an impact on population dynamics, they provide useful data on a variety of topics, including age at first maturity, spawning frequency, individual and stock responses to environmental changes, recruitment success, stock structure, and so on [11–13]. The primary goal of fish stock assessments is to provide information on the best ways to utilize aquatic living resources, such as fish and shrimp, as well as resource management [8]. A fish species, family, or group must be evaluated in terms of how various environmental changes affect its biological and physical characteristics using a variety of models.

The main diet in the lower stretch of the River Ganga, notably in the state of West Bengal, is fish and rice. SIFs are an important source of protein in the region. Some of the species are targeted seasonally with selective fishing gear, while others are captured by catch. The species *Johnius coitor*, locally known as 'Bhola', is an amphidromous sciaenid SIF that is found all along the freshwater stretch of River Ganga. This carnivorous species has been found to live in the pelago-demarsal zone, where it inhabits the freshwater tidal stretch and extends to the mouth of the brackish water zone [14]. The species *Cabdio morar*, belonging to the family Danionidae (Cypriniformes), is a common benthopelagic freshwater fish found across the Ganga River. The fish, which is frequently referred to as "Morari," is a crucial component of the diets of the underprivileged in many communities along the river. *Salmostoma bacaila*, often known as the "Large Razorbelly Minnow," is also a common freshwater benthopelagic species that can be found in rivers, ponds, marshes, and inundated fields. It is a member of the order Cypriniformes and the family Danionidae. The local populace consumes plenty of *S. bacaila* because of its delicious flavour, nutritional value, and delicacy. One of the common small indigenous fish species (SIF) of the River Ganga is the Indian River shad (*Gudusia chapra*). According to Vinci et al. [15] and Kumari et al. [16], the clupeid is a significant and valuable species that supports livelihoods along the Gangetic basin in Bangladesh and India. The species is a crucial component of the artisanal Ganges.

Several authors have studied the population dynamics of fish from the River Ganga and its surrounding basin (for example, Dwivedi et al. (2009) [17], Krishna et al. (2011) [18], Dwivedi (2013) [19], Rizvi et al., 2015 [20], Sarkar et al., 2021 [21], etc.). However, studies on the aspects of population dynamics of SIFs. such as *Johnius coitor*, *Cabdio morar*, *Salmostoma bacaila*, and *Gudusia chapra*, have not been carried out, particularly from the lower stretch of the River Ganga. All of these species are classified as species of Least Concern (LC) on the IUCN Red List (2022) [22], and they are reported to have a large share of the overall catch from the river [2]. Moreover, the length-weight relationship of these four species is also described and compared with previously published data. In this context, the current study was conducted in order to investigate the growth, the mortality, and the stock status of four commercially relevant SIFs from the lower stretch of the River Ganga.

## 2. Materials and Methods

The present study was carried out over a one-year period (April 2020 to May 2021) at four distinct locations along the River Ganga—-namely, Farakka, Berhampore, Balagarh, and Tribeni (Figure 1). The sampling locations included both non-tidal (Farakka and Berhampore) and tidal-influenced freshwater (Balagarh and Tribeni) zones of the lower Ganga. Samples of the four indigenous SIFs, *Johnius coitor* (N = 447), *Cabdio morar* (N = 368), *Salmostoma bacaila* (N = 378), and *Gudusia chapra* (N = 297), were obtained seasonally from fishing boats and commercial fish landing centres during early morning hours (05:00–07:00 h) using gill nets (mesh: 12–25 mm), lift nets (mesh: 14–20 mm), and drag nets. The fish after collection were identified following the standard taxonomical key as per Talwar and Jhingran (1991) [23] and Jayaram (2010) [24] The total lengths (TL) of the fish specimens were obtained to the nearest 0.01 cm using a digital Vernier calliper, and their bodyweights (BW) were estimated to the nearest 0.01 g with a portable digital balance. The measurement of the total length of each species was converted to 0.01 mm range, and was grouped accordingly into different length classes. The length-frequency data were extrapolated from each site, and was finally consolidated all together in order to facilitate further calculation and analysis. The overall annual mean surface water temperature was observed to be 27.5 °C ± 0.10 along the different studied sites of River Ganga. To evaluate the growth and mortality parameters of the fish species, the mean temperature of 27.5 °C was used as an attribute.

In order to estimate the length-weight relationship (LWR), pooled data combining the sex of each species were log-transformed and were then computed following the formulae, '$W = aL^b$', which was elucidated by Le Cren (1951) [6]. The ELEFAN I module of FiSAT II (FAO-ICLARM Stock Assessment Tools), as outlined by Gayanilo et al. (2005) [25], was employed for assessing various population parameters like asymptotic length ($L_\infty$), growth coefficient ($K$), fishing mortality ($F$), total mortality ($Z$) and natural mortality ($M$), recruitment pattern, exploitation rate, selection pattern, relative yield-per recruit ($Y/R$), and biomass-per-recruit ($B/R$). In order to study the different population parameters, a total of 447 specimens of *J. coitor*, 368 of *C. morar*, 378 of *S. bacaila*, and 297 of *G. chapra* were considered for the FiSAT II analysis, comprising all of the size groups. Pauly's (1980) [26] empirical formula was used to calculate the natural mortality ($M$) using the following formulae: $\mathrm{Log}_{10}M = -0.0066 - 0.279\ \mathrm{Log}_{10}L_\infty + 0.06543\ \mathrm{Log}_{10}K + 0.04634\ \mathrm{Log}_{10}T$ where '$T$' is the mean annual water temperature in degree Celsius (°C). Similarly, the rate of total mortality ($Z$) was estimated in FISAT II using the length-converted catch curve method. The fishing mortality rate was also determined following the formula ($F = Z - M$) that was elucidated by Silvestre and Graces in 2004 [27]. Likewise, the exploitation ratio ($E$) was obtained using the formula $E = F/Z$. Length at first capture ($L_{50}$) was also derived following Pauly (1980) [26]. In order to assess the maximum yield exploitation rate ($E_{max}$) of the species, the knife-edge selection method was used [28].

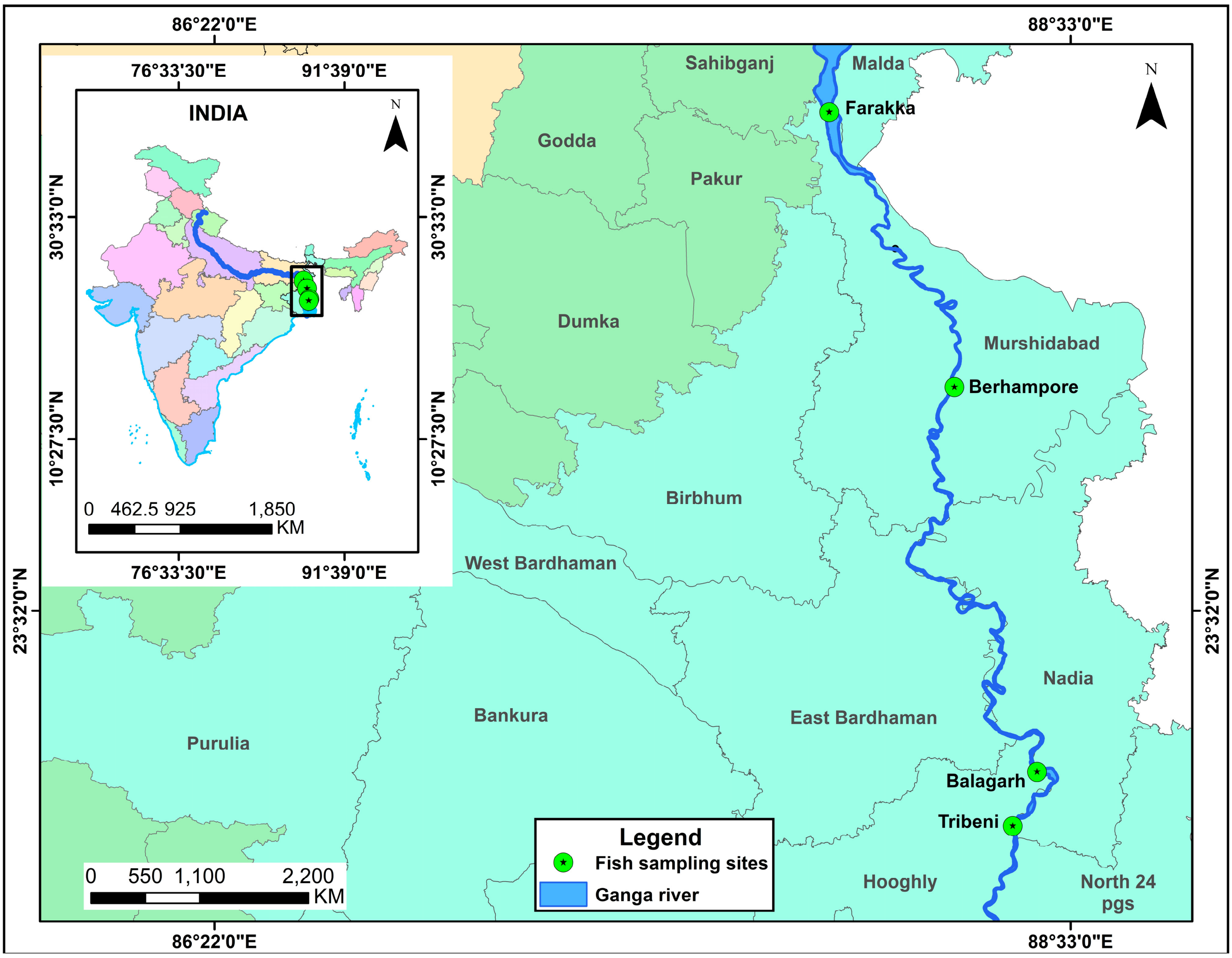



**Figure 1.** Locations of the fish sampling sites in River Ganga. The sampling locations sites viz. Farakka and Berhampore are non-tidal zones while the sites Balagarh and Tribeni are the tidal-influenced freshwater.

## 3. Results

### *3.1. Johnius coitor (Hamilton, 1822)*

The total length (TL) of the species ranged from 24–168 mm, while the bodyweight (BW) ranged from 0.15–41.41 g. In the fish catch, the length frequency distribution between 80 and 109 mm was identified as the most dominant (27.10%) (Figure 2a). The length-weight relationship of the species from the data was found to be $W = 0.007\ L^{2.93}$ ($r^2 = 0.926$, $p < 0.01$), which suggests that the growth of fish is a type of negative allometry. The findings of the VBGF growth parameters derived for the species are presented in Table 1. The results of the growth parameters, such as asymptotic length ($L_\infty$) and growth coefficient ($K$), were found to be 173.2 mm and 0.880 $yr^{-1}$, respectively (Figure 3a). Likewise, the values of other population parameters like total mortality rate ($Z$), natural mortality rate ($M$), and fishing mortality rate ($F$) were estimated to be 1.48 $yr^{-1}$, 1.00 $yr^{-1}$ and 0.48 $yr^{-1}$, respectively (Figure 4a). The value of the rate of exploitation was 0.33. According to the results of a length-based virtual population analysis (VPA), fish with lengths between 105 mm and 145 mm are commonly targeted for commercial exploitation (Figure 5a). It was observed that the calculated maximum yield exploitation rate of the species ($E_{max}$) was 0.50. The recruitment pulse of the species indicated two peaks annually, i.e., the months of August (22%) and September (18%), respectively. The fishing rate at 10% increase ($E_{10}$) and 50% stock reduction was found to be 0.415 and 0.310, respectively. The estimated length at which 50% of the stock ($L_{50}$) was vulnerable to capture was 48.02 mm. Consequently, the predicted lengths at which 25% and 75% of the stock are collected are $L_{25}$ = 40.29 mm and $L_{75}$ = 55.76 mm (Figure 6a).

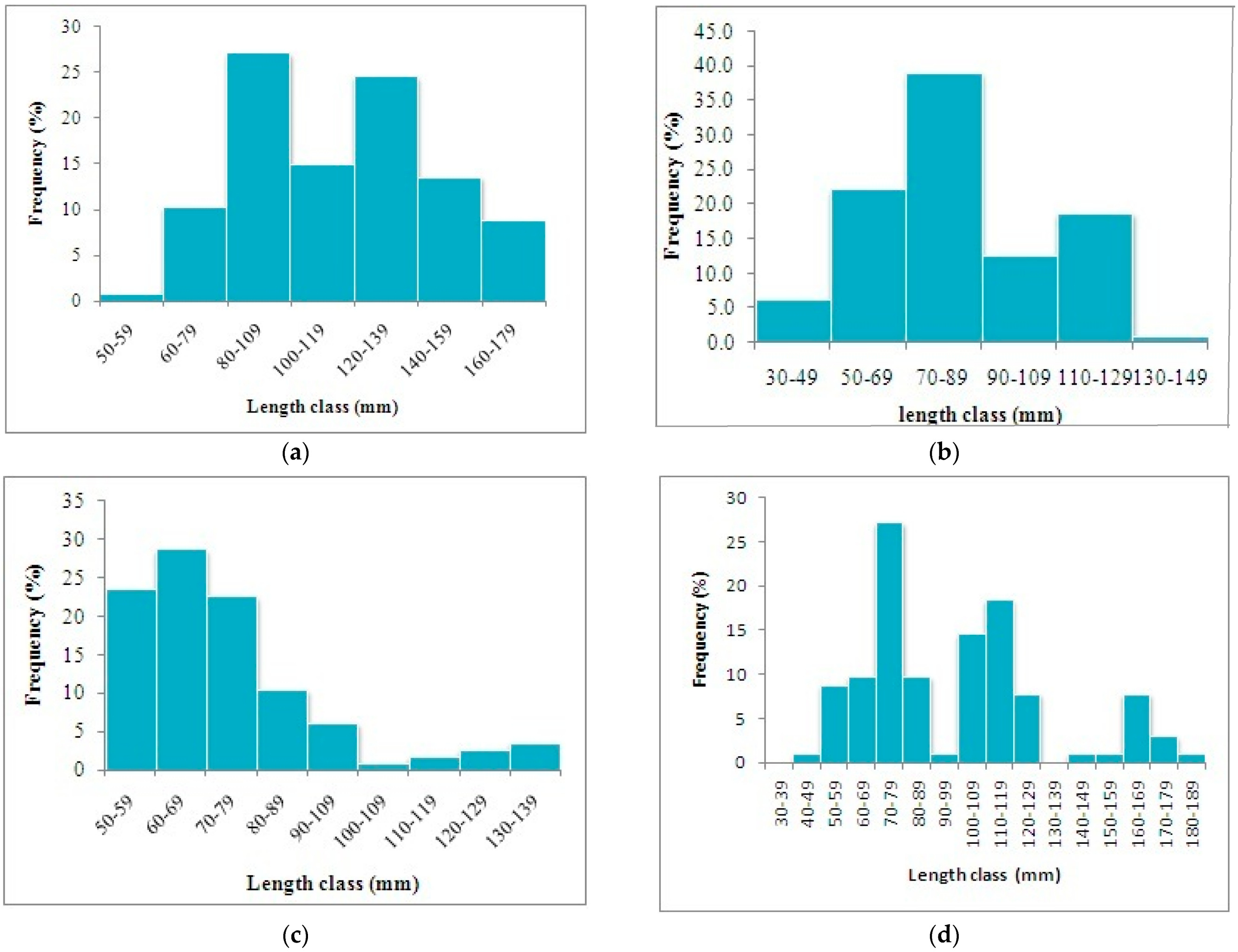


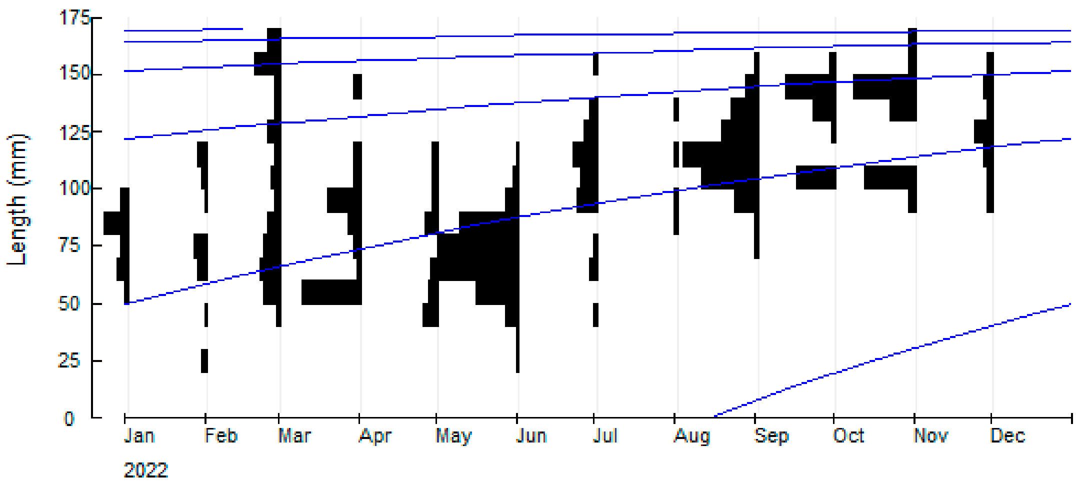

**Figure 2.** (**a**–**d**) Length frequency distribution of (**a**) *Johnius coitor*, (**b**) *Cabdio morar*, (**c**) *Salmostoma bacaila*, and (**d**) *Gudusia chapra* from the River Ganga.

**Table 1.** Population parameters of *J. coitor*, *C. morar*, *S. bacaila*, and *G. chapra*, as estimated in the present study.

| Population Parameters | *J. coitor* | *C. morar* | *S. bacaila* | *G. chapra* |
|---|---|---|---|---|
| TL range (mm) | 24–168 | 34–139 | 50–134 | 30–179 |
| Intercept (*a*) | 0.007 | 0.005 | 0.122 | 0.017 |
| Slope (*b*) | 2.93 | 3.11 | 2.84 | 2.50 |
| Coefficient of determination ($r^2$) | 0.926 | 0.975 | 0.904 | 0.923 |
| 95% CL of *a* | 0.005–0.008 | 0.004–0.005 | 0.105–0.142 | 0.013–0.023 |
| 95% CL of *b* | 2.84–3.03 | 3.04–3.17 | 2.66–3.02 | 2.34–2.64 |
| Growth type | Negative allometric | Positive allometric | Negative allometric | Negative allometric |
| Asymptotic length ($L_\infty$ mm) | 173.25 | 157.5 | 141.75 | 183.75 |

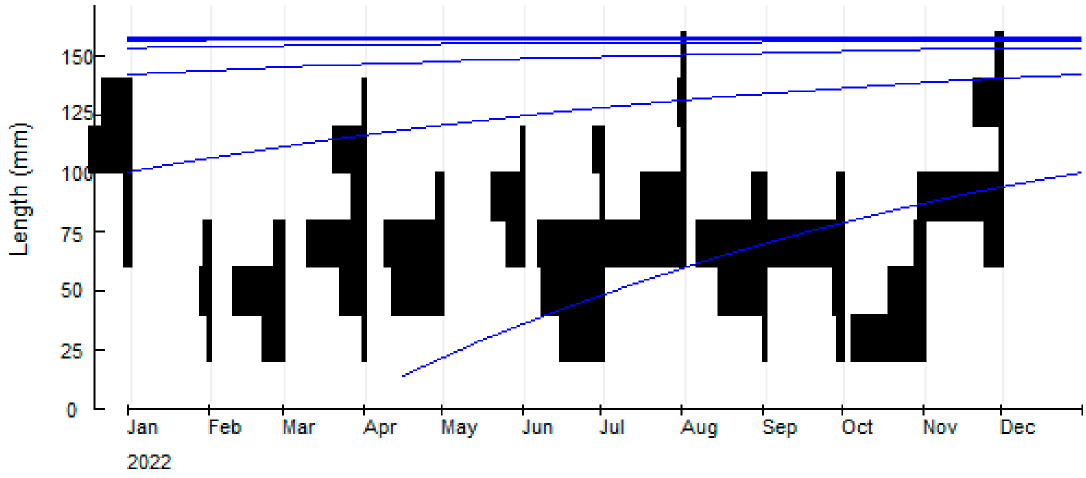
**Table 1.** *Cont.*

| Population Parameters | *J. coitor* | *C. morar* | *S. bacaila* | *G. chapra* |
|---|---|---|---|---|
| Growth coefficient ($K$ yr$^{-1}$) | 0.88 | 1.30 | 0.58 | 0.31 |
| Natural mortality ($M$ yr$^{-1}$) | 1.00 | 1.32 | 0.80 | 0.55 |
| Fishing mortality ($F$ yr$^{-1}$) | 0.48 | 2.15 | 0.26 | 0.38 |
| Total mortality ($Z$ yr$^{-1}$) | 1.48 | 3.47 | 1.06 | 0.93 |
| Exploitation ratio ($E$) | 0.33 | 0.62 | 0.24 | 0.41 |
| $L_{25}$ | 40.29 | 20.11 | 50.26 | 32.03 |
| Length at first capture ($L_{50}$) | 48.02 | 35.11 | 59.37 | 39.53 |
| $L_{75}$ | 55.76 | 50.15 | 68.14 | 47.13 |
| Isopleth ratio ($Lc/L_\infty$) | 0.28 | 0.22 | 0.42 | 0.22 |
| $M/K$ | 1.14 | 1.02 | 1.52 | 1.61 |
| Fishing rate at 10% ($E_{10}$) | 0.415 | 0.407 | 0.506 | 0.358 |
| Fishing rate at 50% ($E_{50}$) | 0.310 | 0.303 | 0.339 | 0.284 |
| Maximum yield exploitation rate ($E_{max}$) | 0.505 | 0.479 | 0.625 | 0.463 |




(**a**)

**Figure 3.** *Cont.*

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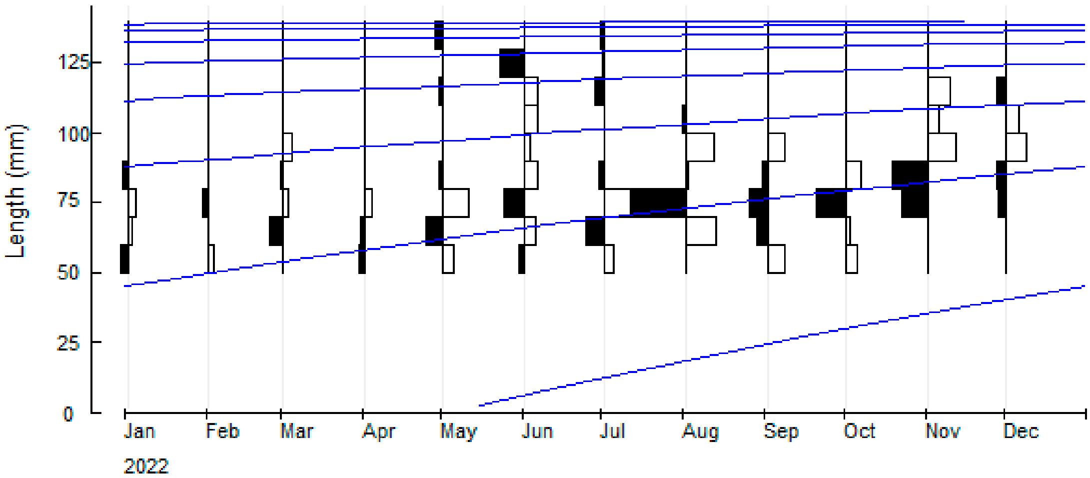


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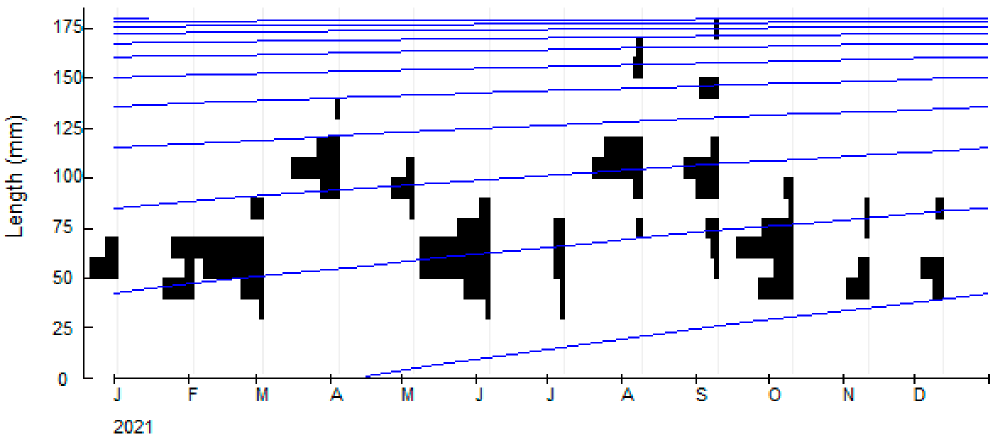


(**d**)

**Figure 3.** (**a**–**d**) Growth curve of (**a**) *Johnius coitor*, (**b**) *Cabdio morar*, (**c**) *Salmostoma bacaila*, and (**d**) *Gudusia chapra* from the River Ganga. The blue lines in the graph indicate the growth rate and the black colours are the length-frequency distribution of different species from river Ganga.

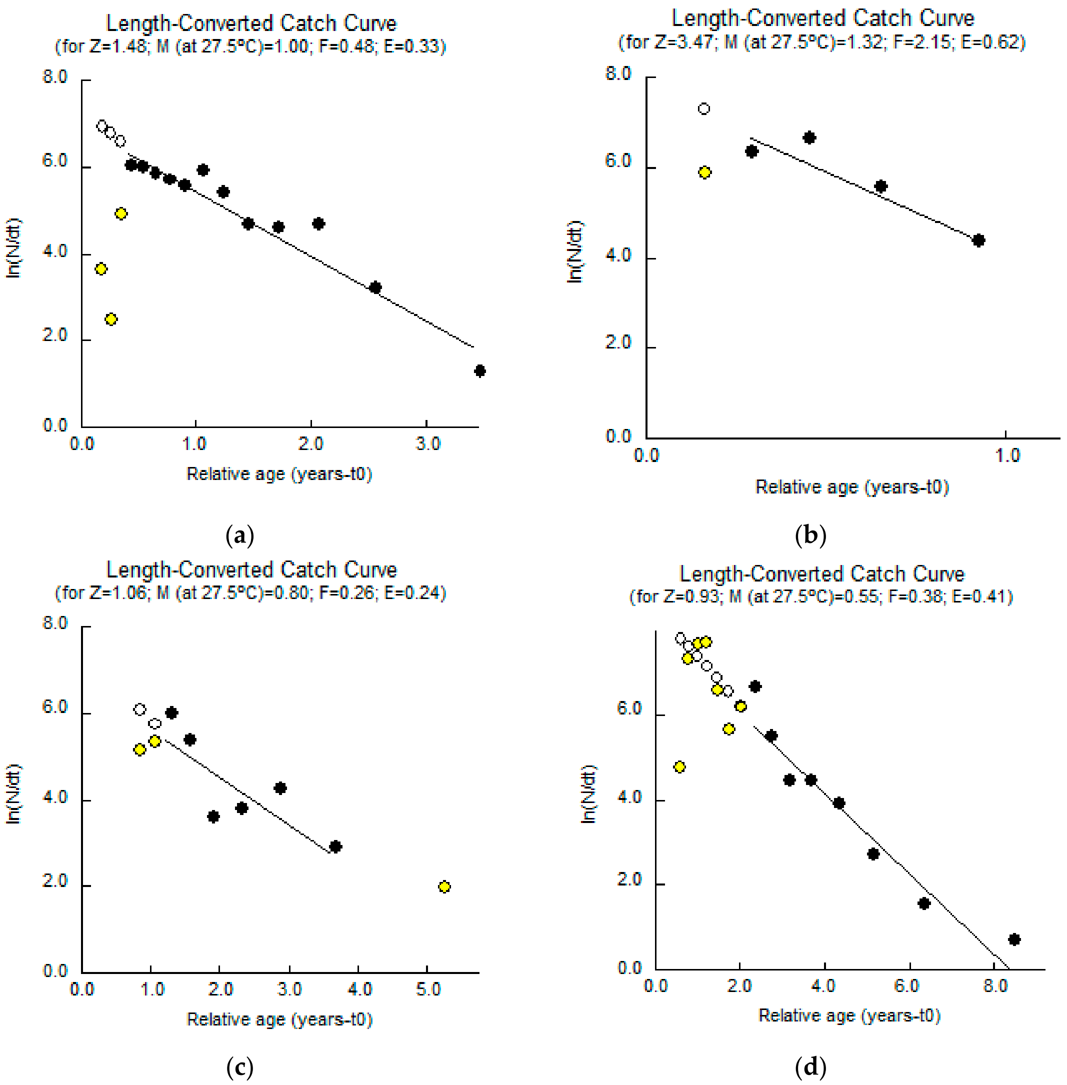


**Figure 4.** (**a**–**d**) Length-converted catch curve for estimation of (**a**) *Johnius coitor*, (**b**) *Cabdio morar*, (**c**) *Salmostoma bacaila*, and (**d**) *Gudusia chapra* from the River Ganga. The slope of the right descending line (black spots) indicates the estimated total mortality (Z). The white spots in the graph are the expected number of fish and the yellow spots are the number of fish sampled (observed).

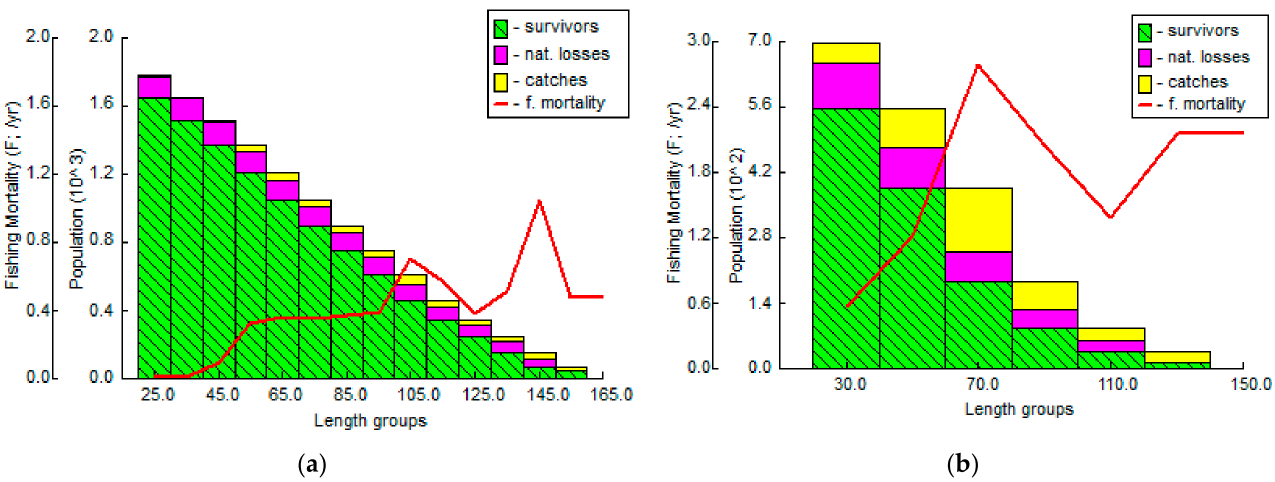


**Figure 5.** *Cont.*

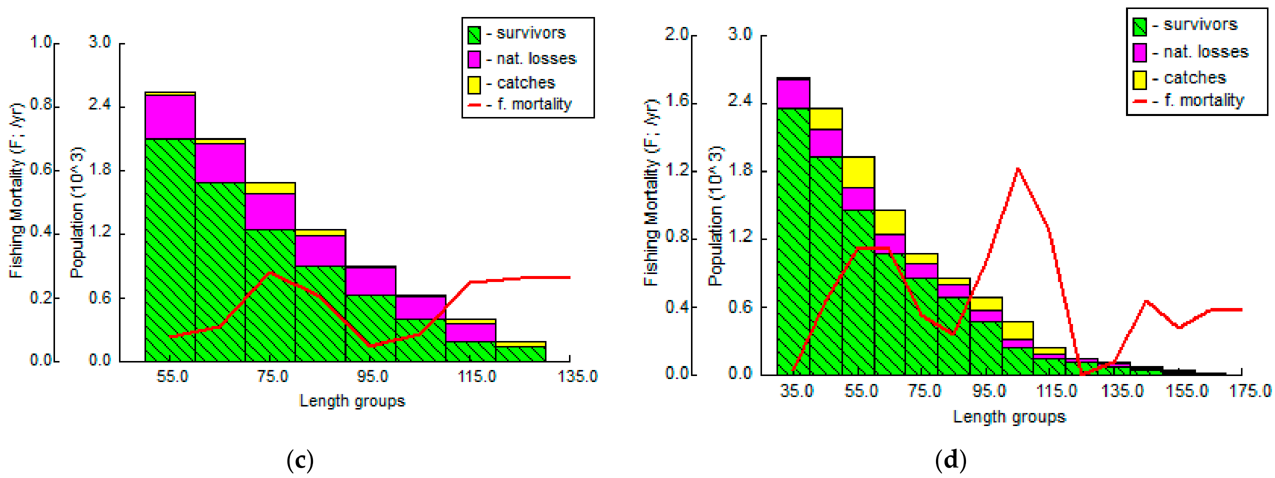


**Figure 5.** (**a**–**d**) Length structured Virtual Population Analysis (VPA) of (**a**) *Johnius coitor*, (**b**) *Cabdio morar*, (**c**) *Salmostoma bacaila*, and (**d**) *Gudusia chapra* from the River Ganga.

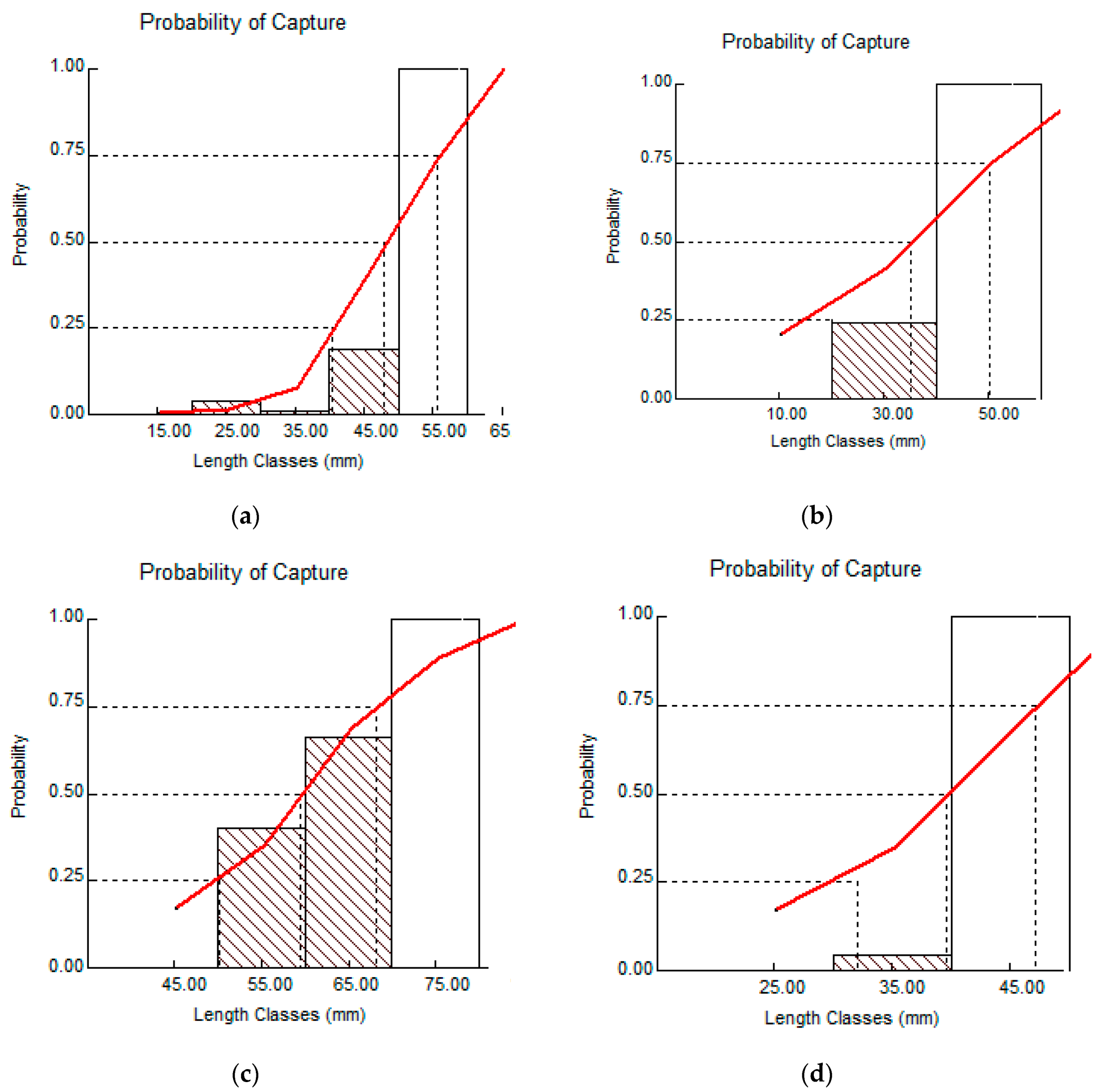


**Figure 6.** (**a**–**d**) The probability of capture: (**a**) *Johnius coitor*, (**b**) *Cabdio morar*, (**c**) *Salmostoma bacaila*, and (**d**) *Gudusia chapra* from the River Ganga. The red lines indicate the logistic selection curve at 25%, 50% and 75% selection length of different species.

### 3.2. *Cabdio morar (Hamilton, 1822)*

The observed TL and total BW for the species (pooled sex) ranged from 34–139 mm and 0.31–22.62 g respectively. The top three length group percentages were 39.13%, 22.22%, and 18.84% for the length classes 70–89, 50–69, and 110–129 mm (Figure 2b), respectively. The computed LWR equation for the species was $W = 0.005\ L^{3.11}$ ($r^2 = 0.975$, $p < 0.01$), which indicates positive allometric growth. The growth constants $L_\infty$ and the $K$ values were estimated to be 157.5 mm and 1.3 $yr^{-1}$, respectively (Figure 3b). The population parameters of the total mortality rate ($Z$), the natural mortality rate ($M$), and the fishing mortality rate ($F$) were assessed to be 3.47 $yr^{-1}$, 1.32 $yr^{-1}$, and 2.15 $yr^{-1}$, respectively (Figure 4b). The rate of exploitation ($E$) was found to be 0.62. Two recruitment peaks for the species were determined, with one major peak from July to September and a minor one in February. The result of the virtual population analysis (VPA) of the species signifies maximum fishing mortality in the length group of 70–79 mm ($F = 2.78\ yr^{-1}$) and minimum fishing mortality at 30 mm ($F = 0.57\ yr^{-1}$) (Figure 5b). The relative yield per recruit ($Y/R$) and biomass per recruit ($B/R$) calculated based on $L_c/L_\infty$ and $M/K$ were computed to be 0.22 and 1.02, respectively. Based on the knife-edge selection, the values of $E_{10}$, $E_{50}$, and $E_{max}$ were 0.407, 0.303, and 0.479, respectively. The $L_{25}$, $L_{50}$, and $L_{75}$ were determined to be 20.11, 35.11, and 50.15 mm, respectively, based on the selection pattern. The length at first capture ($L_c$), which was determined to be 50.15 mm, can be considered as the suitable harvestable size of the species (Figure 6b).

### 3.3. *Salmostoma bacaila (Hamilton, 1822)*

For the species (pooled sex), the observed TL and BW varied from 50–134 mm and 1.11–18.30 g, respectively. The results for the top three (%) length groups were 28.69%, 23.47%, and 22.60%, which correspond to the length classes 60–69, 50–59, and 70–79 mm, respectively (Figure 2c). The parameters for the length-weight relationship for the pooled sex were estimated to be $W = 0.122\ L^{2.84}$ ($r^2 = 0.904$, $p < 0.01$). The growth coefficient $b$ value of the species indicates that the fishes grow in a negative allometric fashion. For the combined sexes, the estimated values of $L_\infty$ and $K$ for the combined sexes were determined to be 141.75 mm and 0.58 $yr^{-1}$, respectively (Figure 3c). Natural mortality ($M$) was calculated to be 0.80 $yr^{-1}$ for both sexes combined. Similarly, the value of fishing mortality ($F = 0.26\ yr^{-1}$) was obtained by subtracting the natural mortality total annual mortality rate ($Z = 1.06\ yr^{-1}$). An exploitation ratio ($E$) of 0.24 was achieved for the species (Figure 4c). The computed $E_{10}$, $E_{50}$, and $E_{max}$ values were 0.506, 0.339, and 0.625, respectively. The length-structured Virtual Population Analysis (VPA) revealed a maximum fishing mortality at length classes at 75 mm and above 115 mm, while the catches were found to be more prevalent in the length groups between 75–95 mm (Figure 5c). The results of $L_{25}$, $L_{50}$, and $L_{75}$ were found to be 50.26 mm, 59.37 mm, and 68.14 mm, respectively (Figure 6c). It can be determined that when the fishes reach a total length of 59.37 mm, according to the predicted $L_{50}$ or $L_c$ value, they become susceptible to fishing.

### 3.4. *Gudusia chapra (Hamilton, 1822)*

As determined from the present study, the minimum and maximum total length of the species varied from 36 to 175 mm, and the weight ranged from 0.30 g to 38.02 g. The length range of 50–69 mm was observed to be the most dominant size group in the River Ganga, with a contribution of 38.26% (Figure 2d). The value of length-weight relationship yielded $W = 0.017\ L^{2.50}$ ($r^2 = 0.923$), where $a = 0.017$ and $b = 2.50$ revealed a negative allometric growth for the species in the river. The VBGF growth parameters derived for the species are presented in Table 2. According to the results, the estimated growth parameters for $L_\infty$ and $K$ were derived as 183.75 and 0.31 $yr^{-1}$, respectively (Figure 3d). Natural mortality ($M$), total mortality ($Z$), and the rate of fishing mortality ($F$) were calculated to be 0.55 $yr^{-1}$, 0.93 $yr^{-1}$, and 0.38 $yr^{-1}$, respectively. The exploitation ratio ($E$) was 0.41, which indicates the optimum exploitation level of the stock (Figure 4d). With two peaks in April and September, respectively, the recruitment behaviour of *G. chapra* indicates that recruitment persists throughout the year. The length at first capture ($L_c$) was determined to be 39.53 mm. The length-structured VPA of the species revealed an increase in fishing mortality from the length range of 55 mm onwards, with the maximum fishing mortality of 0.92 $yr^{-1}$ depicted in the mid-length range of 105 mm (Figure 5d). The obtained results for $L_{25}$, $L_{50}$, and $L_{75}$ were found to be 32.03 mm, 39.53 mm, and 47.13 mm, respectively (Figure 6d).

**Table 2.** Estimation of $L_\infty$, $K$, $\phi$, $Z$, $M$, and $F$ of the available species (*J. coitor*, *S. baciala*, and *G. chapra*) and studied by different researchers from other water bodies.

| Species | Author | Region | $L_\infty$ (mm) | $K$ ($yr^{-1}$) | $\phi$ | $Z$ ($yr^{-1}$) | $M$ ($yr^{-1}$) | $F$ ($yr^{-1}$) | $E$ |
|---|---|---|---|---|---|---|---|---|---|
| *J. coitor* | Rizvi et al. (2011) [29] | River Ganga and Yamuna, Allahabad, India | 215 | 1.51 | - | 4.97 | 2.56 | 2.41 | 0.48 |
| | Rizvi et al. (2015) [20] | River Ganga, Allahabad, India | 198 | 0.868 | 4.53 | 3.31 | 1.76 | 1.55 | 0.46 |
| | Present study | River Ganga | 173.25 | 0.88 | - | 1.48 | 1.0 | 0.48 | 0.33 |
| *S. bacaila* | Sarmina et al. (2021) [30] | Mahananda River, Bangladesh | 126.6 | 0.60 | 1.98 | 1.57 | 0.92 | 0.65 | 0.41 |
| | Present study | River Ganga | 141.75 | 0.58 | - | 1.06 | 0.26 | 0.88 | 0.24 |
| | Rahman and Haque (2006) [31] | Rajdhala reservoir, Bangladesh | 160.8 | 0.51 | - | 2.71 | 1.34 | 1.37 | 0.51 |
| *G. chapra* | Ahmed et al. (2007) [32] | Perennial pond, Bangladesh | Male—140.2 Female—145.39 | Male—1.352 Female—1.30 | - | - | - | - | - |
| | Rizvi et al. (2011) [29] | River Ganga and Yamuna, India | 180 | 2.83 | - | 9.60 | 4.07 | 5.54 | 0.57 |
| | Kumari et al. (2018) [33] | Panchet Reservoir, India | 194 | 1.23 | 2.69 | 6.63 | 2.45 | 4.18 | 0.63 |
| | Sarkar et al. (2021) [21] | Mathura Oxbow Lake, West Bengal, India | 165.5 | 1.10 | 2.48 | 2.72 | 1.25 | 1.47 | 0.54 |
| | Samad et al. (2023) [34] | Bukvora oxbow lake, Bangladesh | 153.8 | 0.70 | 2.20 | 2.25 | 1.71 | 0.55 | 0.24 |
| | Present study | River Ganga | 183.75 | 0.31 | - | 0.93 | 0.55 | 0.38 | 0.41 |

## 4. Discussion

The River Ganga has been obstructed by a series of man-made blockades during its course of flow. The Farakka Barrage, located in the Indian state of West Bengal and constructed in 1975, is the last artificially constructed structure over the River Ganga. It was constructed primarily for the maintenance of Kolkata Port. According to reports, the erection of the barrage has significantly altered the fishery resources of the River Ganga in the Hooghly estuary (West Bengal) and the Padma River basin [2,35–37]. The hydrological profile downstream of the Farakka has altered significantly since the barrage was commissioned [38]. The spatiotemporal distribution of the river's water quality is governed by both anthropogenic and natural impacts (Sarkar et al., 2007) [39], such as monsoons, which cause elevated discharges. Establishing a sustainable strategy for small-scale fisheries is clearly hampered by the lack of crucial information, such as fishing pressure and fish stocks [40]. In the present study, an investigation was carried out to address the basic growth and the stock status of a few important commercially available SIFs from the River Ganga. Although a few of the studies are available on certain species from different water bodies, there are no references available on the growth parameters of the SIFs from the lower stretch of the River Ganga. The value of the growth coefficient value '*b*' influences the overall health of fish. Fish with a value of '*b*' greater than 3 are predicted to grow larger as their length rises while those with a value of '*b*' less than 3 will become more slender [41], and the calculated '*b*' values for LWRs of all of the studied species were within the range of 2.5–3.5, according to Carlander (1997) [42] and Froese (1998) [43]. All of the examined small indigenous species showed negative allometric growth, except *C. morar*, which suggests that at the time of the sampling, the smaller fish specimens had better nutritional conditions. The suggested Bayesian upper and lower limits provided in FishBase (Froese and Pauly, 2016) [44] are well within the observed confidence limits of values *a* and *b* for all of the species. The growth type, coefficient of determination ($r^2$), 95% confidence intervals of *a* and *b*, and regression parameter for all of the species are presented in Table 2. The LWRs vary amongst fish species based on body shape and size, along with certain physiological parameters like age, maturity, and spawning [45]. A comparative study of the population and the mortality parameters of the four SIFs by other researchers from different water bodies is presented in Table 2.

The present findings on the species *J.coitor* were in agreement with the findings of Rizvi et al. (2015) [20], who reported from the River Ganga at Allahabad, Uttar Pradesh. Sarkar et al. (2018) [14] have reported an overall growth coefficient (*b*) value of 3.17 ($r^2$ = 0.955) across various stretches of the river; however, sites Farakka and Tribeni had '*b*' values of 3.011 and 2.28, respectively. Rizvi et al. (2015) [20] reported a higher value of asymptotic length ($L_\infty$ = 198 mm) from the River Ganga compared to the present findings, while the observed *K* value of 0.868 $yr^{-1}$ indicated a similarity. The results on the mortality parameters indicated that natural mortality (*M*) exceeds fishing mortality (*F*) in the commercially exploited fish stocks, which suggests that *J. coitor* in the Ganga waters are primarily non-targeted species and are captured mainly by catch. According to Gulland (1971) [46], overfishing of a species in a particular area is indicated when the optimal rate of exploitation ($E_{opt}$) exceeds 0.50. The calculated exploitation ratio (*E*) and maximum sustainable yield ($E_{max}$) were found to be 0.33 and 0.505for the species, which indicates a lower exploitation of the species. Similar results were also obtained by Rizvi et al. (2015) [20] from the River Ganga, with an exploitation rate of *E* = 0.46, but in another study that was carried out by Rizvi et al. (2011) [29], an exploitation ratio (*E*) of 0.48 was recorded from the River Ganga and the Yamuna River. This indicates that the level of exploitation of commercial fish stocks varies significantly in different water bodies depending on fishing pressure and other environmental factors. The recruitment pattern observed in the present study for *J. coitor* agreed with the findings of Rizvi et al. (2015) [20], which showed major peaks in the months of July (22.16%) and August (19.62%), respectively. Sarkar et al. (2018) [14] have reported a prolonged breeding season (June–January) of *J. coitor* in the lower stretch of the River Ganga at Tribeni, West Bengal, while a shorter span of spawning (spring–summer) was observed in the middle stretch, such as the Patna and Farakka regions of the River Ganga.

Although several works on morphological variations are available for the species *Cabdio morar* [47,48], parameter comparisons are not possible because no study on population dynamics based on the ELEFAN I model has been conducted in the River Ganga or elsewhere. For the length-weight relationship, a growth coefficient (b) value of 3.00 was reported for *C. morar* by Baitha et al. (2018) [49] from the River Ganga. However, for the Jamuna River in Bangladesh, Hossain et al. (2016) [50] reported significantly positive allometric growth (>3.00) in males and within the pooled sex, whereas females exhibited isometric growth (3.00). The results of the exploitation rate indicated a value of 0.62, illustrating an example of overexploitation of the species. Sharpe and Hendry (2009) [51] found that heavy fishing pressure using selective fishing gear may cause a population decline and ultimately accelerate the growth of survivors, thereby increasing the possibility of early maturity. The present results on the recruitment patterns for *C. morar* suggested a major peak between the months of July and September in the River Ganga, particularly during the monsoon months. However, Hossain et al. (2013) [52] indicated that the spawning season of *Aspidoparia morar* (*C. morar*) remains between November and April in the Jamuna River of Bangladesh.

The results of the LWR value of *Salmostoma bacaila* coincide with the findings of Masud and Singh (2015) [53] and Ahamed et al. (2019) [54] from the waters of the Yamuna River (Allahabad, India) and the Payra River (Bangladesh), respectively. Baitha et al. (2018) [49] reported a total length (TL) range of 51–134 mm from the lower stretch of the River Ganga, with a *b* value of 3.05 ($r^2$ = 0.99, $p$ < 0.01). However, Nath et al. (2017) reported a lower total length (TL) range (52–104 mm) from the Barak River, Assam, with a *b* value of 2.47 ($r^2$ = 0.96, $p \leq 0.01$). Karna et al. (2018) [55] illustrated a negative allometric growth rate (*b* = 2.83;

$r^2 = 0.99$, $p < 0.001$) from the Hirakud Reservoir of Odisha, India. A negative allometric growth ($b < 3$) was also reported by Sarmina et al. (2022) [30] from the Mahananda River in Bangladesh. In the present study, the higher percentage of the length class of 60–69 mm of *S. bacaila* suggests the dominance of the specific length group in the catch, as these fish are usually caught using specific gill nets (mesh size: 12–16 mm) and fine-meshed nylon nets from the river. The species *S. bacaila* was observed to be recruited twice a year in the River Ganga, with peaks in April–May and July–August. The result of the recruitment pattern bears similarity with the findings of Mamun and Azadi (2003) from the Kaptai Reservoir in Bangladesh. Ahamed et al. (2019) [54] reported that the spawning season of *S. bacaila* extends from spring to summer in the Payra River of Bangladesh. Sarmina et al. (2022) [30], in a recent report, found an asymptotic length of 126.6 mm from the Mahananda River, Bangladesh, which was well below the present findings of 141.75 mm. Similarly, a growth coefficient value of 0.60 $yr^{-}1$ that was observed by Sarmina et al. (2022) [30] was found to be slightly higher than the present study ($K = 0.58$ $yr^{-1}$). Higher values of both natural mortality ($M = 0.92$ $yr^{-1}$) and total mortality ($Z = 1.57$ $yr^{-1}$) were obtained from the Mahananda River by Sarmina et al. (2022) [30] compared to the results found from the River Ganga. The fishing mortality ($F$) from the Mahananda River was calculated to be 0.65 $yr^{-1}$, and it was also found to be much higher than the River Ganga (0.26 $yr^{-1}$). The exploitation rate ($E$) and MSY ($E_{max}$) were 0.24 and 0.625, respectively. A low exploitation rate indicates that the species is not being exploited to its full potential in the River Ganga. The value of length at first capture ($L_{50}$) was found to be 59.37 mm.

Rahman (1989) [56] described the maximum size of *Gudusia chapra* (200 mm) from Bangladesh waters while the present study observed a length of 175 mm. The value of LWR of *G. chapra* indicated negative allometric growth ($b = 2.50$). The results obtained by various researchers from different water bodies of the Indian subcontinent [15,16,34,57] supported the present findings. This negative allometric growth could be due to ineffective nutrition or environmental incompatibilities with fish growth. The calculated growth parameter values for *G. chapra* in this study (asymptotic length) were found to be significantly greater than the observations reported by Sarkar et al. (2021) [21] ($L_\infty = 165.5$ mm) but less than the value ($L_\infty = 194$ mm)reported by Kumari et al. (2018) [33]. Rizvi et al. (2011) [29] studied the population parameters of the River Ganga and the Yamuna River in the Allahabad region of India, and they found $L_\infty$ and $K$ to be 180 mm and 2.83 $yr^{-1}$, respectively. The authors also reported an exploitation rate of 0.57 higher than the present study from the lower stretch ($E = 0.41$). Ahmed et al. (2007) [32] assessed the growth parameters of *G. chapra* from a perennial pond in Bangladesh as $L_\infty = 140.42$ mm (standard length) and $K = 1.352$ $yr^{-1}$, and as $L_\infty = 145.39$ mm (standard length) and $K = 1.3$ $yr^{-1}$ for males and females, respectively. Sarkar et al. (2021) [21] reported $M$, $Z$, and $F$ values of 1.25, 2.72, and 1.47 $yr^{-1}$, respectively, for the species from a floodplain wetland of the Ganga River basin, which were found to be much higher compared to the present findings from the River Ganga. Kumari et al. (2018) [33] obtained comparable higher values from a large reservoir. Rahman and Haque (2007) [58] also observed an asymptotic length of 160.8 mm and a growth coefficient value of 0.51 from a reservoir in Bangladesh. In the present study, the lowered growth coefficient value ($K$) suggested a faster growth of the species in the River Ganga. In accordance with the findings of Kabir et al. (1998) [59], Rahman and Haque (2007) [58], and Sarkar et al. (2021) [21], the current recruitment pattern revealed two reproductive peaks. Vinci et al. (2005) [15] determined the period of March to October to be the highest breeding season for the species in the floodplain wetlands of West Bengal.

For the species *Johnius coitor* (N = 447), *Cabdio morar* (N = 368), *Salmostoma bacaila* (N = 378), and *Gudusia chapra* (N = 297), we were able to collect a good number of samples over the course of a year, and this implies a good sample size (≈30 samples per month), which has been further taken for FISAT II analysis. Instead of expanding the number of samples, we intended to collect a sizable number of samples that included individuals of all different sizes. According to Chen et al. (2003) [60], several parameters, including the quantity of information on fisheries and length-frequency data, can have an impact on reported stock estimation. An additional study by Maunder and Starr (2001) [61] and Maunder (2011) [62] revealed that catch-at-length or catch-at-age data are key elements in statistical stock assessment strategies. Furthermore, the study of maximum sustainable yield (MSY) for all four of the species indicated that both *G. chapra*, and *J. coitor* were found to be the targeted catch in the studied sites, with values of 36.92 t and 50.69 t, respectively, while species like *C. morar* and *S. bacaila* were found to be the accidental catch in the studied environment in very meagre quantities.

The Ganga River is the most revered river in India, and it also has one of the most diverse ecosystems, with 190 species of finfish, 42 of which are significant for commercial use (Das et al., 2021) [2]. The Gangetic fish variety was originally documented by Hamilton (1822) [63], who described 272 freshwater and estuarine fish species extending from the state of Bihar (India) to Bangladesh. According to Sinha and Khan (2001) [3], there are roughly 260 ichthyofaunal diversity in the River Ganga. The study also discovered that Indian major carps and hilsa *Tenualosa ilisha* were the most affected species, with a significant decline in catch from the period 1961 to 2010 along the middle stretch of the River Ganga.

Fishing pressure, habitat loss, pollution, and water obstruction and abstraction are the main causes of the fall in fish catches and fish diversity. For the Ganga River to be restored for sustainable fisheries, appropriate management methods, including potential policy and government interventions, are needed. In order to lessen the loss of fish diversity, it is also necessary to identify crucial fish habitats in the River Ganga, and to designate them as conservation reserves. Additionally, evaluating the susceptibility of riverine fisheries to potential climate change is also recommended. In order to inform the local fishermen about the negative impacts of deploying destructive nets and, specifically, catching brooders and juveniles, need-based awareness programs should be implemented.

## 5. Conclusions

The River Ganga has been a source of indigenous fish germplasm for decades. Currently, the small indigenous fishes (SIFs) are considered to be the major catch of the River Ganga, besides large fish, and they contribute immensely towards the overall fish landing basket of the river. In addition to the tremendous challenges that are currently posed by climate change and habitat changes, overexploitation of fish stocks through indiscriminate fishing operations creates an imminent threat to these small indigenous fishes. Furthermore, the massive loss of juvenile fish and brooders by using small mesh mosquito nets is one of the primary causes of the constant reduction of fish stocks in the river, since these nets result in a significant reduction in the population of potential juvenile fish before they reach full biological maturity. Species like *J. coitor*, *C. morar*, *S. bacaila*, and *G. chapra* are ubiquitous throughout the freshwater stretch of the River Ganga, and they are available throughout almost all of the year. The present study on the stock status of these species revealed that, aside from *C. morar*, the other three SIFs are being exploited below the optimum exploitation rate. According to our study, less exploited species require sustainable exploitation with appropriate management approaches, which can offer an integrated approach towards ensuring the future livelihood and nutritional status of fishermen. Furthermore, sustainable exploitation of inland fisheries through effective resource management studies may contribute to overall improvement.

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