Assessing the Population Dynamics of *Cirrhinus reba* (Hamilton, 1822) in River Atrai, India, for its Conservation and Sustainability as Natural Stock

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ABSTRACT

Cirrhinus reba (Hamilton, 1822), commonly known as Reba carp, is an economically important freshwater species with high demand for its taste. It has been listed as vulnerable and near threatened species in India and Bangladesh, respectively. This study presents a pioneer assessment of the length-weight relationship and population dynamics of Reba carp using a length-based approach over a three-year period in the Indian part of the Atrai River. Fish specimens ranged from 50 to 237 mm in length and from 0.90 to 184.19 g in weight. Results indicate positive allometric growth, with a unimodal continuous recruitment pattern peaking between June and August. Population parameters, including asymptotic length ($L\infty$ = 250.95 mm), growth coefficient (K = 0.44 $year^{-1}$), growth performance index (ϕ' = 4.442), length at first capture (L_c = 83.77 mm), and size at first sexual maturity (L_m = 110 mm), were computed. This study revealed a higher fishing mortality rate compared to natural mortality, with the mean current exploitation rate (E = 0.63) surpassing E_{max} = 0.541, and the highest exploitation rate observed in 2022. Consequently, the annual yield exceeded the Maximum Sustainable Yield limit, underscoring the urgent need to mitigate fishing pressure, especially during the breeding season, to promote stock replenishment and ensure sustainability.

Keywords: Exploitation, Length-weight relationship, Maximum Sustainable Yield, Reba carp, Recruitment

INTRODUCTION

Fish and fishery products are essential, cheap sources of protein, employment, and revenue-generation for millions of people across the globe (Nelson *et al*., 2016; FAO, 2022), especially in developing nations. The ever-increasing demand for fish, coupled with various anthropogenic and environmental factors, is impacting the natural stock of ichthyofauna (Tidwell and Allan, 2001; Williams-Subiza and Epele, 2021). Therefore, monitoring fish stock is key to gaining insight into the health of the ecosystem by reconciling the concepts of exploitation and conservation (Jisr *et al*., 2018) for sustainable utilization.

Cirrhinus reba (Hamilton, 1822), globally known as Reba carp, belongs to the family Cyprinidae and Order Cypriniformes and is geographically distributed in South and Southeast Asian countries like India, Bangladesh, Nepal, Pakistan, Thailand, and Myanmar (Talwar and Jhingran, 1991; Jayaram, 1999). The vernacular names associated with this carp include bata, kharkebata, and rewa (Gupta and Banerjee, 2016), but it is commonly called Rikor, which is popular

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for its taste in the region surrounding the Atrai River, India. The Atrai (also known as Atreyee), a transboundary river between India and Bangladesh, originates near Baikanthapur forest in Siliguri, West Bengal, India, crosses Bangladesh, again re-enters India in Dakshin Dinajpur district of West Bengal, and finally flows through Bangladesh to meet the river Brahmaputra (Saha and Pal, 2019). It spans latitudes 24°1′07″N to 26°50′17″N and longitudes 88°22′45″E to 89°43′38″E, covering a total length of 390 km, of which only 52 km is in the Dakshin Dinajpur district of West Bengal, India (Mia *et al*., 2019). *C. reba* is one of the major targeted ichthyospecies for fishermen due to its high protein content (Afroz and Begum, 2014). This is driven by consumer demand and economic benefits (Hossain *et al*., 2015a). The declining wild fish population of many species, including *C. reba* (Sarkar *et al*., 2004), can be attributed to various factors such as human interventions, habitat fragmentation, pollution, climate change, and overfishing (Pal and Sarda, 2020). Consequently, Reba carp has already been categorized as a vulnerable species in India (Molur and Walker, 1998; Sarkar *et al*., 2004; Barman, 2007) and near threatened in Bangladesh (IUCN Bangladesh, 2015). In addition, overexploitation of the natural stock population may diminish genetic diversity (Bawole *et al*., 2017), causing a loss of the potential adaptability of the species to changing environments (Gandra *et al*., 2021). Although fish is a renewable resource, the fisheries sector may collapse if harvesting exceeds its chances of recovery.

Using the population dynamics technique, periodical assessment of fish stock provides a framework for understanding the change in fish population over time in response to ecological conditions, fishing pressure, and natural disturbances (Gebremedhin *et al*., 2021). Among many, the length-weight relationship (LWR) is one of the vital techniques that uses length frequency data (LFD) to understand the growth pattern, fitness, health condition, and degree of exploitation of a target species (Froese, 2006; Hossain *et al*., 2012b; Bhatt *et al*., 2021). Moreover, the absence of readily available data on traditional stock assessment, such as catching length, abundance indices, fishing effort, and life-history parameters (Raza *et al*., 2022), makes it difficult for the fisheries manager to assess sustainable fishing levels for most of the fish stock worldwide (Dowling *et al*., 2015). In data-deficient environments, the length-based method is often preferred for its convenience in terms of time, effort, and cost (Raza *et al*., 2022). It is not uncommon that fishing is an extremely selective practice where a fisherman mainly targets specific species that are either easily accessible or profitable. This may create a misbalance of fish diversity and biomass, causing higher mortality in some fish species compared to others (Tsikliras *et al*., 2015).

Despite the fact that stock assessment-based fisheries management is highly efficient, such information is limited in the case of small scale fisheries (Fujita, 2021), resulting in a poor state of the stock (Hilborn *et al*., 2020). Due to the variation in fishing pressure of minor carp in different water bodies, the local assessment of fish stock is necessary for strategy management (Ovando *et al*., 2021; Dereli *et al*., 2022) and conservation of natural population. To date, no record of stock assessment or LWR on Reba carp from the Atrai River is available. Therefore, the present study was designed and conducted during 2019, 2021, and 2022 in the Indian part of the Atrai River to determine its present status for achieving sustainable fisheries. Finally, on the basis of empirical results, management recommendations to ensure the conservation of the stock of this species were provided.

MATERIALS AND METHODS

Study area and fish sampling

Five study sites were selected along the entire stretch of River Atrai (approximately 52 km) in West Bengal, India, (Figure 1) for monthly sampling, i.e., four times a week from January to December for three years (2019, 2021, and 2022). The water temperature was also recorded (OAKTON Multiparameter PCSTestr 35) during the study period. The fishermen used small boats and hand lining like gill nets, cast nets, and seine nets of various mesh sizes for fishing activity. The fish specimens were identified to species level following the available literature (Talwar and Jhingran, 1991; Jayaram, 1999). The total length (L) of each specimen was recorded in 'centimeter (cm)' using a metric scale, and body weight (W) was measured in 'gram (g)' using an electronic balance (up to 0.01 g accuracy) (K. Roy & Co., BW 600).

For the assessment of stock, commercial information such as total monthly catch was obtained from professional local fishermen, nearby markets, and fish landing centres, locally known as Aarat, for the study period through personal interviews. The monthly catch was estimated, considering both the projected daily catch and the number of fishing days in the month.

Data analysis

The analysis of the data was done using FAO-ICLARM Stock Assessment Tools (FiSAT II, 1.2.2 version) software and MS-Excel, 2016. Further, a detailed explanation was made following Gayanilo (1997).

The relationship between length (L) and weight (W) is one of the standard methods for determining the overall fitness of a species and whether a change in length is with respect to a change in weight. The weight of fish can be denoted in terms of length using the following non-linear regression function (Huxley, 1924):

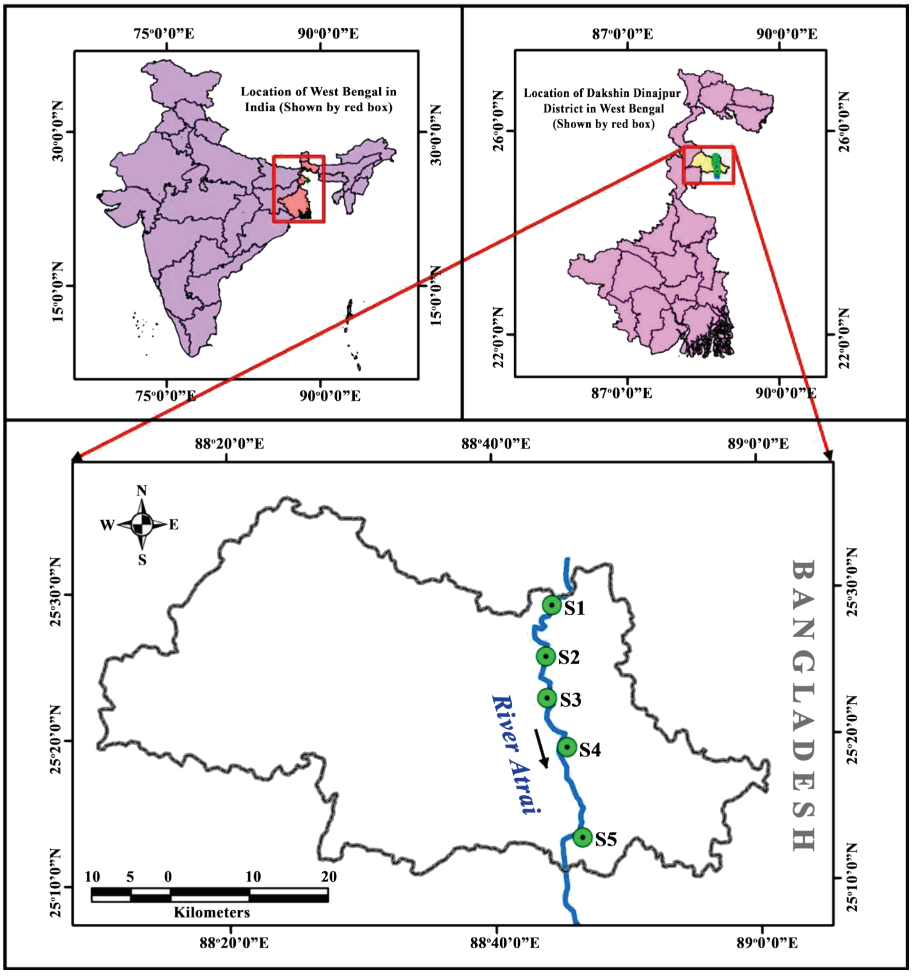

Figure 1. Map showing stretch of River Atrai in Dakshin Dinajpur district of West Bengal, India along with location of study sites in green dots (using ArcGIS, 10.2.2).

$$W = aL^b \quad (1)$$

where 'a is intercept' and 'b is power function' are constants and natural logarithm linear form as:

$$LogW = Loga+bLogL \quad (2)$$

To ascertain the growth forms, whether isometric or allometric, a t test was performed using the equation:

$$t_s = (b–3)/sb \quad (3)$$

where t_s is the two-tailed t-test value, b is the slope, and sb is the standard error of the slope (b). The 'b' values determines the growth pattern, where b = 3 indicates isometric growth, b<3 indicates negative allometric growth, and b>3 indicates positive allometric growth of Reba carp (Sokal and Rohlf, 1987).

In line with Fulton (1911), by comparing length and weight, the overall health and physiological state of fish was determined manually as Fulton's condition factor (K_F) and relative condition factor (K_n) following the equations:

$$K_F = 100W/L^b \quad (4)$$ and

$$K_n = W/aL^b \quad (5)$$ respectively

where, a = intercept, b = regression co-efficient, L = total length, and W = weight.

The recorded monthly data were structured into a time series length frequency distribution table with a constant class size for each year. The growth parameters such as growth constant (K) and asymptotic length (L∞) were estimated using the best fit growth curve by electronic frequency analysis, ELEFAN-1 (Pauly and David, 1981) based on VBGF (Von Bertalanffy Growth Function), which is given by:

$$L_t = L\infty(1–e^{-K(t-t_0)}) \quad (6)$$

where, L_t is the length at age t, L∞ is the asymptotic length, K is the Growth coefficient, and t_0 is the theoretical age at length equal zero. The t_0 was calculated using empirical equation of Pauly (1984) as:

$$Log(–t_0) = -0.3922-0.2752LogL\infty -1.038LogK \quad (7)$$

The life span (t_{max}) was estimated from the equation,

$$t_{max} = \frac{3}{K} + t_0 \quad (8)$$

(Pauly, 1983) and the Growth performance index (ϕ′) was calculated using the equation given by Pauly and Munro (1984):

$$\phi' = Log_{10}K+2Log_{10}L\infty \quad (9)$$

The size at first sexual maturity (L_m) was calculated using the equation given by Binohlan and Froese (2009) as:

$$Log(L_m) = -0.1189+0.9157\times Log(L_{max}) \quad (10)$$

where L_{max} is the maximum length obtained in the study period.

The recruitment pattern of fish was studied using FiSAT-II software with the help of length frequency data and growth parameters for the maximum likelihood approach by NORMSEP (SEParation of the NORMally distributed components of length-frequency samples) to fit the Gaussian distribution (Moreau and Cuende, 1991). The probability of survival of Reba carp was estimated manually by using data on natural mortality and fishing mortality computed from FiSAT for 2019, 2021 and 2022.

The instantaneous total mortality (Z) of *Cirrhinus reba* per year was estimated using the length-converted catch curve method (Gayanilo *et al*., 2005), which is the sum of natural mortality (M) and fishing mortality (F) per year. The natural mortality (M) was calculated using Pauly's empirical relationship (Pauly, 1980):

$$Log_{10}M = 0.0066-0.279Log_{10}L\infty+0.6543Log_{10}K+0.4634Log_{10}T \quad (11)$$

where T, is the mean annual environmental water temperature in °C for Reba carp which is 25.83 °C, 25.37 °C and 25.61 °C for respective years 2019, 2021, and 2022. The Fishing mortality (F) was derived from the equation:

$$F = Z-M \qquad (12)$$

The current exploitation rate (E) is the ratio of Fishing mortality and Total mortality which can be expressed as F/Z.

The probability of capture of *C. reba* was estimated from backward projections of the length-converted catch curve directly using logistic transformation (Sparre and Venema, 1998). It determines the length of the fish at which 25%, 50%, and 75% of the fish population is likely to be vulnerable or caught during the study period. The length at first capture (L_c or L_{50}) was estimated from the plot of the probability of capture (Pauly, 1984).

The relative yield-per-recruit ($\frac{Y'}{R}$) and relative biomass-per-recruit ($\frac{B'}{R}$) were determined as a function of E based on the Beverton and Holt (1966) model using $L_c / L\infty$ ratio and the M/K ratio. Besides, E_{max} (exploitation rate that produces the maximum yield), $E_{0.1}$ (exploitation rate at which the marginal increase of relative yield-per-recruit is 1/10th of its value at E = 0) and $E_{0.5}$ (the value of E under which the stock has been reduced to 50% of its unexploited biomass) are also estimated by using the first derivative. The relative yield-per-recruit (Y′/R) was calculated following this formula:

$$Y'/R = EU^{M/K}\left\{1-\frac{3U}{(1+m)}+\frac{3U^2}{(1+2m)}-\frac{U^3}{(1+3m)}\right\} \qquad (13)$$

where $U = 1-\left(\frac{L_c}{L\infty}\right)$, $m = \frac{1-E}{\frac{M}{K}} = K/Z$ and $E = F/Z$.

Relative biomass-per-recruit ($\frac{B'}{R}$) is estimated from the relationship:

$$\frac{B'}{R} = \left(\frac{Y'}{R}\right)/F \qquad (14)$$

Through length-structured virtual population analysis (VPA), the population sizes and fishing mortality for each length group have been computed by using the inputs like a, b, M, F, L∞, and K in the software FiSAT-II (Pauly, 1984). The total annual stock (Y/U) and average standing stock (Y/F) were calculated by using the values of U, F and Y. The MSY, or Maximum Sustainable Yield, was calculated using the relationship as proposed by Gulland (1979) for *C. reba*:

$$MSY = Z_t \times 0.5 \times B_t \qquad (15)$$

where Z_t is the total mortality in the year t and B_t is the standing stock of size in the year t.

RESULTS

Length-weight relationship and growth type

The descriptive statistics of sample size, minimum and maximum values of length and weight, along with associative relationship parameters for 2019, 2021, and 2022 are computed (Table 1). The studied specimen showed a maximum range of length between 50 and 237 mm (112.37±33.82) in 2022, whereas the minimum length range was between 61 and 214 mm (117.83±31.88) in 2021. The minimum weight was recorded in 2019 (0.90 g) and the maximum weight was 184.19 g in 2022 (Table 1).

The b values during the study period are 3.239, 3.078, and 3.082, which indicate a trend of positive allometric growth of Reba carp in 2019, 2021, and 2022, respectively (Table 1, Figure 2). The results are also confirmed by using the t test (Table 1).

Condition factor

Fulton's condition factor (K_F) and relative condition factor (K_n) are the vital tools necessary to assess the health and overall well-being of a fish. The average K_F values varied between 0.8159 and 0.8340, whereas the K_n lies between 1.2393 and 1.2922 (Table 1).

Table 1. Length-weight relationship, growth form and condition value of *Cirrhinus reba* in Atrai River, India, across the years 2019, 2021, and 2022.

Year	Sample size	Length parameter (mm)			Weight Parameters (g)			Parameters for relationship							Condition factor	
		Min	Max	Mean±SD	Min	Max	Mean±SD	a	b	r^2	CI	t value	p value	Growth form	(K_F) (Mean±SD)	(K_n) (Mean±SD)
2019	512	51	235	110.88±37.95	0.90	176.03	17.82±26.56	0.003821	3.239	0.9849	3.205–3.275	13.4338	1.97E-35	A^+	0.8340±0.1346	1.2393±0.1620
2021	531	61	214	117.83±31.88	1.74	143.73	16.86±16.60	0.005222	3.078	0.9755	3.036–3.119	3.6737	0.0003	A^+	0.8159±0.1520	1.2920±0.2370
2022	503	50	237	112.37±33.82	1.21	184.19	15.94±21.59	0.005201	3.082	0.9794	3.043–3.122	4.1127	4.57E-05	A^+	0.8170±0.1180	1.2922±0.1826

Note: a = intercept; b = slope; CI = Confidence Interval; K_F = Fulton's condition factor; K_n = Relative condition factor; A^+ = positive allometric growth

Table 2. Yearly population parameters, exploitation rates, annual catch and Maximum Sustainable Yield of *Cirrhinus reba* in Atrai River, India.

Year	L_c (mm)	L∞ (mm)	K (year^{-1})	Ø′	L_c / L∞	E_{10}	E_{50}	E_{max}	Z (year^{-1})	M (year^{-1})	F (year^{-1})	E	Annual Catch (kg)	MSY (kg)
2019	76.96	258.30	0.45	4.477	0.298	0.406	0.311	0.515	1.52	0.56	0.96	0.63	5359.59	4243.01
2021	90.36	237.30	0.45	4.404	0.381	0.450	0.331	0.575	1.32	0.57	0.75	0.57	5388.61	4741.98
2022	84.00	257.25	0.42	4.445	0.327	0.457	0.318	0.534	1.73	0.53	1.20	0.69	5312.16	3829.18
2019–2022	83.77	250.95	0.44	4.442	0.335	0.438	0.320	0.541	1.52	0.55	0.97	0.63	5353.45	4271.39

Note: L_c= length at first capture; L∞ = asymptotic length; K = growth coefficient; **Ø′** = growth performance; E_{10} = exploitation rate at which the marginal increase of relative yield-per-recruit is 1/10th of its value; E_{50} = exploitation rate under which the stock has been reduced to 50% of its unexploited biomass; E_{max} = exploitation rate which produces maximum yield; Z = total mortality; M = natural mortality; F = fishing mortality; E = exploitation rate; MSY = Maximum Sustainable Yield

Length frequency distribution and growth parameters

The average length of *Cirrhinus reba* during this study period was found to be 113.75±34.72 mm. The L∞ and K values were estimated from monthly frequency data using the K scan method, followed by the formation of a growth curve by ELEFAN-1. The VBGF was superimposed on the histogram produced using the restructured length frequency data (Figure 3) with the highest goodness of fit index (R_n = 0.309, 0.260, and 0.275 for 2019, 2021 and 2022 respectively). The growth parameters L∞ for 2019, 2021, and 2022 were 258.30 mm, 237.30 mm, and 257.25 mm, respectively, and the K values for the period were determined (Table 2).

Recruitment pattern

The recruitment pattern of *C. reba* was found to be constant annually, with one major peak lying between June and August (Figure 4) during the three-year study period. The peak pulse produced 19.71%, 14.71%, and 17.71% of recruits during 2019, 2021, and 2022, respectively. The group values used for NORMSEP were 6.55, 6.25, and 6.18 during 2019, 2021, and 2022, respectively.

Probability of survival

Based on the probability of survival, the fishing mortality was much steeper in 2022 compared to 2019 (Figure 5). Whereas in 2021, the pressure of fishing mortality was much closer to natural mortality (Figure 5). The life span (t_{max}) of *C. reba* during this period was found to be between 6 and 7 years. The length at maturity (L_m) was estimated during this study period for achieving exploitable stock size.

Mortality and exploitation

Throughout the study, fishing mortality was higher compared to natural mortality (Table 2, Figure 6). During 2022 and 2021, fishing mortality and natural mortality were found to be at their peak respectively. The highest exploitation of Reba carp was recorded in 2022 (E = 0.69), followed by E = 0.63 in 2019 and E = 0.57 in 2021 (Table 2, Figure 6).

Probability of capture

The fish within the range of 81 mm to 126 mm faces the maximum probability of catch in 2019, followed by the range of 91 mm to 136 mm in 2021. In 2022, the length range extends from 80 mm to 125 mm. The computed values associated with the probability of capture using FiSAT II for 2019, 2021, and 2022 were as follows: L_{25} (71.53 mm, 83.88 mm, 77.38 mm), L_{50} (76.96 mm, 90.36 mm, 84.00 mm), and L_{75} (82.40 mm, 96.85 mm, 90.62 mm), respectively (Figure 7).

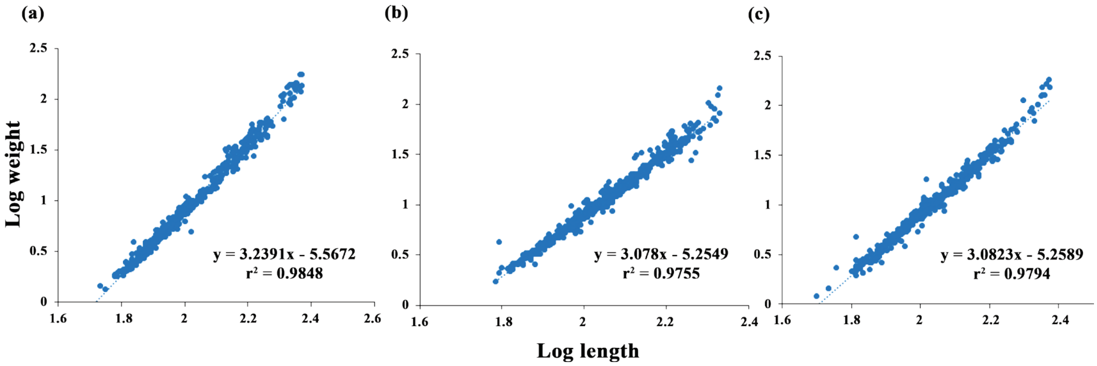

Figure 2. Length-weight relationship of *Cirrhinus reba* during: (a) 2019; (b) 2021; (c) 2022 in the Atrai River, West Bengal, India.

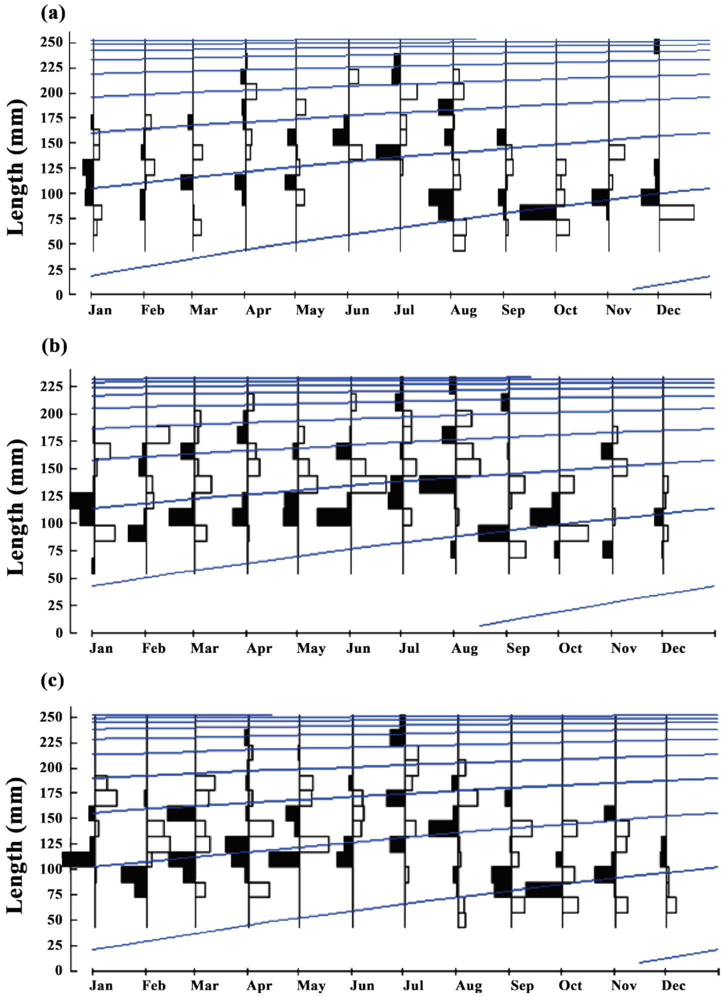

Figure 3. VBGF and length frequency plot of *Cirrhinus reba* in Atrai River, India, in the years: (a) 2019; (b) 2021; (c) 2022.

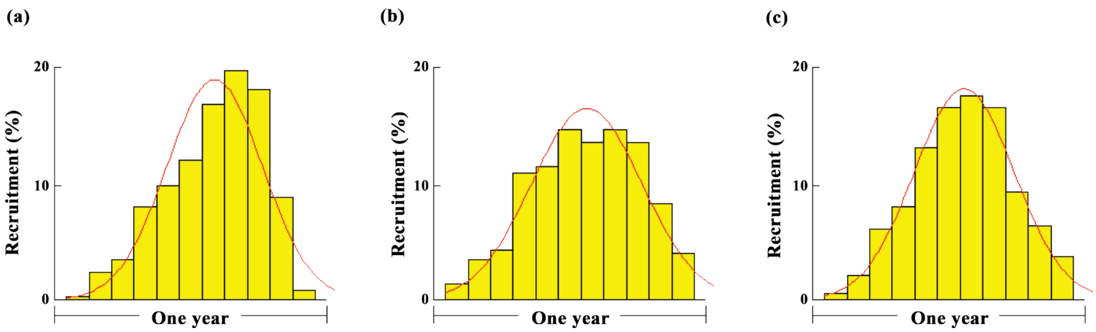

Figure 4. Recruitment curve of *Cirrhinus reba* in Atrai River, India, during the years: (a) 2019; (b) 2021; (c) 2022.

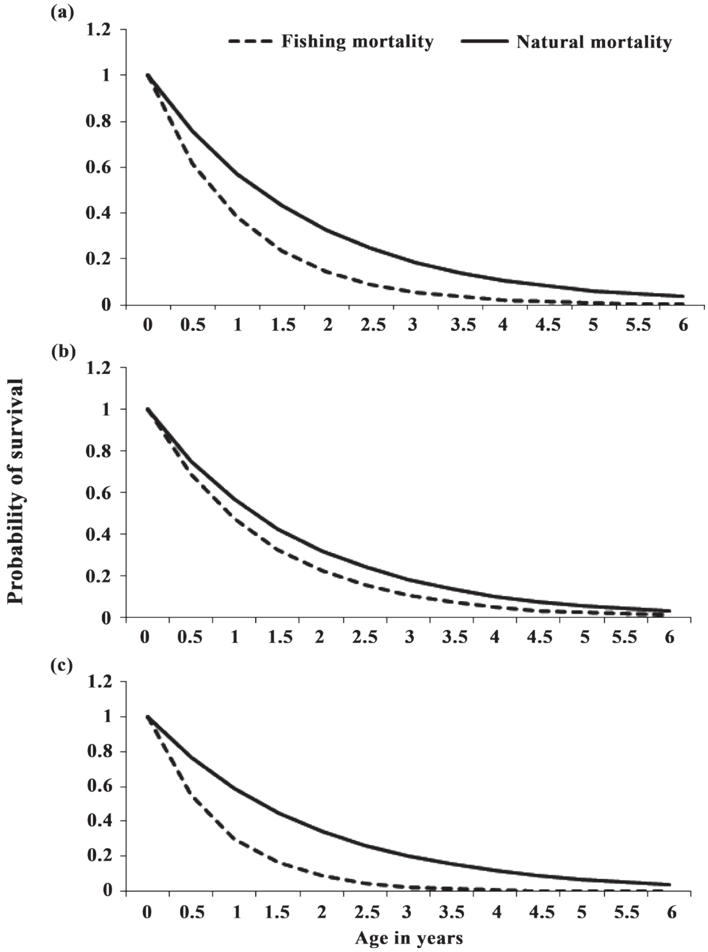

Figure 5. Probability of survival of *Cirrhinus reba* in Atrai River, India, during the years: (a) 2019; (b) 2021; (c) 2022.

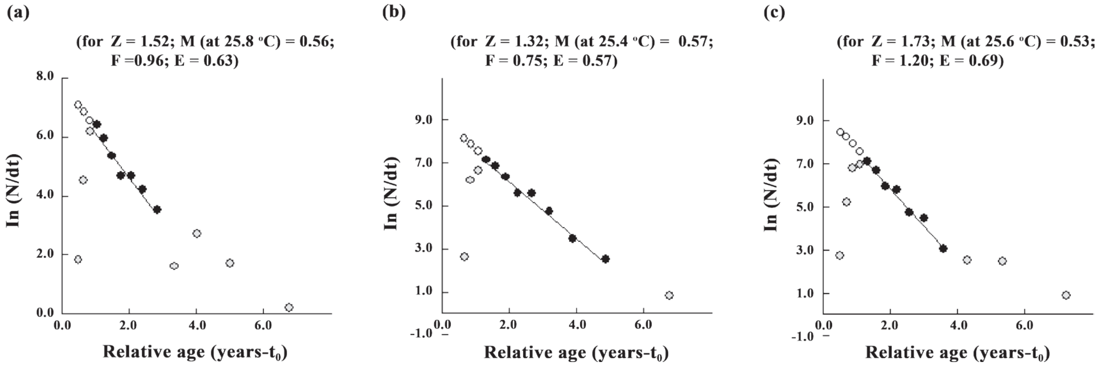

Figure 6 Length-converted catch curve for *Cirrhinus reba* in Atrai River, India, during the years: (a) 2019; (b) 2021; (c) 2022.

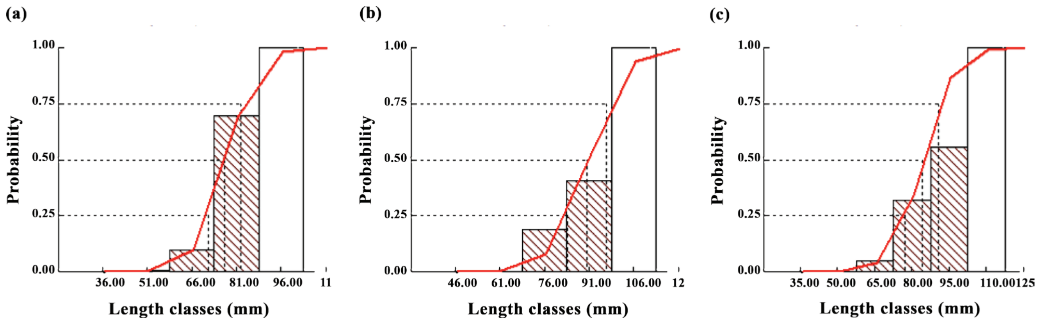

Figure 7 Logistic selection curve for probability of capture, showing 25%, 50% and 75% selection length of *Cirrhinus reba* in Atrai River, India during the years: (a) 2019; (b) 2021; (c) 2022.

Yield per recruit and biomass per recruit

The relative yield-per-recruit (Y´/R) and relative biomass-per-recruit (B´/R) were estimated and plotted against exploitation rate (E) using the knife-edge selection method from FiSAT II software. The E_{10} (0.406, 0.450, 0.457), E_{50} (0.311, 0.331, 0.318), and E_{max} (0.515, 0.575, 0.534) were determined for each year (Table 2, Figure 8).

Virtual population analysis (VPA)

By using the VPA programme of FiSAT-II software, the population from the total catch was reconstructed by size and computed the length structured VPA (Figure 9). The juvenile fish belonging to length groups of 51–66 mm, 61–76 mm, and 50–65 mm showed higher chances of survival in 2019, 2021, and 2022, respectively.

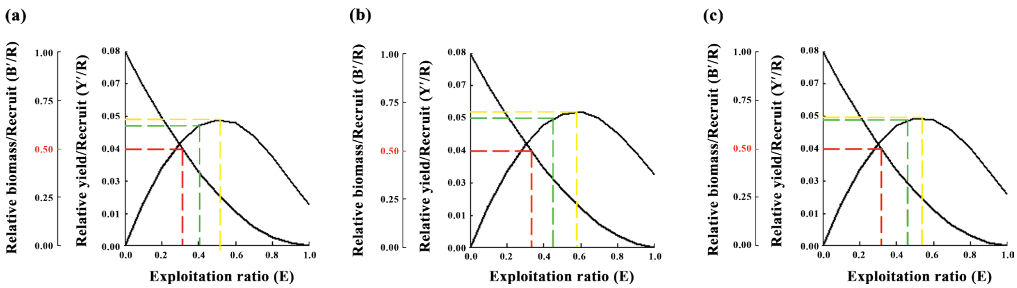

Figure 8 Relative yield-per-recruit and relative biomass-per-recruit of *Cirrhinus reba* in Atrai River, India, during the years: (a) 2019; (b) 2021; (c) 2022, where E_{10}, E_{50}, and E_{max} were repesented by green, red, and yellow dotted line respectively.

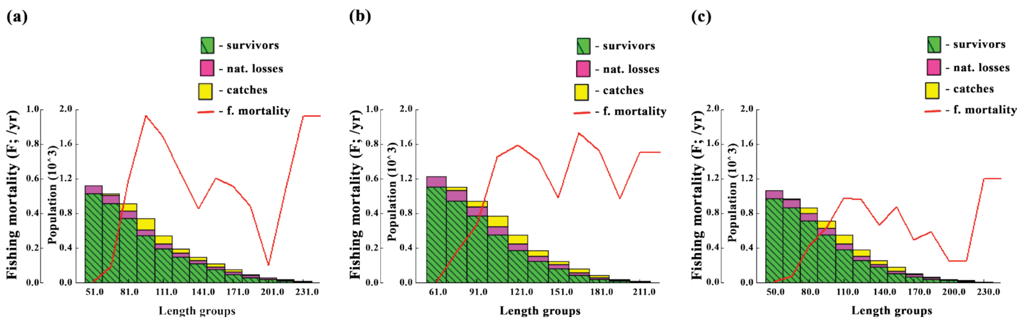

Figure 9 Length structured VPA of *Cirrhinus reba* in Atrai River, India, during the years: (a) 2019; (b) 2021; (c) 2022.

Higher fishing mortality was found in the length class of 81–126 mm, followed by 141–186 mm in 2019. Whereas in 2021, two major fishing morality peaks were obtained in the length groups of 106–136 mm and 151–181 mm. The fishing pressure in 2022 showed one major peak in the length class of 80–125 mm along with another peak in the length class of 140–170 mm.

Stock assessment

The mean current exploitation rate (E = 0.63) exceeded the maximum exploitation level (E_{max} = 0.541) (Table 2). The average annual catch (5,353.45 kg) during the assessment period was significantly greater than MSY (4,271.39 kg) (Table 2), indicating overharvesting of the resource in Indian part of this river.

DISCUSSION

The findings of this study deal with 1,546 *Cirrhinus reba* samples with varying sizes and weights. The smallest size of the sample fish was found to be 50 mm, which was much smaller as compared to 66 mm recorded in the Padma River, Bangladesh (Jewel *et al*., 2019). The maximum length obtained during the study was 237 mm, which was found to be close to 234 mm as recorded by Hossain *et al*. (2012b). However, in the previous studies, the maximum size of Reba carp recorded was 225 mm in Manchar Lake, Pakistan (Narejo, 2006), whereas it was 201 mm in the Ganga River, Bihar, India (Ahirwal *et al*., 2023), which was lower when compared to the present study. Perhaps the regional variation in total length of the individual fish caught is due to differences in the ecological condition of the studied area (Kumar *et al*., 2019) along with differences in using fishing gear or selective species (Hossain *et al*., 2012a). The recorded maximum weight of 184.19 g was found to be smaller than 200 g (Hossain *et al*., 2013) but larger than 147 g, as documented by Muralidharan *et al*. (2011). Moreover, females were recorded to attain significantly higher maximum length and weight as compared to males (Hossain *et al*., 2013) due to the accumulation of higher energy needed for reproductive success.

The reba crap during the study period showed positive allometric growth, indicating faster growth in weight compared to length. This result is in accordance with the study of Karna *et al*. (2020). Besides, Jewel *et al*. (2019) found isometric growth for male Reba carp but positive allometric growth for female carp. Similar studies recorded the negative allometric growth in Lower Anicut, Tamil Nadu (Mathialagan *et al*., 2014a), the Indus River, Pakistan (Muhammad *et al*., 2016), and South West Bangladesh (Islam *et al*., 2021). This variation in LWRs of fish may be due to various factors like environmental parameters, physiological condition of fish during capture, habitat, degree of stomach fullness, gonad development, sex, differences in the observed length ranges of the specimen caught, swimming behavior, and water flow (Froese, 2006; Muchlisin *et al*., 2010). Since these factors were not taken into account in this study, the variation in LWR parameters might be the result of single or multiple factors. The K_F value during this study indicates the healthy condition of the stock and shows parity with the study conducted by Muhammad *et al*. (2016). The estimated KF value was slightly lower compared to the study of Hossain *et al*. (2013) in the Ganges River, North West Bangladesh, but the relative condition factor was higher compared to the study conducted by Narejo (2006). According to De Giosa *et al*. (2014), these changes may be caused by the season, availability of food, or reproductive status in various environmental situations.

The estimated $L\infty$ in each year (2019, 2021, 2022) was in accordance with the study of *C. reba*, indicating values of 237.3 mm and 253.1 mm in males and females, respectively, as reported by Ramasamy and Rajangam (2017). These figures are comparatively lower than those found in species from the Indus River, Pakistan, by Memon *et al*. (2020). The growth constant K = 0.44, which is close to 0.5, indicates a medium rate of growth (Sparre and Venema, 1998; Santos *et al*., 2022) of Reba carp. Variation in $L\infty$ and K within the species may arise due to ecological conditions, fishing pressure, and metabolic rate (Santos *et al*., 2022). The growth performance index (ϕ') is typically species-specific (Pauly, 1991), considering both $L\infty$ and K simultaneously (Pauly and Munro, 1984).

In this study, the estimated (ϕ′) value was notably higher, indicating moderate growth compared to the value recorded by Memon *et al*. (2020) (ϕ′ = 2.317). The growth performance index in *C. reba* was lower than that observed in closely related cyprinid fish such as *Cirrhinus mrigala* (6.180), as studied by Ramulu *et al*. (2022) in the Thamirabarani River, South India. Fast growth rates and growth performance indices may enhance a species' potential for aquaculture (Gosavi *et al*., 2019). The occurrence of immature fish in the catch indicated a more or less continuous spawning period throughout the year, with a single recruitment pulse between June and August. Recruits were added to the fisheries from pre-monsoon (April-May) to July-August (monsoon), aligning with the findings from studies conducted by Chondar (1999) and Hossain *et al*. (2015b).

The probability of survival confirmed a higher fishing mortality, implying that the fish failed to reach its maximum age (>6 years). The average size at first sexual maturity (L_m) was estimated to be 110 mm, which was in accordance with Hossain *et al*. (2013), who found 115 mm for males and 135 mm for females in their study. Islam *et al*. (2021) estimated the L_m to be 144 mm, which was higher compared to the present study. Sossoukpe *et al*. (2013) opined that the L_m value varied along the species with respect to its biogeographic zone of distribution. The estimated average length at first capture (L_c = 83.77 mm) was lower compared to the length at first sexual maturity (L_m = 110 mm). Consequently, 50% of the population is captured before reaching sexual maturity. This signifies the presence of a large fraction of juvenile fish in the catch due to the use of selective fishing gear (Froese, 2004), a finding is further confirmed by the average ratio of $L_c/L\infty$ (Wehye *et al*., 2017). The main reason lies with the use of small mesh-sized gear and disturbing the nursery bed of this carp. The fisheries manager will find L_c and L_m to be useful to limit the mesh size and determine the optimum size for permissible capture of the target species, though this data was very scarce in the previous literature.

According to Beverton and Holt (1966; 2012), a fish stock is considered to be at a sustainable exploitation level when the natural mortality is in equilibrium with the fishing mortality, i.e., the rate of exploitation does not exceed E_{50} (50%). The present study established a high exploitation rate (E), i.e., E > threshold value (0.5), in each year during the study period, indicating high fishing mortality compared to natural mortality for this species. The current exploitation rates for each year were considerably higher than the optimal exploitation rates E_{50} (0.311, 0.331, and 0.318 for 2019, 2021, and 2022, respectively) and E_{max} values. To ensure the continuation of this species in this study area, the existence of 50% of the stock is necessary, which can be obtained by reducing the current exploitation rate from 0.63 to E_{50} = 0.320. On the contrary, values of Z = 0.630, M = 0.617, F = 0.012, and E = 0.019 of *C. reba* by Memon *et al*. (2020) showed no exploitation in the Indus River, Pakistan, which may be due to the use of different fishing gears in different ecosystems.

The average annual catch of Reba carp during 2019, 2021, and 2022 was considerably higher than the Maximum Sustainable Yield (MSY), reaffirming that the stock was facing high fishing pressure. This implies that the existence of this species is in an alarming state in this studied ecosystem. Likewise, a study conducted by Mathialagan *et al*. (2014b) in lower Anicut, Tamil Nadu, reported a decline in the fishery of *C. reba*, which was 7.7 tonnes in 2000–2001 and drastically reduced to 3.7 tonnes in 2011–2012. The trend of decline of this economically important fish indicates its unsustainability, which is a matter of concern for the existence of the species in the near future.

CONCLUSION

The present study provides baseline information related to LWR, condition factors, size at sexual maturity, and growth parameters of *Cirrhinus reba*, a vulnerable species from the Indian part of the Atrai River, to aid future studies related to this or the surrounding ecosystem. It also contributes to the existing literature and information available in the online database. Besides, it explores the varied aspects of population dynamics and reveals the existence of a greater exploitation rate of *C. reba* in the Atrai River amidst the presence of extreme fishing pressure. Presently, there are no management strategies for *C. reba*, and uncontrolled exploitation of this species is a matter of apprehension for the natural stock from collapse henceforward. Therefore, immediate and necessary management monitoring plans should be implemented, like (a) reducing the harvest to the level of MSY by decreasing the fishing pressure by 50% from the current state; (b) preventing fishing of this carp during their breeding season; (c) regulating mesh size and restricting the length of fish to be captured; (d) monitoring fishing gear used by the local fishermen; and (e) conservation plans for the region of river mostly inhabited by *C. reba*. The findings of this study would be an important means for policymakers, fishery biologists, and conservationists to implement the immediate strategies needed for the sustainable exploitation of the remaining stock in this river before it gets too late.

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LITERATURE CITED

Afroz, H. and M. Begum. 2014. Analysis of nutritional value and mineral contents of three different parts of body of *Cirrhinus reba*. **International Journal of Scientific and Engineering Research** 5: 2301–2306.

Ahirwal, S.K., J. Singh, K. Sarma, T. Kumar, V. Bharti and A. Kumar. 2023. Morphometric characteristics, length-weight relationships, and condition factors of five indigenous fish species from the river Ganga in Bihar, India. **Journal of Applied Ichthyology** 1329222: 1–7. DOI: 10.1155/2023/1329 222.

Barman, R.P. 2007. **A Review of the Freshwater Fish Fauna of West Bengal, India with Suggestions for Conservation of the Threatened and Endemic Species.** Records of the Zoological Survey of India (ZSI), West Bengal, India. 48 pp.

Bawole, R., U.N. Rembet, A.S. Ananta, F. Runtuboi and R. Sala. 2017. Growth, mortality and exploitation rate of *Plectropomus maculatus* and *P. oligocanthus* (Groupers, Serranidae) on Cenderawasih Bay National Park, Indonesia. **The Egyptian Journal of Aquatic Research** 43(3): 213–218. DOI: 10.1016/j.ejar.2017.09.002.

Beverton, R.J.H. and S.J. Holt. 1966. **Manual of Methods for Fish Stock Assessment. Part II: Tables of Yield Functions.** FAO, Rome, Italy. 67 pp.

Beverton, R.J.H. and S.J. Holt. 2012. **On the Dynamics of Exploited Fish Populations,** Volume 11. Springer, Dordrecht, Netherlands. 538 pp.

Bhatt, D.M., K.J. Sarma, N.J. Thakkar and P.C. Mankodi. 2021. Length-weight relationship and condition factor of *Rhinomugil corsula* (Hamilton, 1822) (Actinopterygii, Mugiliformes, Mugilidae) in four major estuaries of Gujarat, India. **Journal of Fisheries and Environment** 45(3): 53–63.

Binohlan, C. and R. Froese. 2009. Empirical equations for estimating maximum length from length at first maturity. **Journal of Applied Ichthyology** 25(5): 611–613. DOI: 10.1111/j.1439-0426.2009.01317.x.

Chondar, S.L. 1999. **Biology of Finfish and Shellfish.** SCSC Publishers, Kolkata, India. 514 pp.

De Giosa, M., P. Czerniejewski and A. Rybczyk. 2014. Seasonal changes in condition factor and weight-length relationship of invasive *Carassius gibelio* (Bloch, 1782) from Leszczynskie Lakeland, Poland. **Advances in Zoology** 678763: 1–7. DOI: 10.1155/ 2014/678763.

Dereli, H., Y. Şen, T. Kebapçıoğlu, M. Erdoğuş, Z.S. Ölçek, M. Özdemir and A. Ulman. 2022. Management recommendations for common carp fisheries in Turkey in light of their reproductivity and gear selectivity. **Journal of Fisheries and Environment** 46(1): 141–156.

Dowling, N.A., C.M. Dichmont, M. Haddon, D.C. Smith, A.D.M. Smith and K. Sainsbury. 2015. Empirical harvest strategies for data-poor fisheries: a review of the literature. **Fisheries Research** 171: 141–153. DOI: 10.1016/j.fishres.2014.11.005.

Food and Agriculture Organization of the United Nations (FAO). 2022. **The State of WorldFisheries and Aquaculture 2022. Towards Blue Transformation.** FAO, Rome, Italy. 266 pp.

Froese, R. 2004. Keep it simple: three indicators to deal with overfishing. **Fish and Fisheries** 5: 86–91. DOI: 10.1111/j.1467-2979.2004.00144.x.

Froese, R. 2006. Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. **Journal of Applied Ichthyology** 22(4): 241–253. DOI: 10.1111/j.1439-0426.2006.00805.x.

Fujita, R. 2021. The assessment and management of data limited fisheries: Future directions. **Marine Policy** 133: 104730. DOI: 10.1016/j.marpol.2021.104730.

Fulton, T.W. 1911. **The Sovereignty of the Sea.** William Blackwood and Sons, Edinburgh, UK. 799 pp.

Gandra, M., J. Assis, M.R. Martins and D. Abecasis. 2021. Reduced global genetic differentiation of exploited marine fish species. **Molecular Biology and Evolution** 38(4): 1402–1412. DOI: 10.1093/molbev/msaa299.

Gayanilo, F.C. 1997. **FiSAT: FAO-ICLARM Stock Assessment Tools, Reference Manuals,** Volume 8. FAO, Rome, Italy. 262 pp.

Gayanilo, F.C., P. Sparre and D. Pauly. 2005. **FAO-ICLARM Stock Assessment Tools II: User's Guide (No. 8).** FAO, Rome, Italy. 168 pp.

Gebremedhin, S., S. Bruneel, A. Getahun, W. Anteneh and P. Goethals. 2021. Scientific methods to understand fish population dynamics and support sustainable fisheries management. **Water** 13(4): 574. DOI: 10.3390/w13040574.

Gosavi, S.M., S.S. Kharat, P. Kumkar and S.D. Tapkir. 2019. Assessing the sustainability of lepidophagous catfish, *Pachypterus khavalchor* (Kulkarni, 1952), from a tropical river Panchaganga, Maharashtra, India. **The Journal of Basic and Applied Zoology** 80(1): 1–10. DOI: 10.1186/s41936-019-0080-8.

Gulland, J.A. 1979. **Report of the FAO/UNDP Workshop on the Fishery Resources of the Western Indian Ocean–South Equator.** FAO, Rome, Italy. 8 pp.

Gupta, S. and S. Banerjee. 2016. A review on feeding and reproductive biology of *Cirrhinus reba* (Hamilton, 1822), a threatened freshwater fish of Indian subcontinent with an emphasis on its conservation. **Fisheries and Aquaculture Journal** 7(2): 1–5.

Hilborn, R., R.O. Amoroso, C.M. Anderson, *et al*. 2020. Effective fisheries management instrumental in improving fish stock status. **Proceedings of the National Academy of Sciences** 117(4): 2218–2224. DOI: 10.1073/pnas.1909726116.

Hossain, M.Y., J. Ohtomi, A. Jaman, S. Jasmine and R.L. Jr Vadas. 2012a. Life history traits of the monsoon river prawn *Macrobrachium malcolmsonii* (Milne-Edwards, 1844) (Palaemonidae) in the Ganges (Padma) river, northwestern Bangladesh. **Journal of Freshwater Ecology** 27(1): 131–142. DOI: 10.1080/02705060.2011.633739.

Hossain, M.Y., M.M. Rahman, B. Fulanda, M.A.S. Jewel, F. Ahamed and J. Ohtomi. 2012b. Length–weight and length–length relationships of five threatened fish species from the Jamuna (Brahmaputra River tributary) River, northern Bangladesh. **Journal of Applied Ichthyology** 28(2): 275–277. DOI: 10.1111/j.1439-0426.2011.01900.x.

Hossain, M.Y., M.M. Khatun, S. Jasmine, M.M. Rahman, M.A.S. Jewel and J. Ohtomi. 2013. Life-history traits of the threatened freshwater fish *Cirrhinus reba* (Hamilton, 1822) (Cypriniformes: Cyprinidae) in the Ganges River, Northwestern Bangladesh. **Sains Malaysiana** 42(9): 1219–1229.

Hossain, M.Y., R. Islam, M. Hossen, M. Rahman and J. Ohtomi. 2015a. Threatened fishes of the world: *Cirrhinus reba* (Hamilton 1822) (Cypriniformes: Cyprinidae). **Croatian Journal of Fisheries: Ribarstvo** 73(1): 40–42. DOI: 10.14798/73.1.786.

Hossain, M.Y., S.R.M. Sayed, M.M. Rahman, M.M. Ali, A.M. Hossen, A.M. Elgorban, Z.F. Ahmed and J. Ohtomi. 2015b. Length-weight relationships of nine fish species from the Tetulia River, southern Bangladesh. **Journal of Applied Ichthyology** 31(5): 967–969. DOI: 10.1111/jai.12823.

Huxley, J.S. 1924. Constant differential growth-ratios and their significance. **Nature** 114: 895–896. DOI: 10.1038/114895a0.

International Union for Conservation of Nature (IUCN) Bangladesh. 2015. **Red List of Bangladesh,** Volume 1. IUCN, Bangladesh Country Office, Dhaka, Bangladesh. 122 pp.

Islam, S.I., M.D. Sarower-E-Mahfuj, I. Hoshan, M. Asadujjaman, M.A. Samad and Y. Hossain. 2021. Biometric indices of near threatened reba carp, *Cirrhinus reba* from an oxbow lake in southwestern Bangladesh. **Bangladesh Journal of Fisheries** 33(2): 195–204. DOI: 10.52168 /bjf.2021.33.22.

Jayaram, K.C. 1999. **The Freshwater Fishes of the Indian Region.** Narendra Publishing House, Delhi, India. 551 pp.

Jewel, M.A.S., M.A. Haque, M.S. Ferdous, M.S. Khatun and S. Akter. 2019. Length-weight relationships and condition factors of *Cirrhinus reba* (Hamilton, 1822) in Padma River, Bangladesh. **Journal of Fisheries and Aquatic Science** 14: 39–45. DOI: 10.3923/jfas.2019.39.45.

Jisr, N., G. Younes, C. Sukhn and M.H. El-Dakdouki. 2018. Length-weight relationships and relative condition factor of fish inhabiting the marine area of the Eastern Mediterranean city, Tripoli-Lebanon. **The Egyptian Journal of Aquatic Research** 44(4): 299–305. DOI: 10.1016/j.ejar.2018.11.004.

Karna, S.K., M. Mukherjee, Y. Ali, R.K. Manna and V.R. Suresh. 2020. Length-weight relations of fishes (Actinopterygii) from Chilika Lagoon, India. **Acta Ichthyologica et Piscatoria** 50(1): 93–96. DOI: 10.3750/AIEP/02640.

Kumar, R., B. Sundaramoorthy, N. Neethiselvan, S. Athithan, R. Kumarand and S. Rahangdale. 2019. Fishery and length based population parameters of little tuna, *Euthynnus affinis* (Cantor, 1849) from Gulf of Mannar, South western Bay of Bengal. **Indian Journal of Geo Marine Sciences** 48(11): 1708–1714.

Mathialagan, R., R. Sivakumar, N. Rajasekaran and S. Chandrasekar. 2014a. Length-frequency distribution and length-weight relationship of reba carp *Cirrhinus reba* (Hamilton, 1822 Cypriniformes: Cyprinidae) from Lower Anicut, Tamil Nadu, India. **International Journal of Fisheries and Aquatic Studies** 2(2): 115–125.

Mathialagan, R., R. Sivakumar, S. Chandrasekar, N. Rajasekaran and K. Suresh. 2014b. Diminishing fishery of Reba carp *Cirrhinus reba* (Hamilton, 1822) in Lower Anicut, Tamil Nadu with reference to needful conservational measures. **International Journal of Science and Nature** 5(2): 215–221.

Memon, K.H., R. Bhanbhro, Q. Liu, T.J. Ursani, A.M. Shaikh and S.W. Memon. 2020. Population dynamics of Reba carp *Cirrhinus reba* from Indus River, Sukkur, Sindh, Pakistan. **Bangladesh Journal of Zoology** 48(1): 81–91. DOI: 10.3329/bjz.v48i1.47878.

Mia, M.J., J. Naher, M.G. Azom, M.S.R. Sabuz, M.H. Islam and M.R. Islam. 2019. Spatiotemporal variations in finfish assemblage and diversity indices in relation to ecological indicators of the Atrai River, Dinajpur, Bangladesh. **The Egyptian Journal of Aquatic Research** 45(2):175–182. DOI: 10.1016/j.ejar.2019.06.001.

Molur, S. and S. Walker. 1998. **Report of the Workshop on Conservation Assessment and Management Plan (CAMP) for Freshwater Fishes of India.** Zoo Outreach Organization, Tamil Nadu, India. 156 pp.

Moreau, J. and F.X. Cuende. 1991. On improving the resolution of the recruitment patterns of fishes. **Fishbyte** 9(1): 45–46.

Muchlisin, Z.A., M. Musman and M.N. Siti Azizah. 2010. Length-weight relationships and condition factors of two threatened fishes, *Rasbora tawarensis* and *Poropuntius tawarensis*, endemic to Lake Laut Tawar, Aceh Province, Indonesia. **Journal of Applied Ichthyology** 26(6): 949–953. DOI: 10.1111/j.1439-0426.2010.01524.x.

Muhammad, H., Z. Iqbaland and T. Akhlaq. 2016. Length-weight, length-length relationships and condition factor of fishes of family cyprindae from the Indus River, Pakistan. **Punjab University Journal of Zoology** 31(2): 143–147.

Muralidharan, M., M. Arunachalam and M. Raja. 2011. Length–weight relationships for fish species from Cauvery River at Hogenakal in South India. **Journal of Applied Ichthyology** 3(27): 968–969. DOI: 10.1111/j.1439-0426.2010.01611.x.

Narejo, N.T. 2006. Length-weight relationship and relative condition factor of a carp, *Cirrhinus reba* (Hamilton) from Manchar lake, Distt. Dadu, Sindh, Pakistan. **Pakistan Journal of Zoology** 38(1): 11–14.

Nelson, J.S., T.C. Grande and M.V. Wilson. 2016. **Fishes of the World.** John Wiley and Sons, Hoboken, New Jersey, US. 752 pp.

Ovando, D., R. Hilborn, C. Monnahan, M. Rudd, R. Sharma, J.T. Thorson, Y. Rousseau and Y. Ye. 2021. Improving estimates of the state of global fisheries depends on better data. **Fish and Fisheries** 22(6): 1377–1391. DOI: 10.1111/faf.12593.

Pal, S. and R. Sarda. 2020. Damming effects on the degree of hydrological alteration and stability of wetland in lower Atreyee River basin. **Ecological Indicators** 116: 106542. DOI: 10.1016/j.ecolind.2020.106542.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. **ICES Journal of Marine Science** 39(2): 175–192. DOI: 10.1093/icesjms/39.2.175.

Pauly, D. and N. David. 1981. ELEFAN I, a BASIC program for the objective extraction of growth parameters from length-frequency data. **Meeresforschung** 28(4): 205–211.

Pauly, D. 1983. **Some Simple Methods for the Assessment of Tropical Fish Stocks.** FAO, Rome, Italy. 52 pp.

Pauly, D. 1984. **Fish Population Dynamics in Tropical Waters: A Manual for Use with Programmable Calculators.** ICLARM Studies and Reviews 8. The International Center for Living Aquatic Resources Management (ICLARM), Manila, Philippines. 325 pp.

Pauly, D. and J.L. Munro. 1984. Once more on the comparison of growth in fish and invertebrates. **ICLARM Fishbyte** 2(1): 1–21.

Pauly, D. 1991. Growth performance in fishes: rigorous description of patterns as a basis for understanding causal mechanisms. **Aquabyte** 4(3): 3–6.

Ramasamy, M. and S. Rajangam. 2017. Maturation and reproductive biology of Reba carp *Cirrhinus Reba* (Hamilton) in Lower Anicut Reservoir, Tamil Nadu, India. **Fisheries and Aquaculture Journal** 8(3): 1–11.

Ramulu, D., J. Paulraj, J. Natarajan, S.C.S.K. Das, S. Eswaran, S. Rajagopal and P. Pandurangan. 2022. Stock assessment of three cyprinid fishes along the Potamon zone of Thamirabarani River, Eastern Slope of Western Ghats, South India. **Pakistan Journal of Zoology** 55(6): 1–11. DOI: 10.17582/journal.pjz/20220718070700.

Raza, H., Q. Liu, M.S. Alam and Y. Han. 2022. Length based stock assessment of five fish species from the marine water of Pakistan. **Sustainability** 14(3): 1587. DOI: 10.3390/su14031587.

Saha, T.K. and S. Pal. 2019. Exploring physical wetland vulnerability of Atreyee river basin in India and Bangladesh using logistic regression and fuzzy logic approaches. **Ecological Indicators** 98: 251–265. DOI: 10.1016/j.ecolind.2018.11.009.

Santos, R., U.I. Peixoto, W. Medeiros-Leal, A. Novoa-Pabon and M. Pinho. 2022. Growth parameters and mortality rates estimated for seven data-deficient fishes from the azores based on length-frequency data. **Life** 12(6): 778. DOI: 10.3390/life12060778.

Sarkar, U.K., R.S. Negi, P.K. Deepak, S.P. Singh, S.M. Srivastava and D. Roy. 2004. Captive breeding of vulnerable Indian carp *Cirrhinus reba* with Ovaprim for conservation of wild populations. **Aquaculture Asia** 9: 5–7.

Sokal, R.R. and F.J. Rohlf. 1987. **Biostatistics.** Freeman and Co, New York, USA. 301 pp.

Sossoukpe, E., F.K.E. Nunoo, P.K. Ofori-Danson, E.D. Fiogbe and H.R. Dankwa. 2013. Growth and mortality parameters of *P. senegalensis* and *P. typus* (Sciaenidae) in nearshore waters of Benin (West Africa) and their implications for management and conservation. **Fisheries Research** 137: 71–80. DOI: 10.1016/j.fishres.2012.08.020.

Sparre, P. and S. Venema. 1998. **Introduction to Tropical Fish Stock Assessment. Part 1. Manual.** FAO, Rome, Italy. 407 pp.

Talwar, P.K. and A.G. Jhingran. 1991. **Inland Fishes of India and Adjacent Countries.** Oxford-IBH Publishing Co. Pvt. Ltd., New Delhi, India. 1158 pp.

Tidwell, J.H. and G.L. Allan. 2001. Fish as food: aquaculture's contribution. **EMBO Reports** 2(11): 958–963. DOI: 10.1093/embo-reports/kve236.

Tsikliras, A.C., A. Dinouli, V.Z. Tsiros and E. Tsalkou. 2015. The Mediterranean and Black Sea fisheries at risk from overexploitation. **PloS ONE** 10(3): e0121188. DOI: 10.1371/journal.pone.0121188.

Wehye, A.S., P.K. Ofori-Danson and A.M. Lamptey. 2017. Population dynamics of *Pseudotolithus Senegalensis* and *Pseudotolithus Typus* and their implications for management and conservation within the coastal waters of Liberia. **Fisheries and Aquaculture Journal** 8(2): 1–9. DOI: 10.4172/2150-3508.1000201.

Williams-Subiza, E.A. and L.B. Epele. 2021. Drivers of biodiversity loss in freshwater environments: A bibliometric analysis of the recent literature. **Aquatic Conservation: Marine and Freshwater Ecosystems** 31(9): 2469–2480. DOI: 10.1002/aqc.3627.