Population dynamics of *Gudusia chapra* (Hamilton, 1822) from the Kaptai Lake, Bangladesh

Abstract

Aims: This study aimed to assess the population dynamics of *Gudusia chapra* in Kaptai Lake, Bangladesh, utilizing FiSAT software for comprehensive analysis. Key objectives included determining growth parameters, mortality rates, exploitation status, and length-weight relationships.

Study Design: The study employed a quantitative approach, utilizing length frequency data collected from Kaptai Lake. FiSAT software facilitated the estimation of population dynamics parameters, employing the Von Bertalanffy growth equation and other relevant analyses.

Place and Duration of Study: The research was conducted in Kaptai Lake, Bangladesh, focusing on the intricate aquatic ecosystem from November 2003 to October 2004. Data collection and analysis spanned an extensive duration, providing a robust understanding of the population dynamics of *G. chapra*.

Methodology: FiSAT software was utilized for population dynamics estimation, with a particular focus on growth parameters, mortality rates, and exploitation status. The Von Bertalanffy growth equation was applied, and length-weight relationships were determined. Recruitment patterns were observed, and key indices, including the growth performance index, were calculated.

Results: The estimated asymptotic length ($L\infty$) and growth coefficient (K) of *G. chapra* were found to be 19.95 cm and 0.89 year-1, respectively. Natural mortality (M) and fishing mortality (F) rates were determined as 1.85 and 2.21, respectively. The exploitation rate (E) indicated overfishing, with a value of 0.54 exceeding the optimum E (E=0.5). The growth performance index (φ') was calculated as 2.54, and the recruitment pattern was identified during April to July.

Conclusion: The study concludes that *G. chapra* in Kaptai Lake is experiencing overfishing, as indicated by the elevated exploitation rate. Understanding the growth parameters and mortality rates is vital for sustainable fisheries management in the region.

Implication: The findings have significant implications for fisheries management, highlighting the urgent need for measures to mitigate overfishing of *G. chapra* in Kaptai Lake. Implementing

conservation strategies and monitoring recruitment patterns are crucial for ensuring the long-term sustainability of this important fish species.

Keywords: Fisheries management, aquatic ecosystems, von bertalanffy growth equation, exploitation status, fish population assessment

1. INTRODUCTION

Aquatic ecosystems, marked by dynamic interplays of biotic and abiotic factors, are pivotal in sustaining biodiversity and providing essential resources for human sustenance [1]. This importance extends to freshwater ecosystems, which serve as crucial reservoirs of biological diversity, playing pivotal roles in supporting human livelihoods [2,3]. Kaptai Lake in Bangladesh exemplifies one such freshwater system, presenting a dynamic and complex environment shaped by both natural and anthropogenic influences [4–6]. This study focuses on unraveling the population dynamics of *Gudusia chapra* (Hamilton, 1822), colloquially known as Chapila, within this intricate aquatic landscape.

In the context of Bangladesh, the consumption of Chapila, in both its fresh and dried forms, holds considerable cultural and economic significance [7]. The affordability of this fish species has made it a dietary staple for local communities around Kaptai Lake, providing a reliable source of animal protein [8]. Despite the apparent importance of *G. chapra* in the region, comprehensive reports delving into the dynamics of its population are noticeably scarce [9].

This study unfolds against the dynamic nature of the water system within Kaptai Lake. Previous research efforts have highlighted substantial alterations in the ambient water environment, influenced by a combination of natural processes and human interventions [6]. These changes have, in turn, prompted rapid transformations in fishing practices, necessitating a thorough investigation into the current population parameters of *G. chapra* [10].

Beyond immediate concerns related to the commercial and subsistence aspects of Chapila, this study adopts a broader perspective, recognizing the intrinsic value of understanding population dynamics in fisheries management [11]. Life history patterns of fishes, encompassing growth rates, mortality, and recruitment, fundamentally contribute to the establishment of sound management policies for the conservation of fisheries resources [12]. Population dynamics, as a field of study, transcends numerical analysis, encapsulating the intricate interplay of ecological variables governing the sizes, maintenance, decline, and expansion of populations within a specified area over time [13].

In Bangladesh, both fresh and dried Chapila are immensely popular among local communities due to their affordability [14]. Despite the commercial significance of *G. chapra*, there is a noticeable dearth of reports on its population dynamics [10,15]. The dynamic water system of the lake, coupled with substantial changes in the ambient water environment following previous research, has led to rapid alterations in fishing practices [6]. Therefore, it is imperative to investigate the current population parameters of *G. chapra* in light of these environmental changes.

Highlighting the importance of studying population dynamics, this research not only aims to uncover the life history patterns of fishes but also endeavors to contribute to the establishment of robust management policies for the conservation of fisheries resources [13,16]. Understanding population dynamics, defined as a branch of knowledge concerned with the sizes of populations and the factors influencing their maintenance, decline, and expansion, is crucial for informed and sustainable resource management in a specified area over time [13,17].

Our hypothesis is grounded in the understanding that the population dynamics of *G. chapra* in Kaptai Lake are influenced by multifaceted factors. We propose that variations in environmental conditions, coupled with fishing pressures, contribute to fluctuations in the growth, mortality, and recruitment patterns of *G. chapra*. Specifically, we anticipate that environmental changes and anthropogenic activities may have discernible impacts on the overall population structure of *G. chapra*.

We raised some research questions including how do environmental variables, such as water quality and temperature, affect the growth parameters of *G. chapra* in Kaptai Lake? What is the impact of fishing pressures on the mortality rates of *G. chapra*, and how does this contribute to population dynamics? Are there discernible patterns in the recruitment of *G. chapra*, and how do they correlate with environmental conditions and fishing pressures? How have recent environmental changes affected the distribution and abundance of *G. chapra* in different regions of Kaptai Lake?

The study aims to assess the growth parameters of *G. chapra*, including asymptotic length and growth rates. It seeks to determine total, natural, and fishing mortality rates, investigating recruitment patterns and their correlation with environmental variables and fishing pressures. Virtual Population Analysis (VPA) will be employed for understanding age structure and abundance. Length-at-age data analysis will establish relationships such as the length-weight relationship (a, b), contributing to fisheries management and conservation efforts.

2. MATERIALS AND METHODS

2.1.Study area, periods and samples

The study focused on the collection and analysis of *G. chapra* specimens, conducted monthly from November 2003 to October 2004. Sampling was carried out at the BFDC fish landing center in Kaptai, Rangamati, Bangladesh (Figure 1). The collection method involved the utilization of local fishing gear, specifically 'Ghana chapila jal' (small-meshed, 2.5-3.8 cm) and 'Patla Chapila Jal' (larger meshed, 4-5 cm) gill nets. Immediately after collection, the specimens, totaling 2750 throughout the investigation period, were transported to the laboratory at the Institute of Marine Sciences. In the laboratory, random measurements were taken for each specimen, focusing on both total length and total weight. Total length (cm) was measured using a meter scale, extending from the snout to the end of the tail, while total weight (g) was recorded using a Salter Spring Balance.

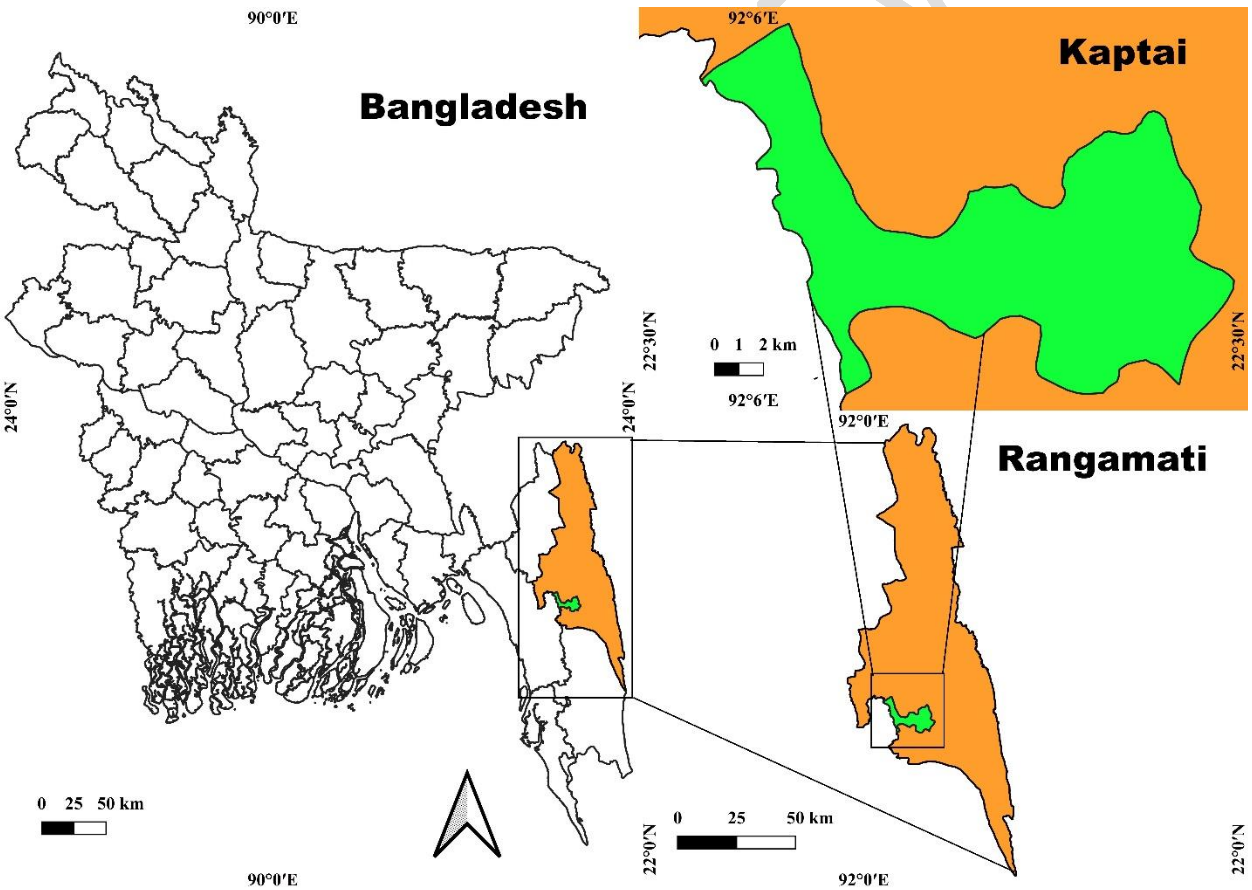

Figure 1. Kaptai Lake in Rangamati, Bangladesh

2.2.Preparation of sample

Following the rinsing of the samples, the total length was measured to the nearest 0.01 cm, extending from the snout to the end of the tail. Subsequently, excess water from the samples was blotted, and the weight of each specimen was measured to the nearest 0.01 gm using a pan balance. Following the length and weight measurements, the specimens were preserved in 10% formalin within plastic containers. All relevant data were meticulously recorded into a computer for subsequent analysis and documentation.

2.3.Statistical analysis

The value of "Asymptotic length" (L_∞) and "Growth constant" (K) were determined by following Von Bertalenffy growth formula [18] using FiSAT software.

$L_t = L_\alpha[1\text{-exp}^{-K\,(t\text{-}to)}]$ -------------------------------------- (1)

Where,

L_t = Length at time t

L_∞ = Asymptotic length

K = Growth constant

t_o = Length at time zero (here t_o is 0)

From equation no (1) we get $L_n\,(1-\frac{L_t}{L_\infty}) = -K_{to} + K_{t;}$ this equation is of a linear form and Ln $(1-\frac{L_t}{L_\infty})$ was plotted against age t. The value of the slope b = -k.

Lα was determined by plotting the value of K, t, and t_o (t_0= 0).

The total mortality (Z) was estimated applying the length based catch curve using cohort analysis by FiSAT program [19].

$L_n(N_i/\Delta t_i) = a + b\, t_i$

Where, N_i = number of fish in length class i

t_i = age corresponding to the mid length of class i (t_0= 0).

Δt_i = time needed for the fish to grow through length class i

a = intercept

b = slope = -Z

The value of natural mortality (M) was determined by using the Pauly's "M" empirical equation which was established by Pauly [18]. The formula is-

$Log_{10}M = -0.0066- 0.279\, log_{10}\, L\alpha + 0.6543\, log_{10}\, K + 0.4634\, log_{10}\, T$ --------- (2)

Here,

M =Natural mortality

$L_{\propto}$= Asymptotic length

K= Growth constant

T= Mean annual habitat temperature (T = 27 ^{o}C).

From the equation (2) the natural mortality (M) was determined by putting the value of $L_{\propto}$, K and T in the equation.

Fishing mortality (F) was determined by subtracting Natural mortality (M) from total mortality (Z).

The exploitation rate (E) of the fish *G. chapra* was determined by using the Gulland [20] exploitation value formula. It states that,

$$E = \frac{F}{Z} \text{ ----------- (3)}$$

Or

$$[E= \frac{F}{Z} = \frac{F}{F+M}]$$

Where,

E= exploitation rate

F = fishing motility

Z = total mortality

The growth increment of a fish stock is determined by using the Gulland [20] method . The growth increment is derived from the successive length. It followed the following formula—

$$\frac{\Delta l}{\Delta t} = a+b\,L^{/} \text{ -------- (4)}$$

Where,

$(\frac{\Delta l}{\Delta t})$ =Growth increment

a= Intercept

b= slope

L' = mid length

The recruitment pattern was obtained by backward projection on the length axis of a set of length frequency data according to the routine ELEFAN I, program.

The estimation of "Probability of capture" was found out by using routine ELEFAN I. The probability of capture by length was determined by extracting the catch curve and calculating the number of fish that would have been caught (Pauly 1984). The calculations were carried out by using the FiSAT program.

Popes cohort analysis (1972) was followed for Virtual Population Analysis with a slight modification by FiSAT program.

Length–weight relationship was estimated by following cube formula [21],

$$W = aL^{b} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

Where,

a = constant

n = an exponent

W= weight

L = corresponding length of the weight (Total length)

The value of 'a' and 'b' was calculated according to the following formula [22]

$$b = \frac{N \times \Sigma XY - \Sigma X \times \Sigma Y}{N \times \Sigma X^{2} - (\Sigma X)^{2}}$$

$$a = Y - bX$$

3. RESULTS

The asymptotic length (Lα) and growth co-efficient (K) values for *G. chapra* were obtained 19.95 cm and 0.89 $year^{-1}$ respectively by K-scan of ELEFAN-1 (Figure 2).

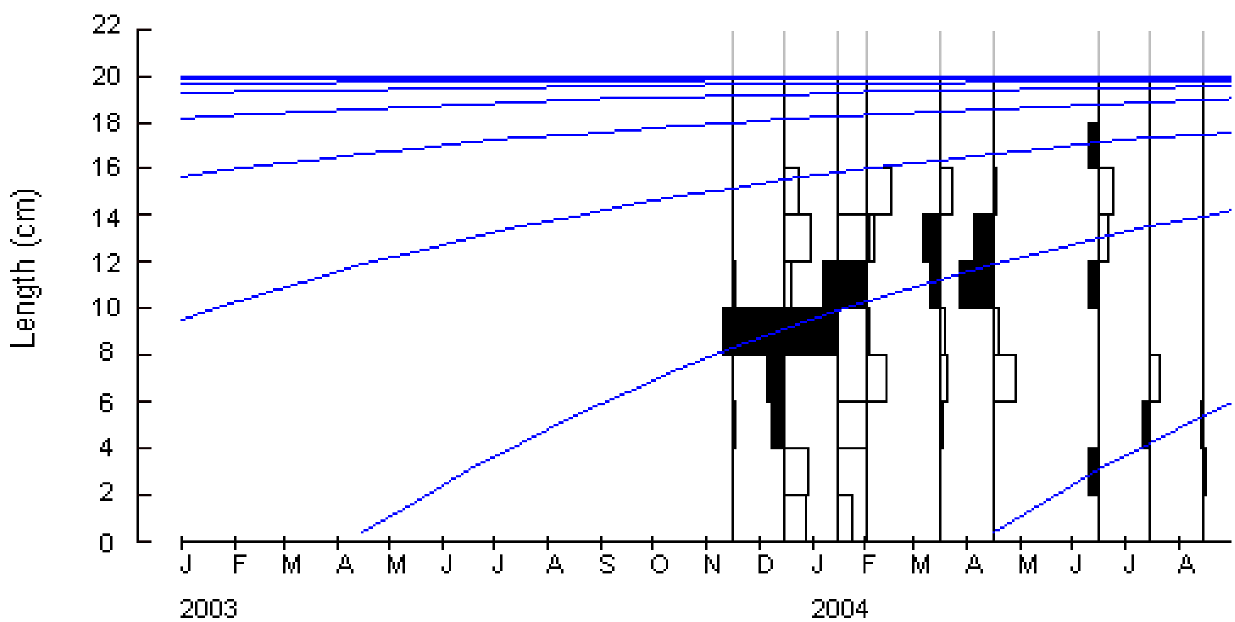

Figure 2. Von Bertallanfy growth function plot and length frequencies of *Gudusia chapra* [Asymptotic length(L_∞) =19.95 cm, & VBGF growth constant(K)=0.89]

The Lα and Z/K values for *G. chapra* were obtained 18.6 cm and 3.58 cm respectively by powell and Wetherall plot (Figure 3).

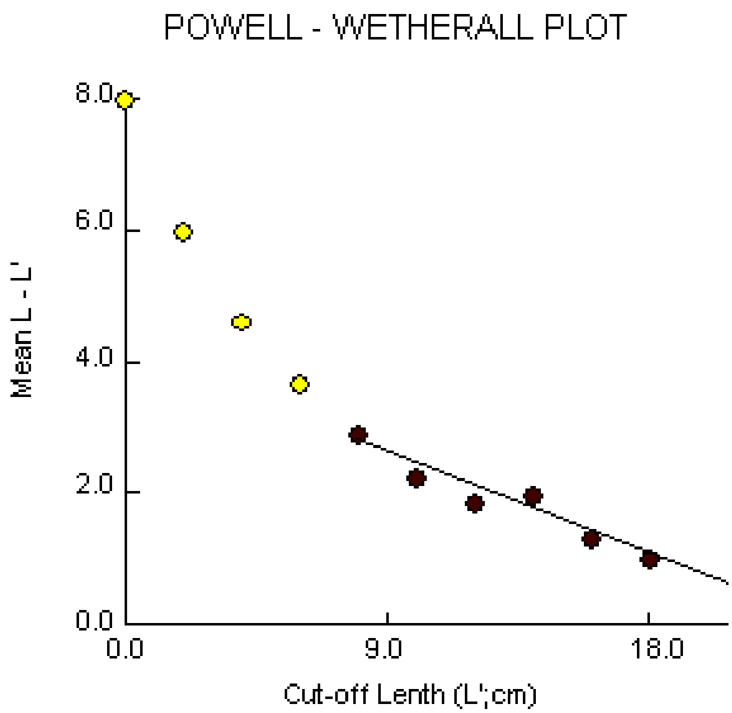

Figure 3. Estimation of L_∞ and Z/K using the methods of Wetherall plot for *Gudusia chapra*

The total mortality (Z) for *G. chapra* was obtained 4.06 year-^{1} by length converted catch curve. The natural mortality (M) rate was obtained 1.85 year^{-1} by Pauly's empirical equation. Fishing mortality (F) was found 2.21 year^{-1}. The E values for *G. chapra* was found 0.54 (Figure 4).

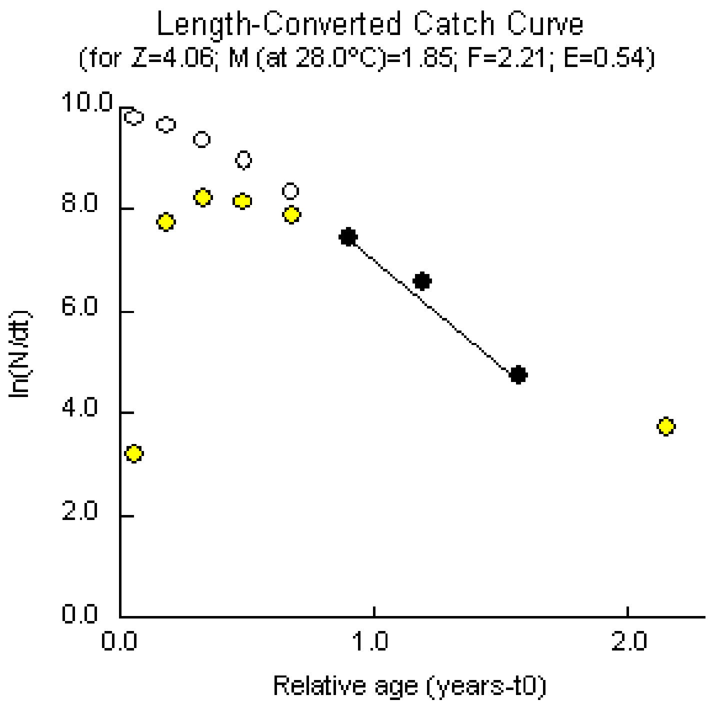

Figure 4. Length-converted catch curve of *Gudusia chapra* for estimation of total mortality

Using ELEFAN-1, *G. chapra* recruited all-round the year in the fishery, with the peak during April-July every year (Figure 5).

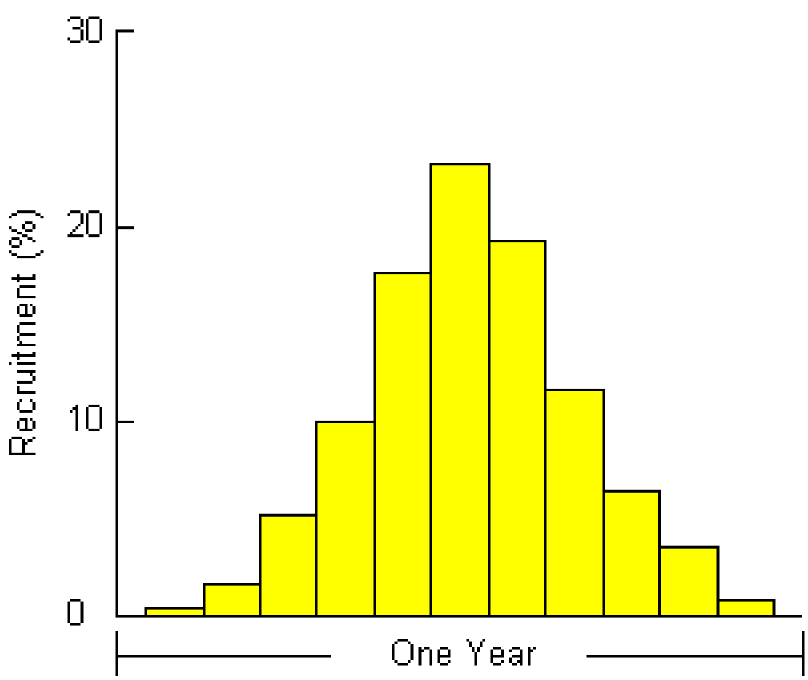

Figure 5. Recruitment pattern of *Gudusia chapra*

The Growth performance index (φ′) of *G. chapra* was found 2.54 cm (Figure 6).

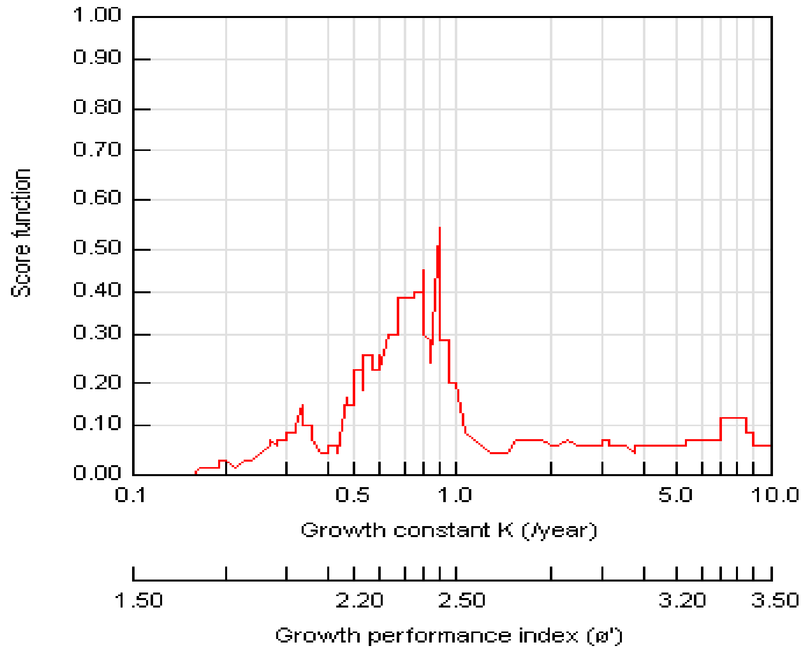

Figure 6. Growth performance index of *Gudusia chapra*

L_{25}, L_{50} and L_{75} values for *G. chapra* were found -1.73 cm, 1.05 cm and 3.83 cm respectively (Figure 7).

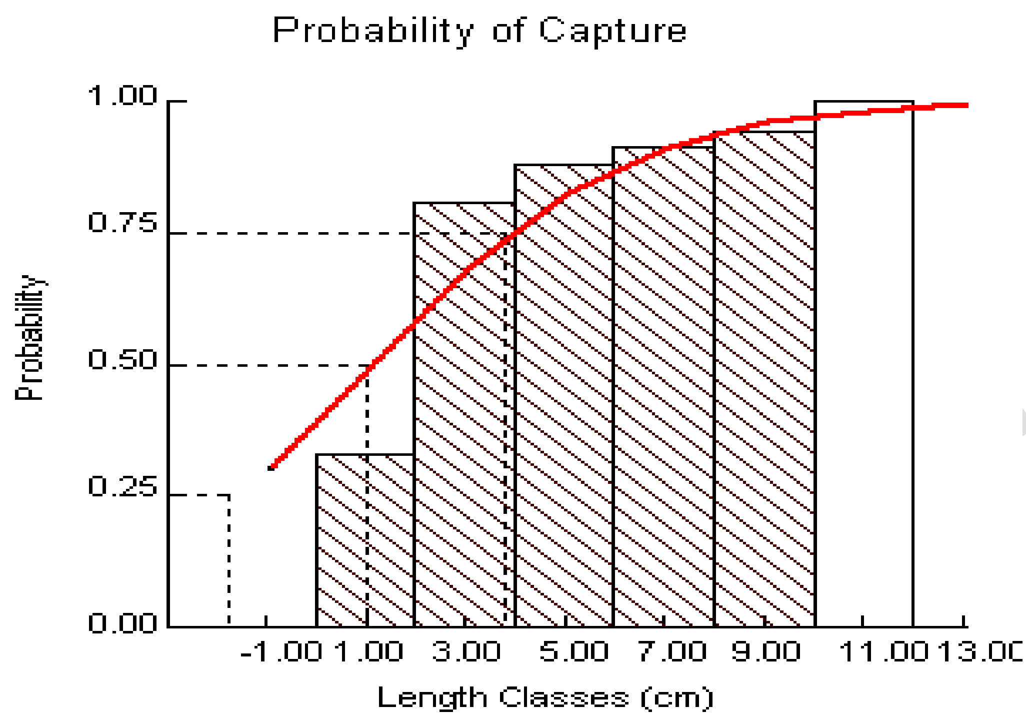

Figure 7. Selection pattern of *Gudusia chapra*

From VPA analysis showed that the maximum fishing mortality of *G. chapra* occurred at the length range between 11 and 12 cm. The maximum abundance was found 6433.10 (in number) at the length class of 2 to 3 cm. Maximum catch (385, in number) was found in the length class between 5 and 6 cm (Figure 8 and Table 1).

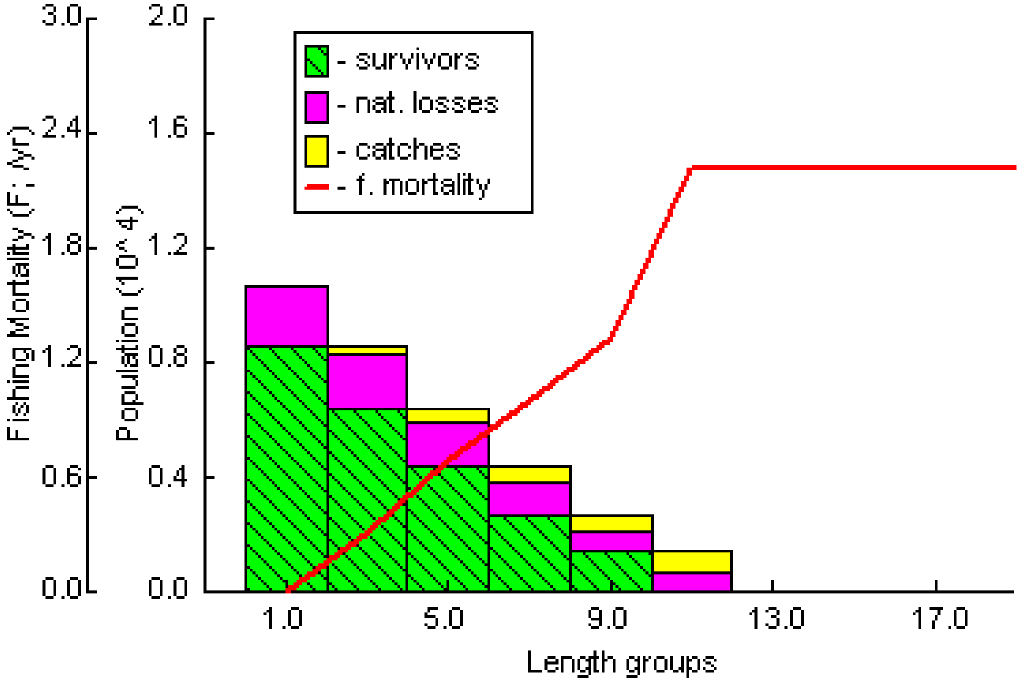

Figure 8. Length structured virtual population analysis of *Gudusia chapra* in the Kaptai Lake, Bangladesh

Table 1. Value obtained by Virtual Population Analysis (VPA)

Length classes (cm)	Population (N)	Fishing mortality (yr^{-1})
2-3	6433.10	0.0894
3-4	5538.86	0.5539
4-5	4585.64	1.2773
5-6	3566.10	1.8358
6-7	2600.81	1.9984
7-8	1806.73	1.7992
8-9	1217.94	1.9475
9-10	762.83	2.2070
10-11	427.03	2.3220
11-12	207.87	2.5825
12-13	79.44	1.9934
13-14	24.51	1.4915
14-15	4.53	2.1900

The predicted extreme length of *G. chapra* was obtained 20.95. At 95% confidence level, the range of extreme length varies from 17.04 cm to 24.85 cm (Figure 9).

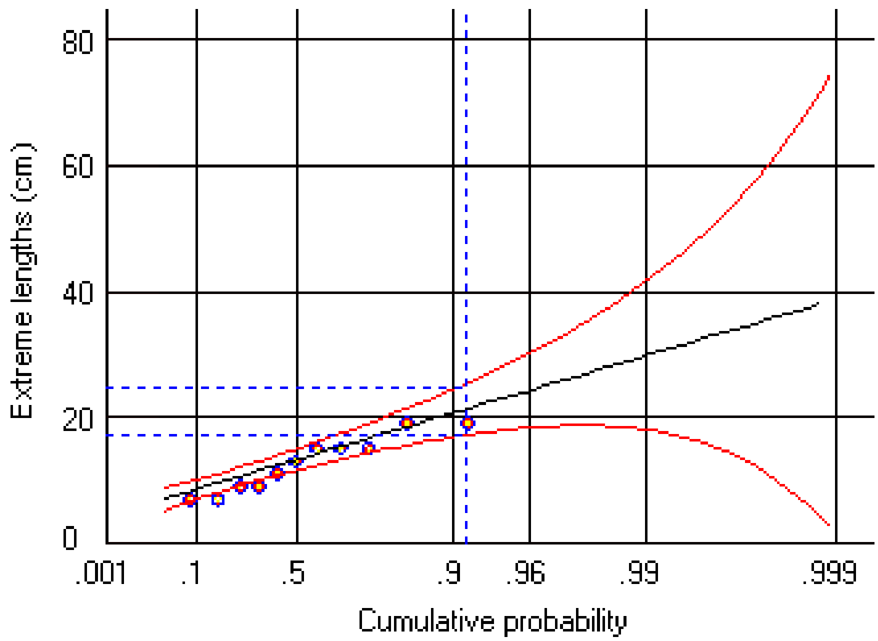

Figure 9. Predicted extreme length of *Gudusia chapra*

The age-length key of *G. chapra* illustrates a positive correlation between age and length, indicating a typical growth pattern for the species. Initial ages exhibit gradual increases in length, suggesting steady growth in the early stages, with a notable acceleration in length as age progresses beyond one year. This trend suggests a phase of more rapid growth until approximately age three, after which the rate of increase in length stabilizes, implying a potential asymptotic growth pattern (Figure 10).

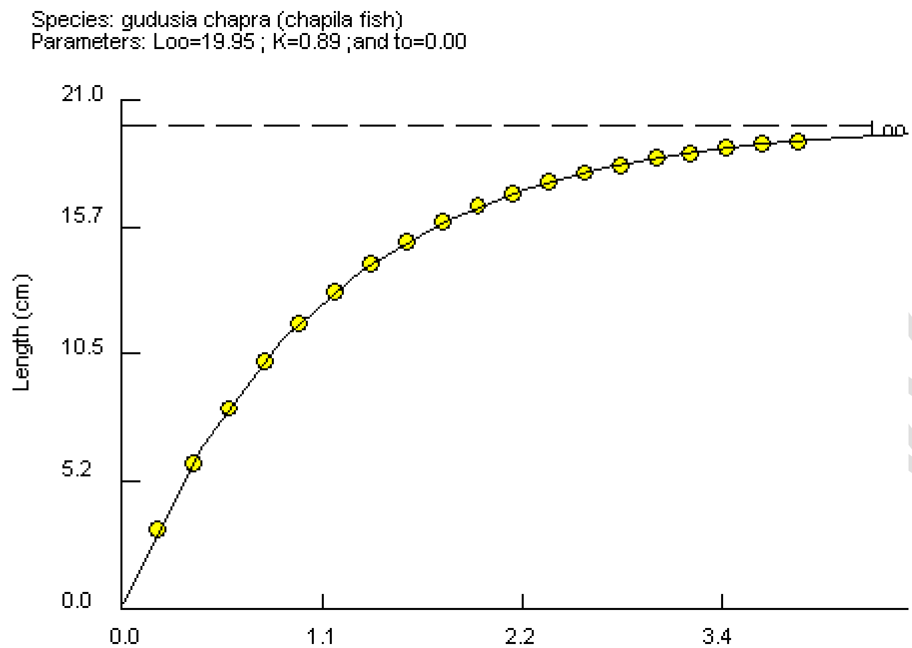

Figure 10. Length-at-age growth analysis

The calculated 'a' and 'b' values for length-weight relationship were found -0.023498 and 0.972016 respectively. The logarithmic form of the equation stands as, log W = -0.023498+ 0.972016 log L. Hence the exponential form of length-weight relationship was, W= -0.0235 $L^{0.972}$ (Figure 11).

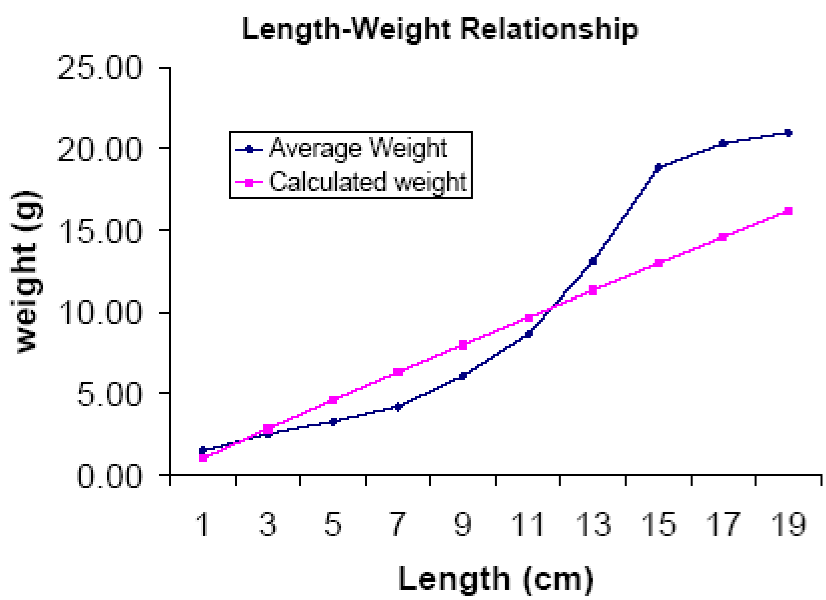

Figure 11. Length-weight relationship of *Gudusia chapra* in Kaptai Lake, Bangladesh

If an animal is growing isometrically (increasing in all dimensions at the same rate) and doubles in lengths, its weight will increase in relation to the increase in volume, that is by 8 (or 2^3) times. Thus by cube relationship theory growth will be isometric when ‘b’ is closed to 3. The value of ‘b’ in this study was distinctly lower than 3, which indicates that the growth of *G. chapra* is not isometric. The average relative condition factor was found 1.08, which was very much close to 1. But when the length class wise relative condition factor was observed it shows a wide range of deviations (Table 2).

Table 2. Length–weight relationship and relative condition factor (RCF) in different size groups of *Gudusia chapra*

Mid length	Avg. weight	LnL	InW	CalLnW	CalW	LnL2	LnL×LnW	RCF
1	1.50	0.00	0.41	0.01	1.01	0.00	0.00	1.48
3	2.54	1.10	0.93	1.05	2.85	1.21	1.02	0.89
5	3.31	1.61	1.20	1.53	4.61	2.59	1.92	0.72
7	4.20	1.95	1.44	1.84	6.33	3.79	2.79	0.66
9	6.09	2.20	1.81	2.08	8.01	4.83	3.97	0.76
11	8.66	2.40	2.16	2.27	9.68	5.75	5.18	0.90
13	13.08	2.56	2.57	2.43	11.32	6.58	6.59	1.15
15	18.83	2.71	2.94	2.56	12.95	7.33	7.95	1.45
17	20.32	2.83	3.01	2.68	14.57	8.03	8.53	1.39
19	21	2.94	3.04	2.78	16.18	8.67	8.96	1.30

The population parameters of *G. chapra* were assessed, revealing an asymptotic length ($L\alpha$) of 19.95 cm and a growth coefficient (k) of 0.89 year^{-1}. The Powell-Wetherall Plot yielded a $L\alpha$ of 18.6 cm and a Z/K ratio of 3.58. Total mortality (Z) was calculated at 4.06 year^{-1}, with natural mortality (M) and fishing mortality (F) recorded at 1.85 year^{-1} and 2.21 year^{-1}, respectively. The exploitation rate (E) was determined to be 0.54, and the length at first capture (Lc) stood at 2.43 cm. The growth parameter index (φ′) was computed as 2.54, and the length-weight relationship was expressed as $W = -0.0235 L^{0.97_2}$. *G. chapra* exhibited a length range from 1 to 19 cm (Table 3).

Table 3. Population parameters of *Gudusia chapra*

Parameters	Evaluation
Asymptotic length (Lα)	19.95 cm
Growth coefficient (k)	0.89 year^{1}
Lα (powell-wetherall plot)	18.6 cm
Z/K(powell-wetherall plot)	3.58
Total mortality (Z)	4.06 year^{1}

Natural mortality (M)	1.85 year^{1}
Fishing mortality (F)	2.21 year^{1}
Exploitation rate (E)	0.54
Length at first capture (Lc)	2.43 cm
Growth parameter index (φ′)	2.54
Length-weight relationship	$W=-0.0235L^{0.972}$
Length range	1-19 cm

4. DISCUSSION

The comprehensive analysis of *G. chapra* population dynamics in Kaptai Lake provides valuable insights into the species' ecological and fishery aspects. The study delved into the population dynamics of *G. chapra*, a key species in the multi-species, multi-gear fishery of Kaptai Lake, Bangladesh. Clupeids, including *G. chapra*, constituted a significant portion, contributing 50% to the total catch [9,23].

The Von Bertalanffy growth formula revealed an asymptotic length (Lα) of 19.95 cm and a growth coefficient (K) of 0.89 year^{-1}, obtained through K-scan of ELEFAN-I. These parameters were critical in understanding the growth dynamics of *G. chapra* in the lake ecosystem [24,25]. The slight variations observed in Lα and K values using different methods in the FiSAT program were addressed, with emphasis placed on the accuracy of the K-scan method in determining asymptotic length [26].

The mortality rates, a key indicator of population health, were thoroughly examined. Total mortality (Z) at 4.06 year^{-1}, natural mortality (M) estimated through Pauly's empirical equation at 1.85 year^{-1}, and fishing mortality (F) at 2.21 year^{-1} highlighted the complex interplay of natural and anthropogenic factors influencing *G. chapra* survival [27]. The calculated exploitation rate (E) of 0.54 using Gulland's formula suggested an overfishing pressure on the *G. chapra* stock in Kaptai Lake [28].

The intricate relationship between fishing practices and population structure emerged from the length structure virtual population analysis [29]. Peaks in fishing mortality at specific length ranges, notably at 6-7 cm and 11-12 cm, were attributed to the extensive use of specific fishing gear, underscoring the need for sustainable fishing practices [30]. This observation aligns with the broader concern of overfishing, particularly evident in the rapid increase in fishing mortality rates over recent years.

The study further explored the length-weight relationship of *G. chapra*, revealing a calculated 'a' of -0.023498 and 'b' of 0.972016. The isometric growth expectation, indicated by a value of 0.972 for the growth parameter 'n,' was not observed, suggesting a non-isometric growth pattern in the species. These findings contribute to our understanding of the species' morphometric relationships and growth patterns [31].

Lastly, the Gulland and Holt Plot emphasized an inverse relationship between growth rate and length, indicating that as length increases, the growth rate decreases. This insight is crucial for fisheries management, highlighting the need for size-specific conservation strategies to maintain a healthy *G. chapra* population in Kaptai Lake [32]. Overall, this comprehensive analysis provides a foundation for informed decision-making in fisheries management, considering both ecological and anthropogenic factors influencing *G. chapra* dynamics in Kaptai Lake [8,33].

5. CONCLUSIONS

The finding of this present study provided a comprehensive overview of the population dynamics of *G. chapra* in Kaptai Lake, underscoring the need for sustainable fisheries management practices to ensure the continued abundance of this vital species. The results serve as a valuable foundation for informed decision-making and conservation efforts aimed at maintaining the ecological balance and economic viability of the fishery in the region.

References

1. Pandey, B.; Ghosh, A. Urban ecosystem services and climate change: a dynamic interplay. *Front. Sustain. Cities* **2023**, *5*, 1281430, doi:10.3389/frsc.2023.1281430.
2. Dudgeon, D.; Arthington, A.H.; Gessner, M.O.; Kawabata, Z.; Knowler, D.J.; Lévêque, C.; Naiman, R.J.; Prieur-Richard, A.; Soto, D.; Stiassny, M.L.J.; et al. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biol. Rev.* **2006**, *81*, 163–182, doi:10.1017/S1464793105006950.
3. Cantonati, M.; Poikane, S.; Pringle, C.M.; Stevens, L.E.; Turak, E.; Heino, J.; Richardson, J.S.; Bolpagni, R.; Borrini, A.; Cid, N.; et al. Characteristics, main impacts, and stewardship of natural and artificial freshwater environments: Consequences for biodiversity conservation. *Water (Switzerland)* **2020**, *12*, 1–85, doi:10.3390/w12010260.

4. Rabina Akther, L.; Azhar, A.; Md Khaled, R.; Md Shoebul, I.; Md, M.; Tamina Akhtar, T. An overview on hydro-biology and management of Kaptai Lake Fisheries, Bangladesh. *Int. J. Aquac. Fish. Sci.* **2023**, *9*, 029–039, doi:10.17352/2455-8400.000089.
5. Karmakar, S.; Sirajul Haque, S.M.; Mozaffar Hossain, M.; Shafiq, M. Water quality of Kaptai reservoir in Chittagong Hill Tracts of Bangladesh. *J. For. Res.* **2011**, *22*, 87–92, doi:10.1007/s11676-011-0131-6.
6. Haque, M.A.; Nabi, M.R.U.; Billah, M.M.; Asif, A. Al; Rezowan, M.; Mondal, M.A.I.; Siddiqui, A.A.M.; Mahmud, S.S.; Khan, M.R. Effect of water parameters on temporal distribution and abundance of zooplankton at Kaptai lake reservoir, Rangamati, Bangladesh. *Asian J. Med. Biol. Res.* **2018**, *4*, 389–399, doi:10.3329/ajmbr.v4i4.40112.
7. Bogard, J.R.; Thilsted, S.H.; Marks, G.C.; Wahab, M.A.; Hossain, M.A.R.; Jakobsen, J.; Stangoulis, J. Nutrient composition of important fish species in Bangladesh and potential contribution to recommended nutrient intakes. *J. Food Compos. Anal.* **2015**, *42*, 120–133, doi:10.1016/j.jfca.2015.03.002.
8. Shalehin, M..; Naher, S.; Galib, S.M. Fishes of Kaptai Lake: management and conservation perspectives. *J. Life Earth Sci.* **2020**, *15*, 53–58.
9. RAHMAN, M.A.; HAQUE, M.M. Population dynamics and stock assessment of Gudusia chapra (Hamilton-Buchanan) in the Rajdhala reservoir, Netrakona, Bangladesh. *Asian Fish. Sci.* **2006**, *19*, 281–292, doi:10.33997/j.afs.2006.19.3.008.
10. Sarkar, U.K.; Johnson, C.; Kumari, S.; Bakshi, S.; Karnatak, G.; Das Ghosh, B.; Lianthuamluaia, M.P.; Das, B.K. Population dynamics of Indian river shad Gudusia chapra (Hamilton, 1822) using length frequency analysis for fisheries management in a floodplain wetland of Ganga River Basin, India. *Lakes Reserv. Sci. Policy Manag.*

Sustain. Use **2021**, *26*, e12365, doi:10.1111/lre.12365.

11. Hossain, M.A.R. An overview of fisheries sector of Bangldesh. *Res. Agric. Livest. Fish.* **2014**, *1*, 109–126.
12. Khatun, D.; Hossain, M.Y.; Rahman, O.; Hossain, M.F. Estimation of life history parameters for river catfish Eutropiichthys vacha: insights from multi-models for sustainable management. *Heliyon* **2022**, *8*, e10781, doi:10.1016/j.heliyon.2022.e10781.
13. Gebremedhin, S.; Bruneel, S.; Getahun, A.; Anteneh, W.; Goethals, P. Scientific methods to understand fish population dynamics and support sustainable fisheries management. *Water* **2021**, *13*, 574, doi:10.3390/w13040574.
14. Nadia, Z.M.; Roy, P.; Hossain, J.; Hossain, M.F.; Rahman, M.; Salam, M.A.; Jahan, R. Fish availability and market channel in Rajbari, Bangladesh. *Heliyon* **2022**, *8*, e10526, doi:10.1016/j.heliyon.2022.e10526.
15. Khatun, M.H.; Zahangir, M.M.; Akhter, B.; Parvej, M.R.; Liu, Q. Clupeids in the kaptai reservoir, a blessing or a curse: estimation of fisheries reference points. *Heliyon* **2023**, *9*, e13818, doi:10.1016/j.heliyon.2023.e13818.
16. Cadrin, S.X. Defining spatial structure for fishery stock assessment. *Fish. Res.* **2020**, *221*, 105397, doi:10.1016/j.fishres.2019.105397.
17. Cooke, S.J.; Fulton, E.A.; Sauer, W.H.H.; Lynch, A.J.; Link, J.S.; Koning, A.A.; Jena, J.; Silva, L.G.M.; King, A.J.; Kelly, R.; et al. Towards vibrant fish populations and sustainable fisheries that benefit all: learning from the last 30 years to inform the next 30 years. *Rev. Fish Biol. Fish.* **2023**, *33*, 317–347, doi:10.1007/s11160-023-09765-8.
18. Pauly, D.; Martosubroto, P. The population dynamics of Nemipterus marginatus (Cuvier & Val.) off Western Kalimantan, South China Sea. *J. Fish Biol.* **1980**, *17*, 263–273,

doi:10.1098/rstb.1990.0187.

19. Gayanilo Jr, F.C.; Soriano, P.; Pauly, D. *The FAO-CLARM Stock Assessment Tools (FiSAT) User guide. FAO Computerised Information Series (Fisheries)*; 8th ed.; FAO: Rome, 1996;

20. Gulland, J.A. *The fish resources of the ocean: Fishing News (Book)*; Farnham, 1971;

21. Ferdous Jerin, J.; Akther, S.; Debnath, J.; Saha, D. Length-weight relationships and vondition factor of four threatened riverine catfish species in the Meghna River Estuary, Bangladesh. *J. Appl. Ichthyol.* **2023**, *2023*, 1–4, doi:10.1155/2023/6651843.

22. Salvatore, D.; Reagle, D. *Theory and problems of statistics and econometrics*; McGraw-Hill, Ed.; McGraw-Hill Companies: New York, 2002;

23. Ahmed, K.K.U.; Rahman, S.; Ahammed, S.U. Managing fisheries resources in Kaptai reservoir, Bangladesh. *Outlook Agric.* **2006**, *35*, 281–289, doi:10.5367/000000006779398281.

24. Tonie, N.; Idris, M.H.; Al-Asif, A.-; Wan Hussin, W.M.R.; Kamal, A.H.M. Population characteristics of the Japanese threadfin bream Nemipterus japonicus (Bloch, 1791) (Actinopterygii: Nemipteridae) at Bintulu coast, Sarawak, South China Sea. *Acta Zool. Bulg.* **2023**, *75*, 273–283.

25. AMIN, S.M.N.; RAHMAN, M.A.; HALDAR, G.C.; MAZID, M.A.; MILTON, D.A. Catch per unit effort, exploitation level and production of Hilsa Shad in Bangladesh waters. *Asian Fish. Sci.* **2008**, *21*, 175–187, doi:10.33997/j.afs.2008.21.2.004.

26. Uddin Ahmed, M.B.; Ahammad, A.K.S.; Shahjahan, M.; Rabbi, M.F.; Ashraful Alam, M.; Sakib, M.N.; Bashar, M.A.; Rahman, M.A.; Hossain, M.Y.; Mahmud, Y. Age, growth and maturity of the Indian Shad, Tenualosa ilisha through otolith examination from different

habitats in Bangladesh. *Egypt. J. Aquat. Biol. Fish.* **2020**, *24*, 343–359, doi:10.21608/ejabf.2020.119368.

27. Todd Howell, E. The aquatic environment of Parry Sound, a deep-water embayment complex of Georgian Bay protected from Dreissena. *J. Great Lakes Res.* **2023**, *49*, 651–671, doi:10.1016/j.jglr.2023.03.015.

28. Adams, C.F.; Alade, L.A.; Legault, C.M.; O'Brien, L.; Palmer, M.C.; Sosebee, K.A.; Traver, M.L. Relative importance of population size, fishing pressure and temperature on the spatial distribution of nine Northwest Atlantic groundfish stocks. *PLoS One* **2018**, *13*, e0196583, doi:10.1371/journal.pone.0196583.

29. Guan, W.; Cao, J.; Chen, Y.; Cieri, M. Impacts of population and fishery spatial structures on fishery stock assessment. *Can. J. Fish. Aquat. Sci.* **2013**, *70*, 1178–1189, doi:10.1139/cjfas-2012-0364.

30. Selgrath, J.C.; Gergel, S.E.; Vincent, A.C.J. Shifting gears: Diversification, intensification, and effort increases in small-scale fisheries (1950-2010). *PLoS One* **2018**, *13*, e0190232, doi:10.1371/journal.pone.0190232.

31. MR, C.; MAB, S. Morphometric parameters and allometric growth in paradise threadfin Polynemus paradiseus (Linnaeus, 1758) from a coastal River of Bangladesh. *J. Aquac. Res. Dev.* **2016**, *07*, 3, doi:10.4172/2155-9546.1000417.

32. Gubiani, É.A.; Gomes, L.C.; Agostinho, A.A. Estimates of population parameters and consumption/biomass ratio for fishes in reservoirs, Paraná State, Brazil. *Neotrop. Ichthyol.* **2012**, *10*, 177–188, doi:10.1590/S1679-62252012000100017.

33. Rayhan, N.; Schneider, P.; Islam, M.S.; Rashid, A.; Mozumder, M.M.H.; Hossain, M.M.; Begum, A.; Shamsuzzaman, M.M. Analyses of protection and conservation according to

the Fish Act 1950 in Bangladesh's Kaptai Lake fisheries management. *Water* **2021**, *13*, 2835, doi:10.3390/w13202835.