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

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study aimed to assess the population dynamics of *Gudusia chapra* in Lake Kaptai, Bangladesh, utilizing FiSAT II software for comprehensive analysis. The key objective was to determine growth parameters, mortality rates, exploitation status, and length-weight relationships to inform policy.
Study Design: The study employed a quantitative approach, utilizing length frequency data collected from Lake Kaptai. FiSAT II 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 Lake Kaptai, 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*.

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Methodology: FiSAT II software was utilized for population dynamics estimation, with a particular focus on growth parameters, mortality rates, and exploitation status using Von Bertalanffy growth equation. Length-weight relationships were also determined. Recruitment patterns were observed, and key indices, including the growth performance index 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), fishing mortality (F) and total mortality (Z) rates were 1.85, 2.21 and 4.06 $year^{-1}$ respectively. The exploitation rate (E) indicated overfishing, with a value of 0.54, which exceeded the optimum E (E=0.5). The growth performance index (φ´) of 2.54 was recorded, and the recruitment pattern occurred between April and July.
Conclusion: The study concludes that *G. chapra* in Lake Kaptai 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 Lake Kaptai. 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]. Lake Kaptai in Bangladesh exemplifies one such freshwater system, presenting a dynamic and complex environment that is 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 *G. chapra* (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 food for local communities around Lake Kaptai, 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 Lake Kaptai. 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 *G. chapra* 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 *G. chapra* 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 *G. chapra* 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 Lake Kaptai 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 Lake Kaptai? 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 Lake Kaptai?

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) was employed for understanding age structure and abundance. Length-at-age data analysis established 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 Bangladesh Fisheries Development Corporation (BFDC) fish landing center in Lake Kaptai, Rangamati, Bangladesh (Fig. 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 (Length × width = 100 m × 1 m). Immediately after collection, the specimens, totaling 2750 throughout the investigation period, were transported to the laboratory at the Institute of Marine Sciences, University of Chittagong, Bangladesh. 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 (Salter Brecknell Model 12, India).

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 Data Collection and Statistical Analysis

The value of “Asymptotic length” ($L_\propto$) and “Growth constant” (K) were determined by following Von Bertalenffy growth formula [18] using FiSAT software.

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

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- $\frac{L_t}{L_\propto}$) = -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 by applying the length based catch curve using cohort analysis by FiSAT program [19].

$$L_n(N_i/\Delta t_i) = a + b\ t_i \text{------------------------------}(x)$$

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:

$$\text{Log } M = -0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.4634 \log T \text{ -------------------------------- } (2)$$

Where,

M =Natural mortality
L_∞= Asymptotic length
K= Growth constant
T= Mean annual habitat temperature (T = 28 ^{o}C) (calculated through secondary data)

From the equation (2) the natural mortality (M) was determined by putting the value of L_∞, 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:

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

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],

$$W = aL^b \text{ ……………………………..…… } (5)$$

Where,

a = constant
n = an exponent
W= weight
L = corresponding length of the weight (Total length)

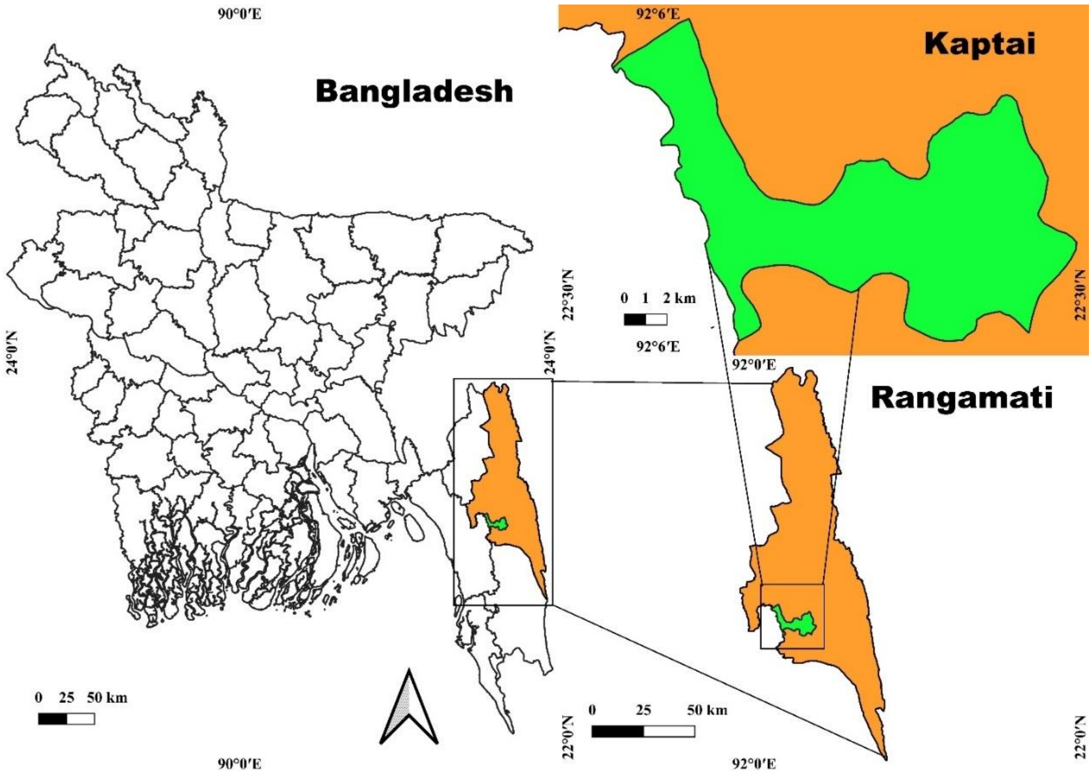

Fig. 1. Lake Kaptai in Rangamati, Bangladesh

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 (L_∞) and growth co-efficient (K) values for *G. chapra* were 19.95 cm and 0.89 year-^{1} respectively (Fig. 2).

The Lα and Z/K values for G. chapra, obtained through Powell and Wetherall plot, were 18.6 cm and 3.58 cm, respectively (Fig. 3).

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

G. chapra recruited all-round the year in the fishery, with the peak during April-July every year (Fig. 5).

The Growth performance index (φ´) of *G. chapra* was 2.54 cm (Fig. 6).

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

The maximum fishing mortality of *G. chapra* occurred at the length range between 11 and 12 cm. The maximum abundance was found to be 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 (Fig. 8 and Table 1).

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

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 (Fig. 10).

The calculated 'a' and 'b' values for length-weight relationship were found to be -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 $L^{0.972}$ (Fig. 11).

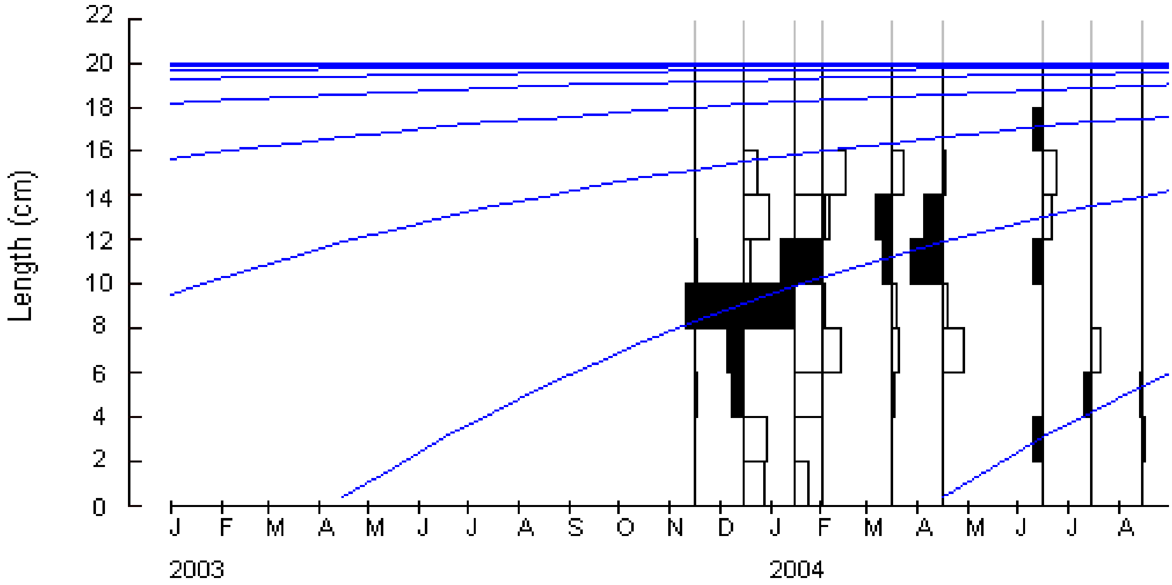

Fig. 2. Von Bertallanfy growth function plot and length frequencies of *Gudusia chapra* [Asymptotic length (L_∞) = 19.95 cm, & VBGF growth constant (K) = 0.89]

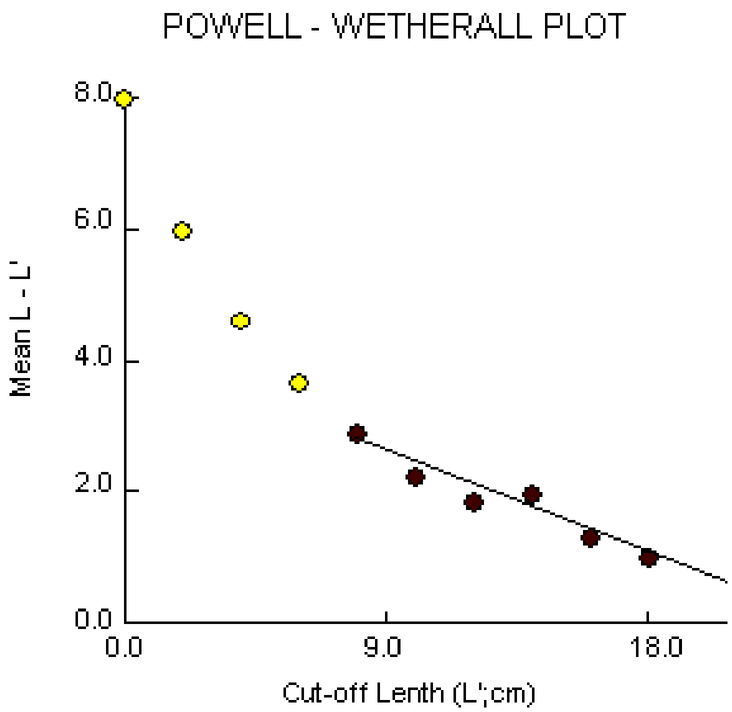

Fig. 3. Estimation of L_∞ and Z/K using the methods of Wetherall plot for *Gudusia chapra*

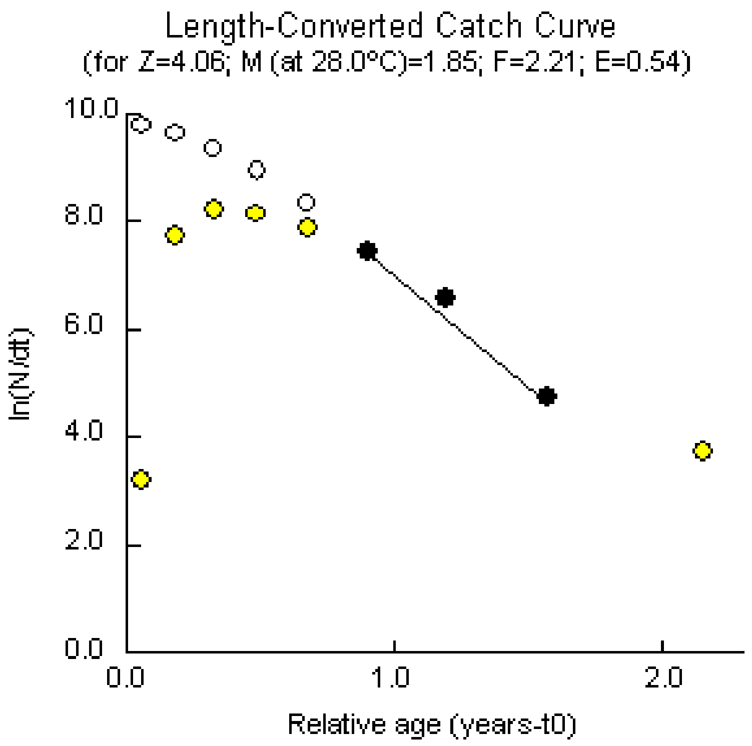

Fig. 4. Length-converted catch curve of *Gudusia chapra* for estimation of total mortality

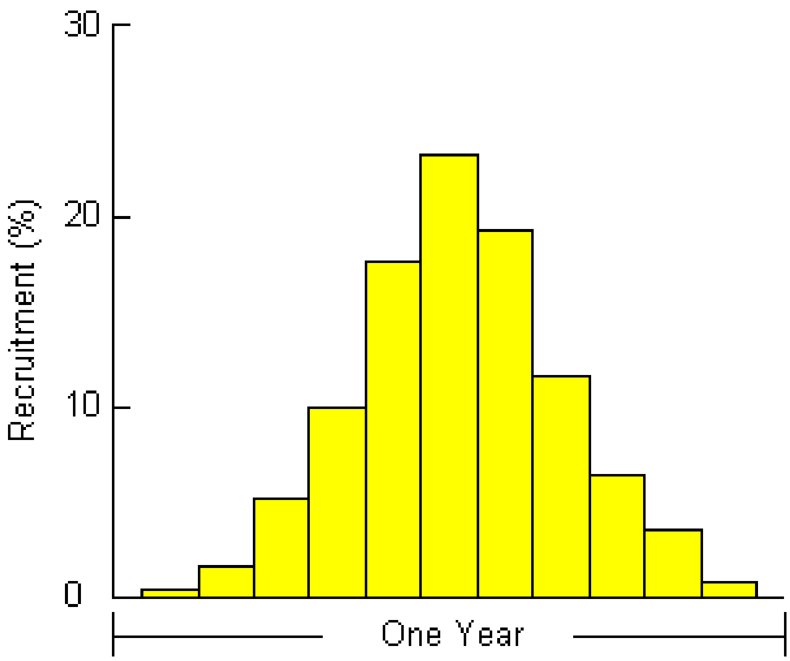

Fig. 5. Recruitment pattern of *Gudusia chapra*

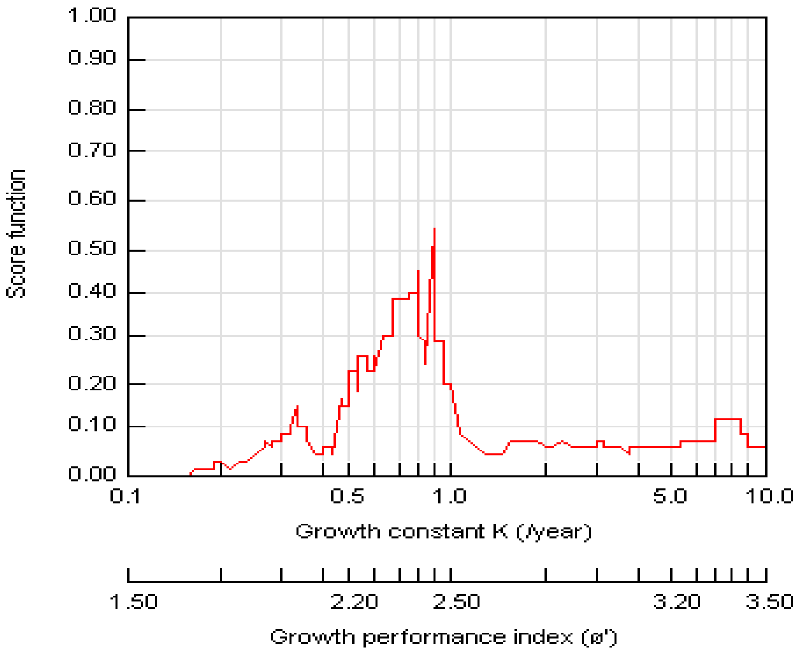

Fig. 6. Growth performance index of *Gudusia chapra*

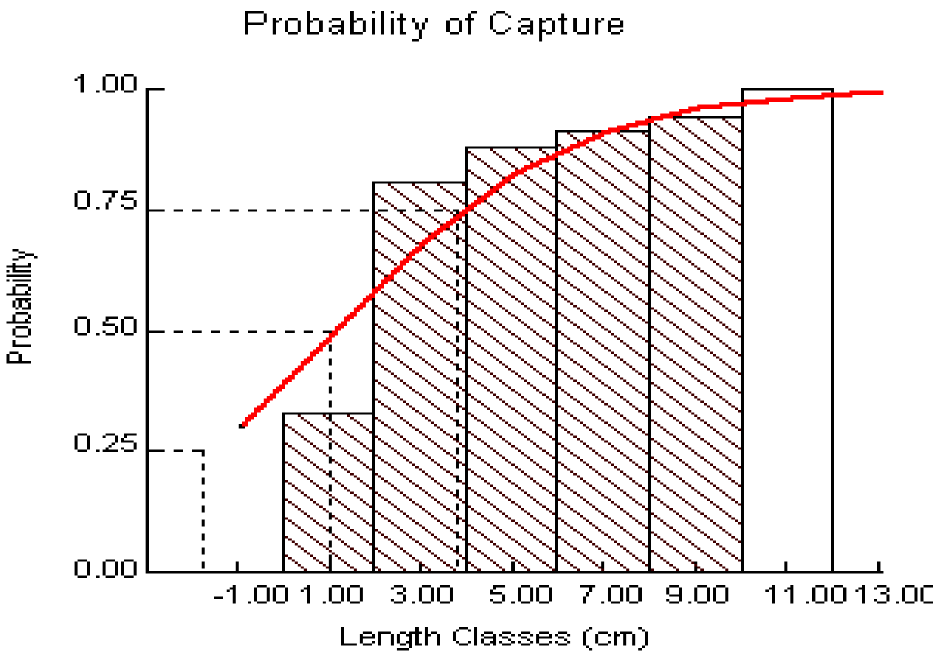

Fig. 7. Selection pattern of *Gudusia chapra*

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 showed a wide range of deviations (Table 2).

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 $L^{0.972}$. *G. chapra* exhibited a length range from 1 to 19 cm (Table 3).

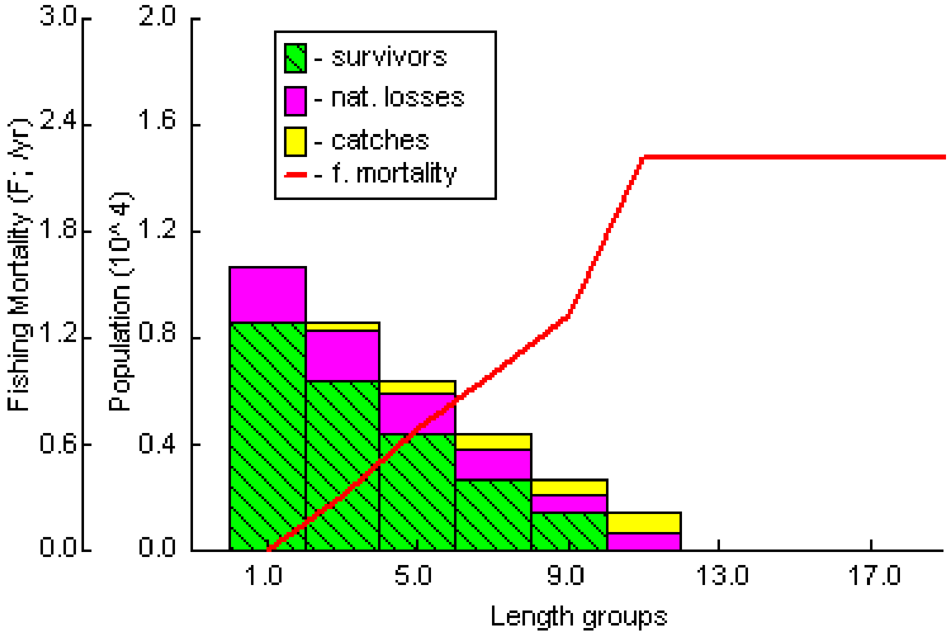

Fig. 8. Length structured virtual population analysis of *Gudusia chapra* in Lake Kaptai, Bangladesh

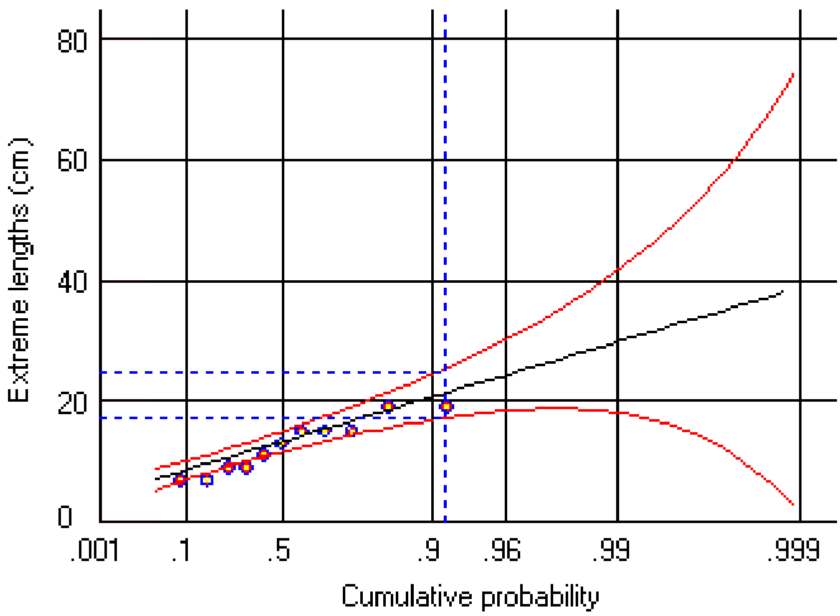

Fig. 9. Predicted extreme length of *Gudusia chapra* in Lake Kaptai, Bangladesh during the study period

Table 1. Fishing mortality values 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

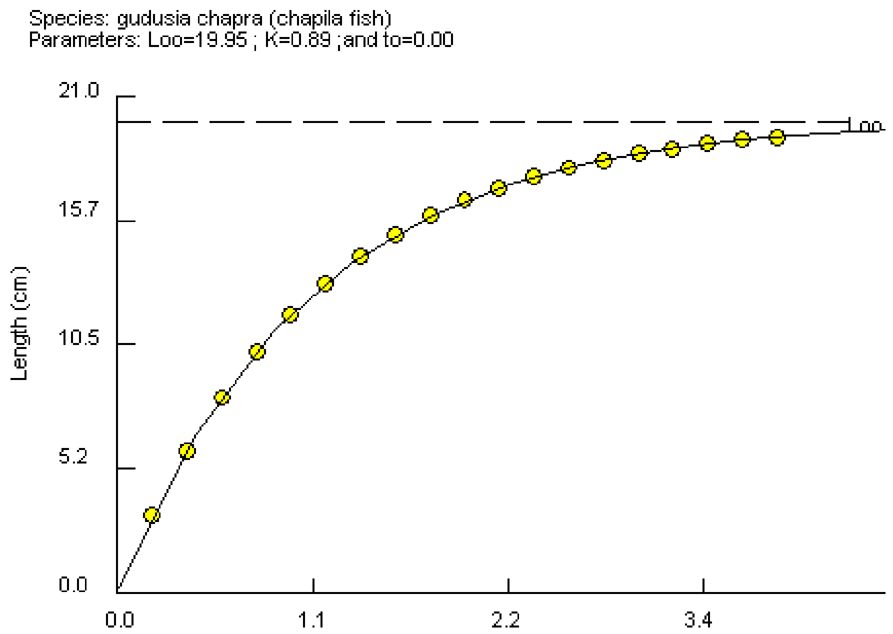

Fig. 10. Length-at-age growth analysis in Lake Kaptai, Bangladesh during the study period

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

Mid length	Avg. weight	lnL	lnW	Cal lnW	Cal W	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

**L=the total length (cm), W=total body weight (g), Cal=calculated, RCF=relative condition factor*

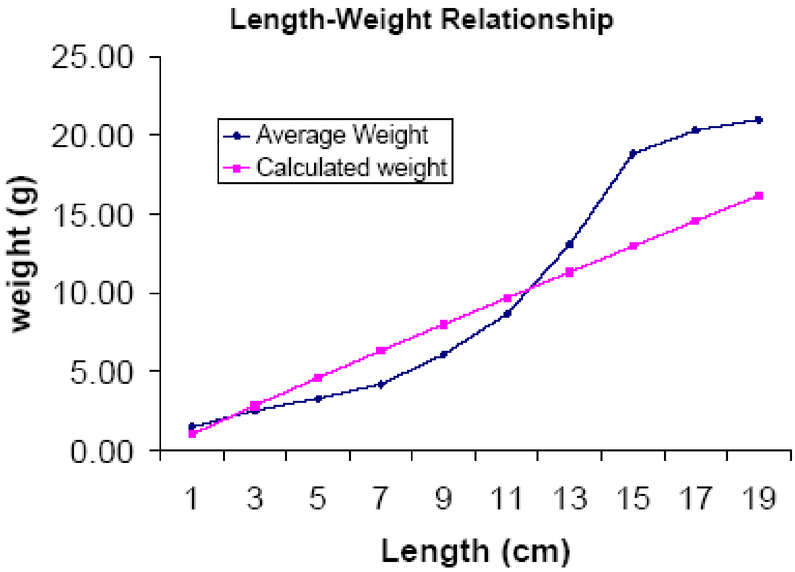

Fig. 11. Length-weight relationship of *Gudusia chapra* in Lake Kaptai, Bangladesh

Table 3. Population parameters of *Gudusia chapra* in Lake Kaptai, Bangladesh during the study period

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 m

4. DISCUSSION

The comprehensive analysis of *G. chapra* population dynamics in Lake Kaptai 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 the lake. 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 ($L\infty$) of 19.95 cm and a growth coefficient (K) of 0.89 $year^{-1}$, obtained through K-scan of ELEFAN-I. A higher K value suggests a faster growth rate, indicating how quickly *G. chapra* reaches its maximum or asymptotic length of 19.95 cm. 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 II 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]. When the fishing mortality rate (F) is higher than the natural mortality rate (M), it indicates an increased impact of human activities on the population dynamics of *G. chapra*, the higher fishing mortality implies that fishing activities are exerting more pressure on the population than the natural processes of mortality. The calculated exploitation rate (E) of 0.54 using Gulland's formula suggested an overfishing pressure on the *G. chapra* stock in Lake Kaptai [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 Lake Kaptai [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 Lake Kaptai [8,33].

5. CONCLUSION

The study concludes that *G. chapra* in Lake Kaptai is experiencing overfishing, as indicated by the elevated exploitation rate. The finding of this present study provided a comprehensive overview of the population dynamics of *G. chapra* in Lake Kaptai, 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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