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Exploring the life history traits of *Polynemus paradiseus* (Linnaeus 1758) in the Bay of Bengal, Bangladesh

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ABSTRACT

Polynemus paradiseus (Linnaeus, 1758), holds substantial economic importance and is a valuable nutritional source as a food fish in South Asia. This current study represents the comprehensive information of the life-history traits, *i.e.*, population structure, growth pattern, condition factors (allometric, K_F ; Fulton's, K_F; relative, K_F; relative weight, W_R), form factor ($a_{3.0}$), size at first sexual maturity (L_m), asymptotic length (L_∞) and weight (W_∞), life span (t_{max}), natural mortality (M), and optimum catchable length (L_{opt}) of *P. paradiseus* in the Bay of Bengal, Bangladesh. Sampling was managed utilizing various traditional fishing gears between the months of January to December in 2021. Throughout this study period, a total of 374 specimens were accurately measured, exhibiting a size range from 11.50 to 22.00 cm TL and a weight range of 16.00 to 62.00 g BW. The growth pattern exhibited negative allometric in this species. Among the condition factors examined, Fulton's condition factor stood out as the most informative, and the mean relative weight displayed no significant deviation from 100, indicating a balanced population structure. The values for $a_{3.0}$, L_m, L_∞, W_∞, t_{max}, and M were recorded as 0.0053, 12.89 cm, 23.18 cm, 64.77 g, 2.90 years, and 1.59 year^{-1} for *P. paradiseus* from the Bay of Bengal, respectively. Furthermore, the optimal catchable length (L_{opt}) was determined to be 15.30 cm (TL). This study provides a critical metric for guiding sustainable fishing practices and conservation efforts of *P. paradiseus* to maintain the population in the Bay of Bengal and its adjacent area.

Introduction

The fish *Polynemus paradiseus*, belonging to the Polynemidae family, which is one of the most economically significant species in Bangladesh. This species is known as tapasi, bairagi, topse, muni, ramsos, riksha, and rishi in Bangladesh (Talwar and Jhingran 1991), according to Hossen et al. (2017), it is also known as paradise threadfin. This species has a widespread presence across numerous countries in South and Southeast Asia, with a particular focus on Bangladesh, India, Pakistan, and Sri Lanka (Talwar and Jhingran 1991). Although primarily inhabiting in the Bay of Bengal and the estuaries of Bangladesh, it also occupies River ecosystems (Rahman 1989 and 2005). In addition, it may be inhabited in the Sundarbans (Huda et al. 2003), as well as in the Meghna and Padma Rivers (Shafi and Quddus 2001). While it displays a preference for saline environments, it exhibits a propensity to venture into freshwater during the breeding season. Its diet predominantly consists of crustaceans, particularly shrimp, small fish, and benthic organisms, (Menon et al. 1984; Hossen et al. 2017). The economic significance of *P.*

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paradiseus extends extensively across multiple nations due to its substantial consumption. Both large-scale industrial operations and local small-scale fishers actively target this species for its prized meat, renowned for its exquisite taste and gourmet status. To gain insights into the composition of fresh *P. paradiseus*, one can employ measurements of its moisture, protein, fat, and ash content. According to Nowsad (2007), approximately 96 to 98% of fish tissue comprises these essential components. However, due to widespread harvesting, habitat deterioration, and other ecological shifts occurring within Bangladeshi water bodies, there is concern about the declining natural population of this species, (Hossen et al. 2015). Consequently, it has been classified as a species not currently threatened within Bangladesh (IUCN 2000) and holds the status of "Least Concern" on a global scale (IUCN 2022). The "Least Concern" designation is assigned to species whose population size or distribution has experienced gradual reduction, warranting the establishment of management strategies to ensure their sustained survival within their native habitats (Nature Conservation Act 1992; Mawa et al. 2022).

Population structure aids in the comparison of morphological characteristics between species or different population of the similar individual across diverse environs (Sabbir et al. 2020). Furthermore, it serves as an indicator of species' stock status and breeding periods (Ranjan et al. 2005). Length-weight relationships (LWRs) are regarded as valuable tools in fisheries studies for estimating weight, biomass, and condition factors (Khatun et al. 2019). Additionally, the utilization of LWRs becomes imperative for the conversion of lengths into corresponding weights, as direct weight assessment on-site can need a lot of time; these parameters hold essential significance in fish biology and can offer insights into the stock or stock status of the organism (Rahman et al. 2020). Furthermore, it is noteworthy that length-length relationships prove to be more relevant than age, as several ecological and physiological factors exhibit a stronger dependence on length rather than age (Rahman et al. 2020).

In evaluating the physiology, well-being, and growth of fish (Richter 2007), multiple condition factors are employed. These factors encompass numerical parameters that measure the health of fish, elucidating their immediate and prospective reproductive potential through influences on development, survival, as well as reproduction (Le Cren 1951; Mawa et al. 2022). The relative weight (W_R) stands as a crucial and widely employed index for evaluating the condition of fish (Rypel and Richter 2008). Furthermore, W_R stands as the predominant metric employed to assess the prey-predator dynamics of fish within a specific environment (Froese 2006). The form factor applied to ascertain distinctions in the body shape across various fish species or populations. (Froese 2006; Mawa et al. 2022; Ilah et al. 2023).

The size at first sexual maturity in fish might be influenced by environmental conditions and can aid in establishing the lowest catchable size for fish (Hasan et al. 2021). Accurate identification of the spawning as well as peak-spawning season of mature fish holds significance for conservation and management strategies, helping to mitigate risks such as overharvesting and related impacts (Templeman 1987). Fish mortality serves as a metric employed to quantify the depletion of fish within a stock due to mortality. This depletion can be attributed to two distinct types of mortality: natural mortality and fishing mortality. Natural mortality encompasses factors beyond fishing, including causes such as pollution, disease, competition, old age, predation, cannibalism, or other naturally occurring conditions leading to fish mortality. (Sparre et al. 1989). The L_{opt} for a given stock is defined as the intermediate length class, where the product of individuals times their average weight reached a maximum (Mawa et al. 2022). One of the reasons L_{opt} was recognized is the selection of gear which is a vital part of fisheries management (Rahman et al. 2023).

There have been several studies of this fish species (Table 1), but none on this feature of *P. paradiseus* in the Bay of Bengal, Bangladesh. Therefore, the present research was intended to describe the comprehensive information on life-history traits including (i) population structure through length-frequency distribution (LFD), (ii) growth pattern through length-weight relationships (LWRs) & length-length relationships (LLRs), (iii) best condition factor through multiple-functions (K_A, K_F, K_R and W_R), (iv) form factor ($a_{3.0}$), (v) size at first sexual maturity (L_m), (vi) asymptotic length (L_∞) and weight (W_∞), (vii) Life span (t_{max}), (viii) natural mortality (M) and (ix)optimum catchable length (L_{opt}) of *P. paradiseus* in the Bay of

Bengal having a number of specimen with assorted sizes across the research time.

These fish were caught in 2021 from January to December using gill nets and trawls (wire spacing: 2-3

Table 1. Available study of *Polynemus paradiseus* from worldwide water bodies

Aspects	Habitat/Country	References
Fecundity and Gonadosomatic index	Meghna estuary, Bangladesh	Rahman et al. (2013)
Growth pattern and condition	Tetulia River, Bangladesh	Hossen et al. (2017)
Length–weight and length–length relationships	Ganga River, India	Baitha et al. (2018)
Length-weight relationship and condition factor	Hooghly-Matlah estuary, India	Borah et al. (2020)
Length-weight relationships	Tetulia River, Bangladesh	Hossain et al. (2015)
Morphometric and Meristic Characteristics	Sundarbans estuary, Bangladesh	Naser et al. (2023)
Morphometric parameters and allometric growth	Coastal River, Bangladesh	Chaklader et al. (2016)
Population dynamics	Cox's Bazar & Chattogram, Bangladesh	Rashed-Un-Nabi et al. (2007)
Proximate composition	Meghna River, Bangladesh	Majumder et al. (2016)
Taxonomic diversity	Coastal Rivers, Bangladesh	Chaklader et al. (2015)

Materials and methods

Study region and sampling

Across the Bay of Bengal in southern Bangladesh (Patharghata 22° 3'7.53"N, 89°58'19.14"E; Kuakata 21°51'16.53"N, 90° 7'19.75"E; Cox's Bazar 21°27'6.48"N, 91°58'5.43"E) (Figure 1), 374 *P. paradiseus* specimens were gathered from fishers.

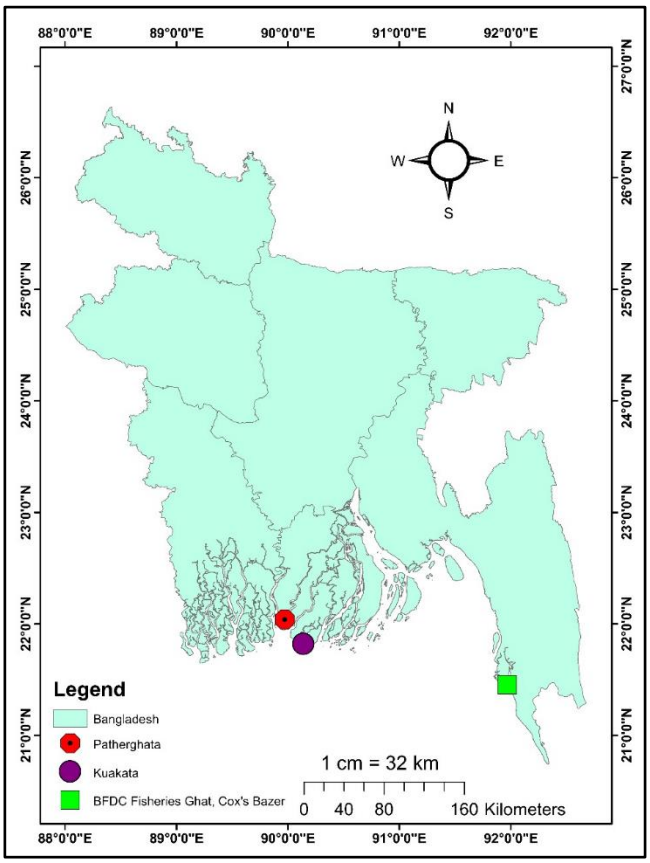

Fig. 1. Map of the study site in the Bay of Bengal, Bangladesh

cm) and conventional fishing methods. Samples were preserved in 10% buffered formalin and stored on ice immediately upon collection to ensure they would be in usable condition for future studies. The following day, in the lab, we used digital slide calipers to measure each *P. paradiseus* to within 0.01 cm of its actual length. In addition, each specimen's total body weight was weighed to an accuracy of 0.01 g utilizing an electric balance.

Population Structure

The length frequency distribution is an incredibly important feature to consider when attempting to determine the age of a fish. The species of *P. paradiseus* have their length frequency distributions, commonly known as LFD, exhibited throughout a class interval of total length of 1.0 cm (TL).

Length-weight and Length-length relationships

The relationships between length and weight, as described by the equation $W = a \times L^b$ (Le Cren 1951), where W represents the total body weight (BW, g); L signifies the total length (TL, cm) and parameters 'a' and 'b' were derived through the logarithmic transformation $ln(\text{BW}) = ln(a) + b\, ln(\text{TL})$. To enhance the reliability of the regression analyses, outliers at the extremes of the dataset were identified and subsequently removed, following the methodology outlined by Forese (2006). Furthermore, the b values derived from LWRs – specifically TL *vs.* BW, SL *vs.* BW, and FL *vs.* BW – were calculated. Additionally, the relationships between Total Length (TL) and Standard Length (SL), as well as Fork Length (FL), for *P. paradiseus* were determined, denoted as LLRs.

Condition factors

The allometric condition factor (K_A) was estimated applying the formula W/L^b as introduced by Tesch in 1968. For Fulton's condition factor (K_F), the computation involved the expression $K_F = 100 \times (W/L^3)$ (Fulton 1904). To assess the relative condition factor (K_R), the equation $K_R = W/(a \times L^b)$ was employed (Le Cren 1951). Additionally, the relative weight (W_R) was determined by evaluating $W_R = (W/W_S) \times 100$, in accordance with the methodology established by Froese in 2006.

Form factor ($a_{3.0}$)

The form factor was computed utilizing the equation $a_{3.0} = 10^{\log a\text{-}s(b\text{-}3)}$, as described by Froese in 2006. In this equation, '*a*' and '*b*' represent the regression parameters of LWRs, while'*s*' signifies the regression slope of *ln* (*a*) *vs. ln* (*b*).

Size at first sexual maturity (L_m)

The L_m of *P. paradiseus* in the Bay of Bengal was determined utilizing the Binohlan and Froese (2009) equation: $log(L_m) = -0.1189 + 0.9157 \times log\, L_{max}$, which applies separately to both male and female specimens.

Asymptotic length (L_∞) and weight (W_∞)

The estimation of the asymptotic length (L_∞) was carried out using the logarithmic expression: $log\, L_\infty = 0.044 + 0.9841 \times log\, L_{max}$ (Froese and Binohlan 2000). Concurrently, the determination of the asymptotic weight (W_∞) was achieved by employing the formula $W_\infty = a \times {L_\infty}^b$ (Ricker 1975).

Life span (t_{max})

Applying the model developed by Froese and Binohlan (2000), the relationship $log\, t_{max} = 0.5496 + 0.957 \times log(t_m)$ was utilized. In this context, t_{max} represents the maximum age or lifespan attained within a population in years, while t_m denotes the average age at first sexual maturity in years. The formula for t_m is given by $t_m = (-1/1) \times ln(1 - L_m/L_\infty)$ (King 2007).

Natural mortality (M)

The calculation of the *M* for *P. paradiseus* was executed employing the formula $M = -ln[0.01]/t_{max}$ (King 2007). In this equation, *M* signifies the annual natural mortality rate, ln represents the natural logarithm, and t_{max} corresponds to the lifespan or longevity.

Optimum catchable length (L_{opt})

The L_{opt} is defined as the length at which the highest yield of fish would be obtained (Froese et al. 2006). By applying the Froese and Binohlan (2000) model, the estimation of L_{opt} was carried out using the equation: $log\, L_{opt} = 1.0421 \times log(L_\infty) - 0.2742$, wherein L_∞ represents the asymptotic length.

Statistical analysis

The statistical analysis was delegated to the use of the software Microsoft Excel (version 2013) and Graph Pad Prism 6.0. The Spearman rank correlation test was carried out with the purpose that determined whether or not there was a link between the condition factors and either TL or BW. For the purpose of distinguishing the mean relative weight (W_R) from 100, a Wilcoxon sign-ranked test was carried out (Anderson & Neumann 1996). In the statistical analysis that was carried out, a significance level of 5% ($p < 0.05$) was used.

Results

Population Structure

The descriptive statistics for the length and weight measurements, a total of 374 *P. paradiseus* specimens, accompanied by their corresponding 95% confidence limits (CL) are shown in Table 2. The analysis of the LFD illustrates that the population's smallest and largest individuals measured 11.50cm and 22.00cm in TL respectively, while their body weights (BW) spanned from 16g to 62g.

Table 2. Explanatory statistics on the length (cm) and weight (g) measurements of *Polynemus paradiseus* in the Bay of Bengal, Bangladesh

Measurement	*n*	Minimum	Maximum	Mean ± SD	95% CL
Total length (cm)		11.50	22.00	16.65 ± 1.76	16.47 - 16.83
Fork length (cm)	374	9.50	19.00	13.77 ± 1.55	13.61 - 13.93
Standard length (cm)		8.28	16.49	12.34 ± 1.25	12.21 - 12.47
Body weight (g)		16.00	62.00	33.98 ± 7.76	33.19 - 34.77

n, sample size; SD, standard deviation; CL, confidence limit for mean values

Significantly, the size group within the 16 to 18cm TL range emerges as the numerically dominant category, and this observation is represented in Figure 2.

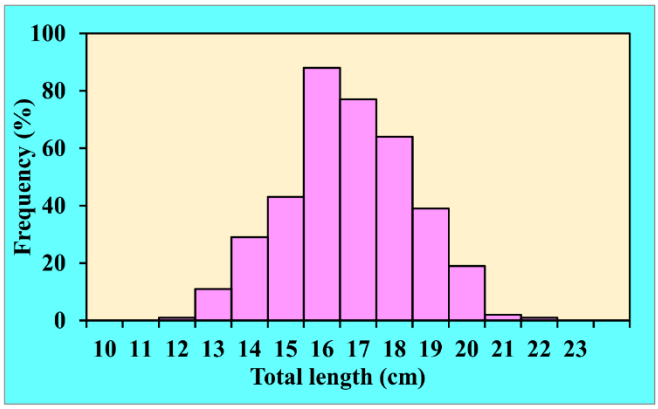

Fig. 2. Length-frequency distribution of *Polynemus paradiseus* in the Bay of Bengal, Bangladesh

Length-weight and length- length relationships

The regression parameters for the Length-weight Relationships, along with the 95% confidence intervals for coefficients '*a*' and '*b*', the coefficient of determination (r^2), and the growth pattern analysis of *P. paradiseus*, are presented in Table 3 and Figure 3.

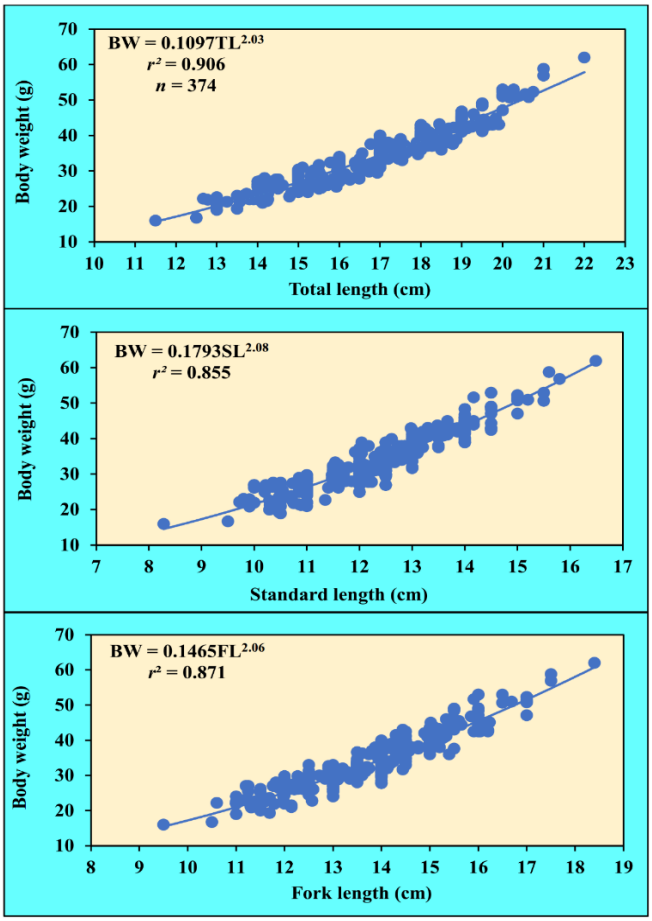

Fig. 3. Length-weight relationships of *Polynemus paradiseus* in the Bay of Bengal, Bangladesh

Table 3. Descriptive statistics and estimated parameters of the total length (TL), standard length (SL), fork length (FL) and body weight (BW) relationship of *Polynemus paradiseus* in the Bay of Bengal, Bangladesh

Equation	Regression parameters		95% CL of *a*	95% CL of *b*	r^2	GT
	a	*b*				
$BW=a*TL^b$	0.1097	2.03	0.0909 - 0.1323	1.97 - 2.10	0.906	A-
$BW=a*SL^b$	0.1793	2.08	0.1440 - 0.2232	1.99 - 2.17	0.855	A-
$BW=a*FL^b$	0.1485	2.06	0.1201 - 0.1835	1.98 - 2.14	0.871	A-

a, intercept; *b*, slope; CL, confidence limit for mean values; r^2, coefficient of determination; GT, growth type

Table 4. The estimated parameters of the total length, standard length (SL) and fork length (FL) relationships of *Polynemus paradiseus* in the Bay of Bengal, Bangladesh

Equation	Regression parameters		95% CL of *a*	95% CL of *b*	r^2	GT
	a	*b*				
$TL=a+b*SL$	1.0949	0.68	0.7194 - 1.4704	0.65 - 0.70	0.904	A-
$TL=a+b*FL$	0.9857	0.77	0.5756 - 1.3959	0.75 - 0.79	0.911	A-

a, intercept; *b*, slope; CL, confidence limit for mean values; r^2, coefficient of determination; GT, growth type

In the LWRs (TL *vs.* BW; SL *vs.* BW; FL *vs.* BW), the '*b*' value indicates a pattern of negative allometric growth. Additionally, the '*b*' value observed in the Length-length Relationships (TL *vs.* SL; TL *vs.* FL) also points towards a negative allometric growth trend (Table 4 and Figure 4).

Best condition factor (CF)

The values for all condition factors (K_A, K_F, K_R, and W_R) have been presented in Table 5. The results of the Spearman rank correlation test highlighted a strong and significant association between the condition factors (CFs) and body weight (BW). Notably, a -

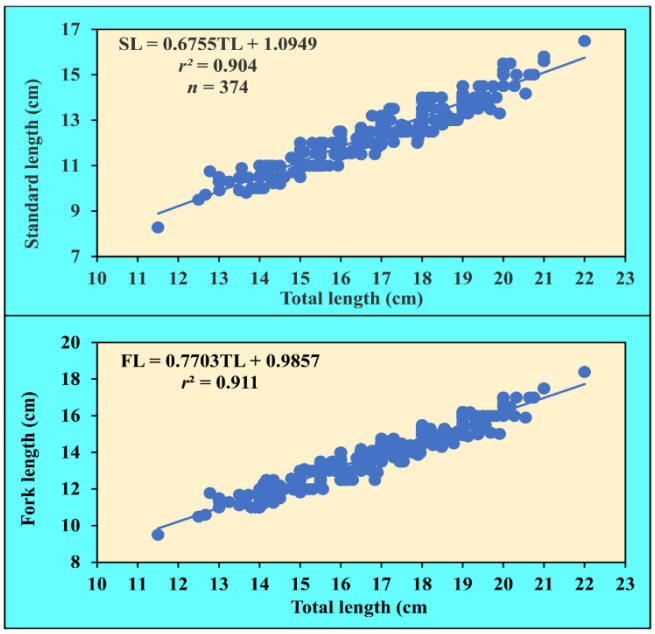

Fig. 4. Length-length relationships of *Polynemus paradiseus* in the Bay of Bengal, Bangladesh

highly significant correlation was observed between K_F and TL (Figure 5). However, it is worth noting that no significant correlation between TL and K_A, K_R, or W_R was found (Table 6). The W_R exhibited significant deviation from 100 (p = 0.3083) for *P. paradiseus* (Figure 6).

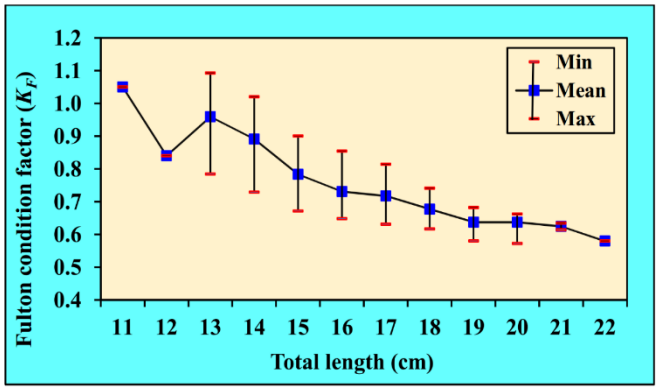

Fig. 5. Fulton condition factor (K_F) of *Polynemus paradiseus* in the Bay of Bengal, Bangladesh

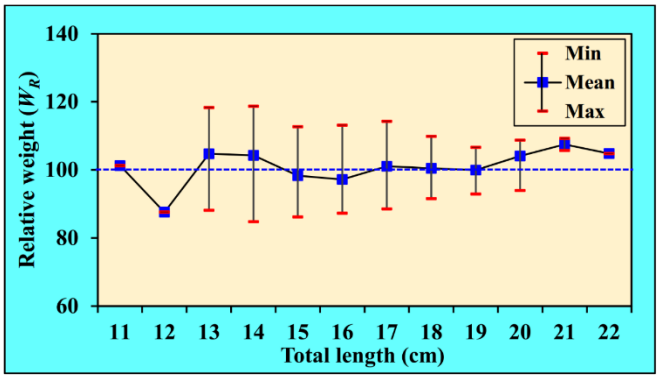

Fig. 6. Relative weight (W_R) of *Polynemus paradiseus* in the Bay of Bengal, Bangladesh

Table 5. Condition factors measurements and with their 95% CL of *Polynemus paradiseus* in the Bay of Bengal, Bangladesh

Condition factors	*n*	Minimum	Maximum	Mean ± SD	95% CL
Allometric condition factor (K_A)		0.0930	0.1303	0.1098 ± 0.0077	0.1090 - 0.1106
Fulton's condition factor (K_F)	374	0.57	1.09	0.74 ± 0.10	0.73 - 0.75
Relative condition factor (K_R)		0.85	1.19	1.00 ± 0.07	0.99 - 1.01
Relative weight (W_R)		84.81	118.74	100.10 ± 7.04	99.39 - 100.82

Table 6. Relationships of condition factor with total length (TL) and body weight (BW) of *Polynemus paradiseus* in the Bay of Bengal, Bangladesh

Relationships	r_s values	95% CL of r_s	*p* values	Significance
TL *vs.* K_A	0.05110	-0.05357 to 0.1547	0.3244	ns
TL *vs.* K_F	-0.7982	-0.8331 to -0.7569	< 0.0001	****
TL *vs.* K_R	0.05614	-0.04853 to 0.1596	0.2789	ns
TL *vs.* W_R	0.05198	-0.05269 to 0.1555	0.3161	ns
BW *vs.* K_A	0.3205	0.2236 to 0.4111	< 0.0001	****
BW *vs.* K_F	-0.5976	-0.6608 to -0.5261	< 0.0001	****
BW *vs.* K_R	0.3252	0.2286 to 0.4155	< 0.0001	****
BW *vs.* W_R	0.3212	0.2244 to 0.4118	< 0.0001	****

K_A, allometric; K_F, fulton's; K_R, relative condition factors; W_R, relative weight; CL, confidence limit for mean values; r_s, Spearman rank-correlation values; CL, confidence limit; *p*, shows the level of significance; ns, not significant; ***very highly significant.

Form factor ($a_{3.0}$)

The $a_{3.0}$ was identified as 0.0053 within the Bay of Bengal, Bangladesh. Furthermore, Table 7 provides the values of $a_{3.0}$ across diverse populations worldwide.

Natural mortality

The estimation of natural mortality resulted in a value of 1.59 year^{-1} (Table 7), and the mean M was determined as 0.83 year^{-1} (Figure 8) for *P. paradiseus* in the Bay of Bengal, Bangladesh.

Table 7. The calculated form factor ($a_{3.0}$), size at first sexual maturity (L_m) and natural mortality (M) for the *Polynemus paradiseus* of different habitats using available length-weight relationships (LWRs) parameters in the worldwide

Water body	*n*	Regression parameter		L_{max}	References	$a_{3.0}$	L_m	95% CL of L_m	M
		a	*b*						
Bay of Bengal, Bangladesh	**374**	**0.1097**	**2.03**	**22.0**	**Present study**	**0.0053**	**12.89**	**10.15-16.36**	**1.59**
Cox's Bazar & Chattogram, Bangladesh	250	0.0087	2.74	20.00	Rashed-Un-Nabi et al. (2007)	0.0039	11.82	9.33-14.95	1.57
Coastal River, Bangladesh	105	-	-	20.00	Chaklader et al. (2015)	-	11.82	9.33-14.95	1.57
Coastal River, Bangladesh	221	0.030	2.82	13.70	Chaklader et al. (2016)	0.016	8.36	6.70-10.45	1.50
Ganga River, India	129	0.004	3.08	19.70	Baitha et al. (2018)	0.0051	11.65	9.21-14.74	1.57
Hooghly-Matlah estuary, India	260	-	3.18	26.50	Borah et al. (2020)	-	15.29	11.94-19.51	1.61
Meghna estuary, Bangladesh	75	-	-	18.90	Rahman et al. (2013)	-	11.22	8.88-14.17	1.55
Sundarbans estuary, Bangladesh	120	0.0022	3.34	23.50	Naser et al. (2023)	0.0064	13.70	10.75-17.42	1.59
Tetulia River, Bangladesh	300	0.0058	3.04	21.70	Hossen et al. (2017)	0.0061	12.73	10.02-16.15	1.59
Tetulia River, Bangladesh	158	0.0034	3.23	17.10	Hossain et al. (2015)	0.0179	10.24	8.14-12.89	1.55

Size at first sexual maturity (L_m)

The assessment of the L_m occurs in *P. paradiseus* resulted in a determination of 12.89 cm TL (95% CL= 10.15-16.36 cm TL) in the Bay of Bengal, Bangladesh. Nevertheless, Table 7 and Figure 7 provide a comprehensive display of L_m values across various populations worldwide.

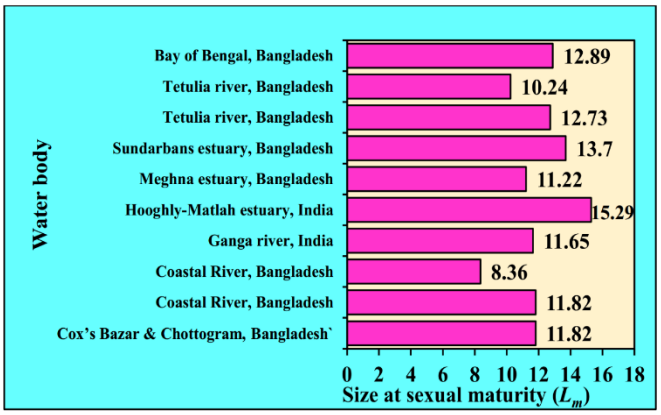

Fig. 7. Size at sexual maturity (L_m) of *Polynemus Paradiseus* from different water bodies in world wide

Asymptotic length (L_∞) and weight (W_∞)

The calculated asymptotic length was found to be 23.18 cm, and W_∞ was recorded as 64.77 g for *P. paradiseus* in the Bay of Bengal.

Life span (t_{max})

From the study area, t_{max} determined for *P. paradiseus* was 2.90 years.

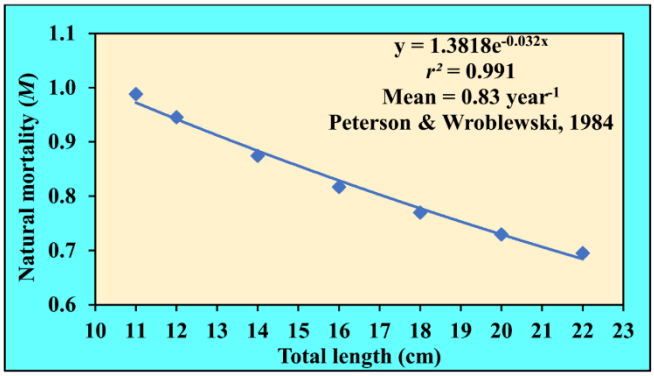

Fig. 8. Natural mortality (M) of *Polynemus paradiseus* in the Bay of Bengal, Bangladesh

Optimum catchable length

The ascertained optimal catchable length (L_{opt}) for *P. paradiseus* from the Bay of Bengal was observed to be 15.30 cm TL.

Discussion

Limited research has been conducted on specific aspects in various water bodies of Bangladesh (Table 1). However, a comprehensive analysis of life-history traits including parameters such as t_{max}, M using different models, asymptotic weight, and optimal catchable length for *P. paradiseus* remains unexplored in the Bay of Bengal and other water bodies within Bangladesh.

Nevertheless, the current study focuses on the comprehensive life-history traits of *P. paradiseus*,

including population structure, growth pattern, condition factor, $a_{3.0}$, size at first sexual maturity, asymptotic length and weight, life span, natural mortality, and L_{opt}. A total of 374 individuals were collected from the Bay of Bengal, Bangladesh, utilizing a variety of specimens with small to large body sizes through regular fishing gear.

Despite this, capturing *P. paradiseus* individuals below the 11.50 cm TL mark proved unachievable throughout the sampling duration. This circumstance could stem from either the scarcity of fish smaller than 11.50 cm TL within the stocks or the discerning nature of the fishing gear employed (Islam et al. 2021). Our observations revealed that the largest recorded size of *P. paradiseus* in the study area, was 22.00 cm (TL). The TL interval of 16.0 to 18.0 cm was dominant. In contrast, Borah et al. (2020) and Naser et al. (2023) have indicated maximum lengths of 26.50 cm and 23.50 cm in the Hooghly-Matlah estuary, India, and the Sundarbans estuary, Bangladesh, respectively, surpassing the measurements from our study. Conversely, previous research by Rashed-Un-Nabi et al. (2007), Rahman et al. (2013), Hossain et al. (2015), Chaklader et al. (2015, 2016), Hossen et al. (2017), and Baitha et al. (2018) documented maximum TL of 20.00, 18.90, 17.10, 20.00, 13.70, 21.70, and 19.70 cm, respectively, originating from locations within Bangladesh – such as Cox's Bazar & Chattogram, Meghna estuary, Tetulia River, Coastal River, and Ganga River, India. Remarkably, these measurements were consistently lower than our recorded findings. These differences in total length measurements likely correlate with variations in water temperatures and other environmental parameters, which in turn influence fish growth dynamics (Mommsen 1998). The computation of the asymptotic length and growth coefficient of fish species depends critically on knowledge of the maximum length (Samad et al. 2023). This information holds significant importance for the effective management and planning of fisheries resources (Ahmed et al. 2012; Hossain et al. 2012; Hossain et al. 2016). Furthermore, in the current study, the highest recorded body weight (BW) for *P. paradiseus* was 62.00 g. This measurement falls below that reported by Naser et al. (2023) and Hossen et al. (2017), who documented BW of 100.87 g and 69.60 g, respectively in the Sundarbans estuary and Tetulia River, Bangladesh. In contrast, our observed BW exceeded the values reported by Rashed-Un-Nabi et al. (2007), Rahman et al. (2013), Hossain et al. (2015), Chaklader et al. (2015, 2016), and Baitha et al. (2018), which were 33.50 g in the Cox's Bazar & Chattogram, Bangladesh, 38.05 g Meghna estuary, Bangladesh, 30.20 g Tetulia River, Bangladesh, 60.64 g and 50.67 g Coastal River, Bangladesh, and 47.85 g Ganga River, India, respectively.

The allometric coefficient '*b*' can exhibit a range from 2 to 4 (Carlander 1969); however, according to Froese (2006), the optimal range for fish falls between 2.5 to 3.5. Generally, despite the marked differences in fish anatomies across species, '*b*' values approximating 3 indicate isometric growth, while deviations from 3.0 signify allometric growth (Tesch 1968), with values above 3 indicating positive allometric growth and values below 3 indicating negative allometric growth. Notably, the '*b*' value for *P. paradiseus* was below 3.00. Consequently, the growth pattern of *P. paradiseus* indicates negative allometric growth in the Bay of Bengal, Bangladesh, signifying faster growth in length than in weight (Hossain et al. 2017). On the contrary, in previous studies, the '*b*' value of *P. paradiseus* exhibited varying measurements: 3.23, 3.04, 3.08, 3.18, and 3.34, indicating positive allometric growth in each case (Hossain et al. 2015; Hossen et al. 2017; Baitha et al. 2018; Borah et al. 2020; Naser et al. 2023). Conversely, two separate studies revealed findings of negative allometric growth of this species: Rashed-Un-Nabi et al. (2007) reported '*b*' as 2.74, while Chaklader et al. (2016) observed a '*b*' value of 2.82.

Throughout the present study, our focus encompassed an examination of four distinct condition factors (K_A, K_F, K_R, and W_R) to comprehensively evaluate the physical and environmental well-being of *P. paradiseus* within the Bay of Bengal. Utilizing the Spearman rank correlation test, we observed a highly significant relationship between these condition factors and body weight (BW). However, in contrast, only K_F (ranging from 0.57 to 1.09) demonstrated a significant correlation with TL and BW. Therefore, it can be assumed that, the K_F ($p < 0.0001$) is the best for determining the well-being of *P. paradiseus* in the Bay of Bengal. Furthermore, the relative weight exhibited no significant deviation from 100 ($p = 0.3161$), indicative of an optimal habitat replete with ample food availability and a controlled presence of predators for *P. paradiseus* within the Bay of Bengal. In contrast, Chaklader et al. (2016) focused solely on K_F

and observed a range of 1.02-2.23 in males and 1.80-2.05 in females from the Coastal River, Bangladesh. Hossen et al. (2017) conducted research on K_F and W_R, finding values of 0.579-0.768 (highly correlated) and 90.71-122.08 (significant) in the Tetulia River, Bangladesh, respectively. In parallel, Borah et al. (2020) concentrated solely on the relative condition factor, reporting values of 1.002-1.177 in males and 0.986-1.239 in females from the Hooghly-Matlah estuary, India. The observed fluctuations in condition could potentially be linked to the seasonal patterns of the flooding cycle associated with monsoons, which in turn govern the biological cycle and growth dynamics of fish individuals in Bangladesh (Mawa et al. 2022).

In accordance with the research conducted by Froese in 2006, the projected $a_{3.0}$ value of 0.01 suggests that the fish possesses an elongated body structure. In our investigation, the computed $a_{3.0}$ value stood at 0.0053, affirming the elongated morphology of *P. paradiseus* within the Bay of Bengal. A similar outcome, signifying an elongated shape, was also documented by Hossen et al. (2017) for the same species. The determination of the size at first maturity holds practical significance in establishing the minimum allowable capture size and facilitating stock assessment (Lucifora et al. 1999; Khatun et al. 2019). For *P. paradiseus* in the Bay of Bengal, the L_m was computed to be 12.89 cm. In contrast, Borah et al. (2020) documented a higher L_m value of 14.5 cm for *P. paradiseus* in the Hooghly-Matlah estuary, India, which surpasses the measurement from our study.

In the current study, the L_∞ was determined to be 23.18 cm, surpassing the value reported in the earlier study by Rashed-Un-Nabi et al. (2007). Additionally, the parameters W_∞ and t_{max} were quantified as 64.77 g and 2.90 years, respectively. Notably, no prior research has explored the dimensions of W_∞ and t_{max}, making it difficult to draw comparisons with existing data. The estimation of natural mortality of this species in the Bay of Bengal yielded a value of 1.59 $year^{-1}$, surpassing the earlier study's finding of 1.21 $year^{-1}$ as reported by Rashed-Un-Nabi et al. (2007). This disparity can be attributed to several influencing factors such as competition, disease, environmental conditions, pollution, and various other natural or anthropogenic factors (Sparre et al. 1989).

L_{opt} holds a crucial significance in the strategic selection of fishing gear for effective fisheries management. Fishing gear should be created to ensure that individuals below the L_{opt}-indicated size are allowed to escape (Mawa et al. 2022). In our current study, suggested L_{opt} value was at 15.30 cm which is the first evident in the literature for *P. paradiseus*. This information serves as a baseline for future research studies in this field.

Conclusion

This study has provided a comprehensive understanding of the life history traits of P. paradiseus, encompassing aspects such as population structure, growth pattern, optimal condition factor, form factor, size at first sexual maturity, asymptotic length and weight, lifespan, natural mortality, and optimum catchable length. The size at sexual maturity, the natural mortality and optimum catchable length were recorded as 12.89 cm, 1.59 year-1 and 15.30 cm. To ensure the sustainability of P. paradiseus in the Bay of Bengal, it is highly recommended to implement fisheries management strategies that consider the identified optimum catchable length (L_{opt}) of 15.30 cm and maintaining a balanced population structure. This amassed knowledge serves as a valuable resource for fishery executives, fish scientists, and conservationists, equipping them with essential insights to initiate proactive management strategies and regulations. These measures are crucial for the sustainable preservation of the remaining stocks of this species within the Bay of Bengal and the adjacent areas.

Conflict Of Interest

There is no competing interest that might influence the research work.

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