ISSN (online): 3006-5542; ISSN (print): 3006-5534

Fisheries Studies

Journal homepage: www.journal.inrrd.com/fs

Original article

Assessing the population structure, growth, conditions and sexual maturity of *Sillaginopsis panijus* in the Bay of Bengal, Bangladesh

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ARTICLE INFO

Article history

Received 06 March 2024
Revised 10 May 2024
Accepted 17 May 2024
Available online 31 May 2024

Keywords

Population Structure
Growth
Condition factor
Sexual Maturity
Sillaginopsis panijus

ABSTRACT

This study focuses on the population structure, growth, condition, and size at sexual maturity of *S. panijus* from the Bay of Bengal. The total length (TL) of each individual was measured using measuring board, while body weight (BW) was measured with an electric balance. The TL ranged from 11.50 to 38.00 cm, and the BW varied between 6.79 and 548.0 g. All length-weight relationships (LWRs) were statistically significant ($p < 0.001$), with r^2 values exceeding 0.968. The calculated allometric coefficient (b) for the combined sexes was greater than 3, indicating positive allometric growth. Additionally, the length-length relationship (LLR) was also statistically significant ($p < 0.001$), with r^2 value exceeding 0.985. Among condition factors, K_F was expressed a best condition factor to describe the health status of *S. panijus*. The values for $a_{3.0}$, L_m and M_w for the species *S. panijus* were as 0.0064, 21.27 cm TL and 1.69 yr^{-1}, respectively. The findings would be highly beneficial for the future research and management of the fishery in the Bay of Bengal, Bangladesh and its adjacent environment.

Introduction

The flathead sillago (*Sillaginopsis panijus*) is a demersal fish species typically found in estuarine environments and is classified under the family Sillaginidae. It was originally described by Hamilton in 1822. The species has a broad distribution in India, Myanmar, and Malaysia, but is infrequently found in the Indonesian archipelago. In Bangladesh, it is commonly referred to by the name "Tular Dandi". This species is highly valued in the food industry for its unique taste. McKay (1992) reported that it spawns biannually, with major spawning seasons taking place between November and February, and again from August to September. Current species is frequently found in shallow, open bays and estuaries along the coast on silty or muddy soils. *S. panijus* feed on small fish, crustaceans and algae. This species is enriched with Omega-3 fatty acid (0.647g/100g), Vitamin A (78.2µg/100g), Protein (20.4g/

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100g) etc. (Hicks et al. 2019). This is amphidromous marine fish (Riede 2004), the species is taken largely using trawl nets (mesh size: 2-3 cm) and shore seines bag net (mesh size: 1.5-3 cm) fishing techniques across its entire range. Despite of this, fisheries only place a small emphasis on the species. Due to the lack of adequate cultural practices, this species is catching a large number of individuals from wild habitats. However, the wild population of *S. panijus* faces its greatest challenge from the practice of overfishing.

Population structure can be represented by length-frequency distribution (LFD). The LFD is widely recognized as an important biometric statistic for estimating fish mortality, recruitment rate and growth performance index (Ilah et al. 2023). It is also utilized in assessing the overall health of rivers by evaluating standing biomass and spawning periods (Ranjan et al. 2005; Hossain et al. 2013a). Additionally, the LFD is valuable for comparing the morphological characteristics of different aquatic specimen and stocks of the same specimen that reside in several aquatic environments (Sabbir et al. 2020a).

Length-weight relationships (LWRs) and length-length relationships (LLRs) are important biometric tools that offer valuable information about various eco-physiological traits (Hossain et al. 2008). LWRs and LLRs are used to explain the relationship between the length and weight or length and length of a fish specimen, respectively (Sabbir et al. 2020a). These relationships are essential for the effective management of wild fish stocks in open water environments (Muchlisin et al. 2010).

The form factor ($a_{3.0}$) which is another method commonly applied to assess the structure of fish specimens in their natural aquatic ecosystem (Froese 2006). Given that the fisheries industry is a major global source of nitrogenous matter, it is essential to have a thorough understanding of fish health. The condition factor, an index used to analyze fish reproductive success, maturity levels, and current health issues, is crucial in this regard. It is also used to determine survival rates (Le Cren 1951; Sabbir et al. 2020b). In addition to this, it is taken into consideration as the water quality index of the water, in addition to the health status of the population that inhabits in a particular area (Tsoumani et al. 2006). It's recognized that the condition of the fish may be influenced by a variety of factors, including stress, environmental parameters, sex, season and feed availability (Hossain et al. 2006). In order to effectively manage and maintain the stability of an ecosystem, it is crucial to perform an evaluation of the life cycle of a definite population and collect pertinent data regarding the current status of the fish within stated population. (Hossain et al. 2013b). In addition, overfishing, pollution, habitat loss, destructive fishing behavior and a range of other factors, whether acting independently or in conjunction with one another, constitute a substantial danger to the fish resources in the Bay of Bengal.

There is little literature on *S. panijus* from the Bay of Bengal (Table 1). Furthermore, relative weight (W_R) is an important metric that is commonly applied to assess the condition of fish in a given ecosystem while taking into account their role as either prey or predator (Froese 2006; Khatun et al. 2023). The goal of this research is to determine which of the many biological aspects of *S. panijus* (such as their LFD, LWR, LLRs, relative weight, condition factor, size at sexual maturity, form factor and natural mortality) should be protected and carefully managed to ensure the fish's long-term viability in their natural habitat.

Table 1. Available literature on *Sillaginopsis panijus* from worldwide water bodies

Aspects	Water body	References
Multivariate morphometric investigation to delineate stock structure	Southwest coast, Bangladesh	Siddik et al. (2016)
Biometry, Length-weight and length-length relationships	North western Bay of Bengal, India	Pradhan et al. (2020)
Morphometric and meristic analysis	Rupnarayan river, India	Mukherjee and Chanda (2021)
Biometric indices	Bay of Bengal, Bangladesh	Sabbir et al. (2022)

Materials and methods

Sampling and measurement

Between September 2021 and October 2022, a total of 684 *S. panijus* individuals were captured by fishers in the Bay of Bengal using traditional fishing gears, including trawl nets with a mesh size of 2.0–3.0 cm and coastal bag seines with mesh sizes ranging from 1.5 to 3.0 cm. The samples were instantaneously placed on refrigeration as well as kept in the lab with 10% buffered formalin for later research. Measuring board was used in the lab to measure each specimen (*S. panijus*) lengths to the nearest 0.1 cm and electric balance was applied to measure body weight to the nearby 0.01 g.

Population structure

The length frequency distribution is an important factor in estimating a fish age and growth rate. Length frequency distributions, also known as LFDs, were displayed for the species of *S. panijus* across a class interval of total length measuring 2.0 centimeters (TL).

Growth pattern

The formula $BW = a*(TL)^{b}$ is commonly used to determine the relationship between length as well as weight in various species. This relationship is typically computed using natural logarithms to determine the parameters *a* and *b* in linear regression analysis, as shown in the equation $ln\ (BW) = ln\ (a) + b\ ln\ (TL)$. To ensure accurate results, extreme outliers are often removed from the analysis, as recommended by Froese (2006).

In addition to the length-weight relationship, the length-length relationship has also been studied using linear regression analysis. This involves establishing the relationship between different body lengths, such as total length (TL), standard length (SL) as well as fork length (FL), using the equation $y = a + bx$, in this equation *a* is a constant whereas *b* is the regression coefficient.

Condition factors

The allometric condition factor (K_A) was determined using the formula $K_A=W/L^{b}$; as proposed by Tesch (1968), where *W* denotes the total body weight in grams, *L* is the total length in centimeters, and *b* is the exponent derived from the length-weight relationship. The equation is followed to determined Fulton's condition factor (Fulton 1904): $K_F = 100*(W/L^3)$, there is *W* represents total body weight in grams as well as *L* represents overall length in cm. Conducted by Froese (2006), the scaling factor of 100 results in a K_F value that is relatively close to 1.

According to Le Cren (1951), the relative condition factor (K_R) was evaluated by the formula $K_R = W/(a*L^{b})$. In this equation, *W* represents the total body weight measured in grams, *L* represents the total length measured in cm, whereas *a* and *b* are the parameters of the length-weight relationship (LWR). Another method to estimate the relative weight (W_R) is presented by Froese (2006), expressed as $W_R = (W/W_S)$ 100. In this formula, W_S represents as expected standard weight for the same specimen and is determined using the formula $W_S = aL^{b}$, where *a* as well as *b* is the regression parameters of the length-weight relationship (LWR).

Form factor

The form factor ($a_{3.0}$) of *S. panijus* was calculated using the method proposed by Froese (2006), expressed as: $a_{3.0}= 10^{\log a\ -\ s\ (b-3)}$, where '*a*' and '*b*' are parameters from the length-weight relationship and '*s*' is a regression slope constant. The equation involves LWR parameters *a* and *b* and regression slope *S* of *ln a vs b*. However, the lack of adequate information on LWRs for this particular species has hindered our ability to estimate the regression slope (*S*) of *ln a* versus *b*. Instead, *a* refers to slope of -1.358 was employed as an alternative to estimate the form factor during the course of this research. The utilization of this approach was deemed necessary due to the requirement of adequate understanding of LWRs in order to determine the regression slope (*S*) of *ln a* versus *b*.

Size at sexual maturity (L_m)

To estimate the L_m value of *S. panijus*, the formula developed by Binohlan and Froese (2009) was employed, which is expressed as $\log (L_m) = -0.1181 + 0.9157 *(L_{max})$, in this equation L_{max} denotes the highest length recorded for the species.

Natural mortality (M_w)

The model was used to estimate M_w value by Peterson and Wroblewski (1984), which includes the following equations: $M_w = 1.92\ year^{-1} * (W)^{-0.25}$; in this equation M_w refers to natural mortality at corpus *W* as well as *W*

is calculated as $W = a*L^b$, in this formula *a* as well as *b* is the LWR parameters.

Statistical analyses

The Microsoft Excel (version 2010) and GraphPad Prism 8.0 software packages were utilized for data processing and statistical analyses. The Spearman rank correlation test was employed for the determination of the correlation between the condition factors and total length (TL) and body weight (BW). Furthermore, a Wilcoxon signed-rank test was performed to distinguish the mean relative weight (W_R) from 100, as outlined by Anderson and Neumann (1996). All statistical analyses were performed at a 5% significance level ($p < 0.05$), in accordance with established scientific standards.

Results

Population structure

A total of 684 fish specimens were provided by local fishers in the Bay of Bengal, Bangladesh, for analysis. These samples were used to estimate the length-weight relationship (LWR) regression parameters, including 95% confidence limits. Table 2 contains the descriptive data of the length and weight of 684 *S. panijus* and their respective confidence limits (*CL*) for 95%. The length frequency distribution (LFD) revealed that the specimens ranging in length from 11.5 cm to 38 cm in *TL* were the lowest and biggest, respectively, whereas the body weight ranged from 6.79 to 548.0 g. In order to the length frequency distribution, the *TL* size ranging from 27.99 to 28.99 centimeters had a statistically dominant position (Fig. 1).

Growth pattern (LWR & LLR)

The results of the coefficient of determination (r^2), the *CL* (confidence limit) as well as the growth pattern of *S. panijus* are shown in Table 3 and Fig. 2. The *b* coefficient of the length-weight relationship (TL *vs* BW) exhibited an allometric growth pattern in the case of this particular species. Furthermore, Fig. 3 demonstrate that the *b* value of LLR (TL *vs.* SL and TL *vs.* FL) indicated the same growth pattern ($b>1$).

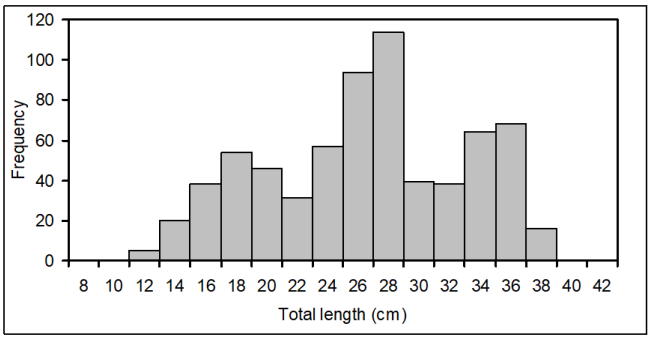

Fig. 1. The length frequency distribution of *Sillaginopsis panijus* in the Bay of Bengal, Bangladesh

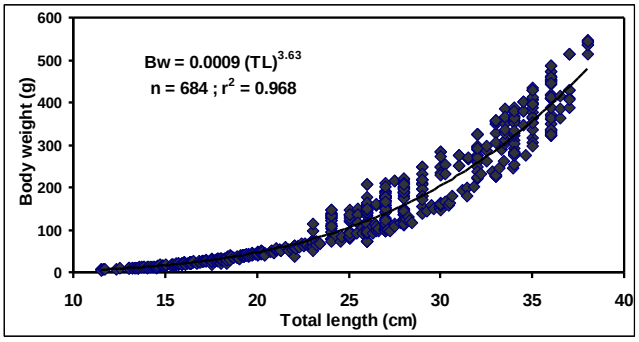

Fig. 2. The length frequency distribution of *Sillaginopsis panijus* in the Bay of Bengal, Bangladesh

Condition factor

In Table 4 presents the values of four condition factors (K_F, K_A, K_R, and W_R). The results of the Spearman rank correlation test indicated a high correlation between the condition factors *vs.* TL and BW (Table 5). Additionally, the average relative weight (W_R) of *S. panijus* in the studied area did not significantly differ from 100 ($p < 0.0001$).

Form factor

The calculated form factor ($a_{3.0}$) of *S. panijus* in the Bay of Bengal was 0.0064.

Table 2. Descriptive statistics on length (cm) and weight (g) measurements (i= 684) with their 95% confidence limit of *Sillaginopsis panijus* in the Bay of Bengal, Bangladesh

Measurement	Minimum	Maximum	Mean ± SD	95% CL
Total length	11.50	38.00	25.91 ± 6.62	25.41 - 26.41
Fork length	11.30	36.00	24.60 ± 6.16	24.14 - 25.07
Standard length	9.60	34.50	22.48 ± 6.08	22.02 - 22.93
Body weight	6.79	548.0	160.43 ± 130.75	150.61 - 170.25

Table 3. Descriptive statistics (*n*=684) of length-weight and length-length relationships (LWR & LLR) of *Sillaginopsis panijus* in the Bay of Bengal

Formula	Regression variables		95% CL of *a*	95% CL of *b*	r^2
	a	*b*			
$BW = a \times TL^b$	0.0009	3.625	0.001 to 0.001	3.575 to 3.674	0.968
$SL = a + b \times TL$	-1.132	0.911	-1.361 to -0.903	0.903 to 0.920	0.985

Table 4. Descriptive statistics (*n*=684) of length-weight and length-length relationships (LWR & LLR) of *Sillaginopsis panijus* in the Bay of Bengal

Conditions	Minimum	Maximum	Mean ± SD	95% CL
Allometric condition factor (K_A)	0.0005	0.0016	0.0009 ± 0.0002	0.0009 - 0.0009
Fulton's condition factor (K_F)	0.336	1.189	0.695± 0.178	0.682 - 0.709
Relative condition factor (K_R)	0.527	1.552	0.916 ± 0.169	0.903 - 0.929
Relative weight (W_R)	52.65	155.19	91.60 ± 16.91	90.33 - 92.87

Table 5. Relationships of condition factor with total length (TL) and body weight (BW) of *Sillaginopsis panijus* in the Bay of Bengal

Relationships	r_s values	95% CL of r_s	*p* values	significance
TL vs. K_A	0.04014	-0.03715 to 0.1169	0.2945	*ns*
TL vs. K_F	0.7040	0.6628 to 0.7409	<0.0001	****
TL vs. K_R	0.04168	-0.03561 to 0.1185	0.2763	*ns*
BW vs. K_A	0.2559	0.1824 to 0.3267	<0.0001	****
BW vs. K_F	0.8453	0.8217 to 0.8660	<0.0001	****
BW vs. K_R	0.2612	0.1878 to 0.3317	<0.0001	****

Size at sexual maturity (L_m)

L_m of *S. panijus* in studied area was determined 21.27 cm in TL with 95% CL= 16.37-27.45 cm.

Natural Mortality (M_W)

During this study, the M_W of *S. panijus* was determined as 1.69 year^{-1} in the studied area (Fig. 4).

Discussion

Prior to this study, limited information was available regarding the population structure and ecological status of *Sillaginopsis panijus*. The present study provides a comprehensive and accurate assessment of the population structure, growth patterns, and condition of Sillaginopsis panijus, incorporating analyses such as length-frequency distribution (LFD), length-weight relationships (LWR), length-length relationships (LLR), multiple condition factors, size at sexual maturity, and natural mortality during a one-year period, a variety of fish individuals of varying

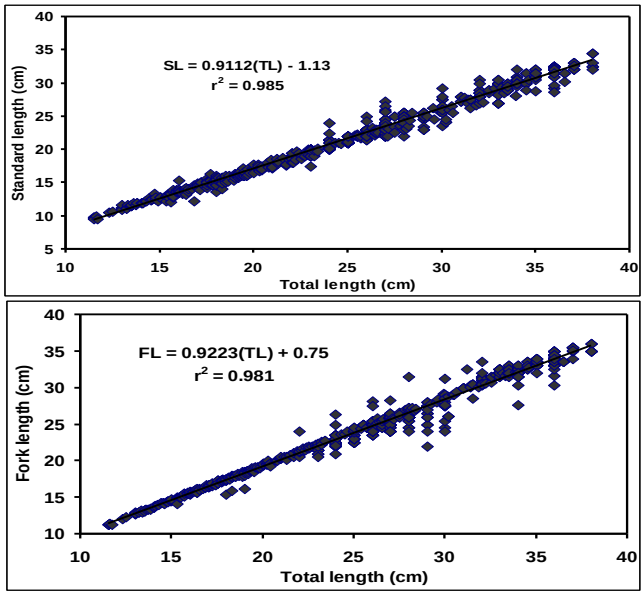

Fig. 3. Relationship between standard length, fork lenth and total length (SL = a+b×TL and FL = a+b×TL) of *Sillaginopsis Panijus* in the Bay of Bengal

sizes were collected from the Bay of Bengal in Bangladesh.

The current study provides a comprehensive and detailed assessment of the species' population structure, growth patterns, and condition including LFD, LWR, LLR, multi-type condition factors, size at sexual maturity and natural mortality in the Bay of Bengal, Bangladesh. Over the course of one year, specimens of varying sizes were collected to ensure accurate representation of the population.

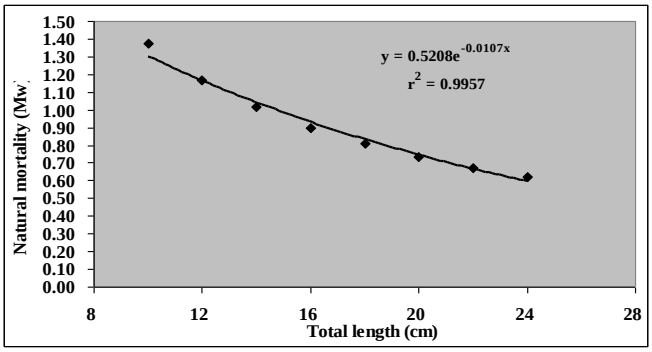

Fig. 4. Natural mortality of *Sillaginopsis Panijus* in the Bay of Bengal

Nevertheless, *S. panijus* was unable to catch in minor than 11.5 cm TL during sampling time that might be recognized to both a scarcity of tiny fish (11.5 cm TL) in the stock or the discrimination of fishing gears (Hossain et al. 2012a). Maximum total length of *S. panijus* measured in this research was 38 cm that is smaller from the highest noted values in 40.3 cm of TL (Pradhan et al. 2020) and 44.0 cm in TL for combined data according to Talwar and Jhingran (1991). This variance would be attributed to geographic site as well as food accessibility (Hossain & Ohtomi 2010). For the planning and management of fisheries resources, including growth coefficient and asymptotic length of specimens, data on maximum length is required (Hossain et al. 2012b; Parvin et al. 2018; Khatun et al. 2018, 2019).

Allometric coefficient *b* value of the length-weight relationship (TL *vs.* BW) for *S. panijus* was determined to be 3.63. This value aligns with a predicted range of 2.0-4.0, as suggested by Tesch (1971) as well as similarly (2.50-3.50) conducted by Froese (2006). Allometric coefficient *b* value of LWR for *S. panijus* was found to fall within the expected range. In present study, *b* value indicated positive allometric growth (3.63) for that we can say, fish become heavier as length increases, which is in accordance with Tesch (1971). Again, Sabbir et al. (2022) found a growth trend in the Bay of Bengal that was comparable to the research and their findings are presented here.

To find the best condition index to assess *S. panijus*'s general health, we combined several condition components (K_F, K_A and K_R). The healthier state of the fish is indicated a significant correlation between K_F and TL for this species, showing that K_F was extremely significant to describe the health of *S. panijus* (Table 5). According to Froese (2006), a W_R (relative weight) value less than 100 suggests limited food availability, while a value greater than 100 reflects a habitat with ample prey resources. Throughout the course of our research, we determined that the average W_R indicated that neither *S. panijus* statistically strayed from the value of 100, which provided evidence that the ecosystem was in a stable state. There is an inadequate amount of literature identified on the condition factor of *S. panijus*. As a result, we were unable to compare the results with those of other investigations. Additionally, to considering the relative weight of *S. panijus*, our study represents the first attempt to elucidate the condition component.

The $a_{3.0}$ value of 0.0064 indicates that the *S. panijus* population in studied region has an elongated body shape. Even though, there were a few research conducted on form factor and the literature did not make any reference to this species. The length at sexual maturity (L_m) of *S. panijus* was 21.27 cm in total length. The L_m studies are limited in the Bay of Bengal (except Hossain et al. 2010, 2012c). According to Fishbase (McKay 1992), the length of the TL at the time it reached sexual maturity was 12.0 cm (Indo-Pacific region), which is comparable to the length that we determined. In accordance with Khatun et al. (2019), this variation can be attributed to sampling or ecologic dissimilarities in population densities, food availability, mesh size or water temperature. A few researches have been done on L_m, which makes it difficult to compare it to other topics. This work, on the other hand, is the very first attempt to determine the L_m for *S. panijus* in the various waters of the Indian subcontinent. In the current investigation, the natural mortality (M_w) of *S. panijus* in the studied area was determined to be 1.69 year^{-1}. On the other hand, there

is not enough information on M_w, because of the comparison with other species is limited.

Conclusion

This study comprised population distribution, growth pattern, growth parameters, form factor, suitable condition factor, size at sexual maturity, prey predator condition as well as natural mortality. These traits might help fish biologists, fisheries managers and conservationists to develop management methods and restrictions to preserve the surviving populations of this specimen in the Bay of Bengal and adjacent area in Bangladesh.

Conflict of interest

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

Acknowledgement

We sincerely appreciate the financial support provided by PIU-BARC-NATP-2 PBRG-156. The researchers also extend their heartfelt thanks to the fishers, who wish to remain anonymous, for their cooperation and valuable help throughout the sample collection.

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How to cite this article: Abedin MJ, Khatun MS, Ilah NEF, Molla S, Laboni TA, Akhi TA, Kamruzzaman, Nesa MM, Hasan MA, Nasrin K, Parvin MF & Habib KA (2024). Assessing the population structure, growth, conditions and sexual maturity of *Sillaginopsis panijus* in the Bay of Bengal, Bangladesh. Fisheries Studies, 02, 31-39.