2021

Stock Assessment of the Hooghly Croaker Panna Heterolepis From the Bay of Bengal in Bangladesh Through Multi-Mode

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STOCK ASSESSMENT OF THE HOOGHLY CROAKER *PANNA HETEROLEPIS*

FROM THE BAY OF BENGAL IN BANGLADESH THROUGH MULTI-MODELS

A THESIS SUBMITTED TO
THE UNIVERSITY OF RAJSHAHI, BANGLADESH
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY (Ph.D)

Submitted by

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July, 2021

Dedicated
To My Beloved Family
Members

Declaration

I hereby declare that the whole work submitted as a thesis entitled "**STOCK ASSESSMENT OF HOOGHLY CROAKER *PANNA HETEROLEPIS* FROM THE BAY OF BENGAL IN BANGLADESH THROUGH MULTI-MODELS"** to the Department of Fisheries, Faculty of Agriculture, University of Rajshahi, Rajshahi-6205, Bangladesh for the degree of Doctor of Philosophy is the result of my own investigation which has been carried out under the supervision of Dr. Md. Yeamin Hossain, Professor, Department of Fisheries, Faculty of Agriculture, University of Rajshahi, Rajshahi-6205, Bangladesh. I further declare that the thesis has not been submitted elsewhere for any other degree. Besides, I have published some parts of this thesis as scientific papers for fulfillment of the requirements of Ph.D degree.

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Certificate

This is to certify that the entitled **"STOCK ASSESSMENT OF HOOGHLY CROAKER *PANNA HETEROLEPIS* FROM THE BAY OF BENGAL IN BANGLADESH THROUGH MULTI-MODELS"** has been prepared by Wasim Sabbir, Unique ID. 1913067503 under my supervision for submission to the Department of Fisheries, Faculty of Agriculture, University of Rajshahi, Rajshahi-6205, Bangladesh for the degree of Doctor of Philosophy (Ph.D). All the data presented in this thesis are based on his own observation and no part of this work has been previously published or submitted for any other degree.

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Acknowledgements

All admiration and gratitude are solely due to the Almighty Allah, the creator, great, merciful, sustainer and supreme power of the universe who enabled the author to complete the research work successfully and finally gave patience to write this manuscript and to materialize the dream for the Ph. D degree in Fisheries Science.

The author sincerely expresses his heart-felt sense of gratitude and indebtedness to his respected research supervisor, Dr. Md. Yeamin Hossain, Professor, Department of Fisheries, University of Rajshahi, for his congenial patience and practical cooperation, distinguishable scholastic guidance, valuable suggestions, stimulating counsel, constructive criticism, fruitful discussion and constant encouragement in carrying out this research work. Dr. Hossain sacrificed many of his precious hours during preparing this thesis and critically revising the manuscripts to bring this thesis up to its present standard.

The author wishes to take this opportunity to record his gratitude to all the teachers of the Department of Faculty, Faculty of Agriculture for their love and affection during his entire period of study at this University.

The author gives thanks to (i) MoST (Ministry of Science and Technology) for providing financial support and (ii) PIU-BARC, NATP-2, PBRG-156 for technical support to complete the research work. The author also likes to express his gratitude to the fishers of Bay of Bengal, Bangladesh, for their co-operation during sampling and data collection.

The author also takes this opportunity to express his gratefulness to Md. Nuruzzaman Khan, Md. Akhtarul Islam, Md. Ataur Rahman, Obaidur Rahman, Zannatul Mawa, Md. Rabiul Hasan and Md. Ashekur Rahman, Masters students and those working in the Laboratory under Dr. Md. Yeamin Hossain, Division of Fisheries Management, Department of Fisheries, University of Rajshahi, Rajshahi-6205, for their valuable information and cordial assistance during data collection.

Finally, the author expresses his heartiest gratitude and ever indebtedness to his family members for their inspiration, constant blessings, kind co-operation, valuable advices and a lot of sacrifice in all respect throughout his life.

The Author
January, 2021

Abstract

The Hooghly croaker (*Panna heterolepis* Trewavas, 1977) is a very popular marine and brackish water fish species in Bangladesh under the family Sciaenidae. This species is locally known as *Poa* and commercially very important as a table food item in the coastal region of Bangladesh. The overall objective of this study is to assess the stock of *P. heterolepis* in the Bay of Bengal, Bangladesh. A total of 1223 specimens were collected monthly basis using traditional fishing gears from the Bay of Bengal, Bangladesh, during January to December, 2019. Male and female individuals were identified by gonadal observation under microscope. Individual total length (TL) and body weight (BW) were measured by measuring board and digital balance with 0.01 cm and 0.01 g accuracy. The length frequency distribution was estimated by 1.0 cm TL intervals. The length-weight relationship (LWR) was calculated by $W=a*L^b$. Multiple condition factors (Fulton's, K_F; allometric, K_A; Relative, K_R and relative weight, W_R) were analyzed for assessing the well-being of this species in relation to eco-climatic factors. To assess the size at sexual maturity (TL_m), spawning season and peak - spawning season; the GSI (gonadosomatic index in %), MGSI (modified gonadosomatic index in %) and DI (Dobriyal index) were considered. The von Bertalanffy growth function (VBGF) was used to determine asymptotic length (L_∞), growth coefficient (K), growth performance index ($Ø'$) and life-span (t_{max}). Total mortality (Z) was calculated by the length-converted catch curve method. Natural mortality (M) was assessed as $\log_{10}M$ = -0.0066 – 0.279$\log_{10} L_\infty$ + 0:6543$\log_{10}K$ + 0:0463$\log_{10}$T; where T indicates the average temperature of the habitat (28.5^{o}C). The fishing mortality (F) was estimated as Z-M. Besides, exploitation rate (E) was determined as $E = F/Z = F / (F + M)$. Recruitment rate was assessed from the analysis of the total time series of LFDs and growth parameters using VBGF models. Finally, MSY (Maximum Sustainable Yield) was determined following the formula of Gulland (1983). The fin formula was: D. 43 – 55 (VIII–X + i/34–44); P. 15 17 (i/14–16); Pv. 6 (I/5); A. 7 – 10 (II/5–8); C. 17 – 19 (ii/15–17). The overall sex ratio (male: female=1.00:0.87) varied statistically from the predictable ratio of 1:1 (df =1, $\chi 2$ = 5.91, p > 0.05). The overall growth pattern was negative allometric (b < 3.0) for both sexes. Further, the allometric co-efficient (b) of LWRs was found significantly related with habitat temperature for both male and female, respectively. Total length varied between 10.7-31.4 cm for males and 10.5-34.5 cm for females. The calculated form factor ($a_{3.0}$) was 0.0070 and 0.0071 for male and female *P. heterolepis*, respectively. The K_F was found the best for assessing the well-being of this species. Moreover, K_F was found significantly related with temperature for both male and female. The W_R denoted that the ecosystem was in balanced condition. Based on GSI, MGSI and DI index, the L_m was documented 15.0 cm in TL. Further, the higher values of GSI, MGSI and DI denoted that the spawning season was extended from January to July, with a peak in February. In addition, GSI was recorded statistically correlated with water temperature. The von Bertalanffy growth function revealed growth coefficient (K = 0.13 year^{-1}), growth performance index ($Ø'$ = 2.30) and life-span (t_{max} = 3.85 year). Further, *P. heterolepis* was found to grow rapidly with an asymptotic length (L_∞) of 39.08 cm. We found that the natural mortality (M = 0.44 year^{-1}) rate is almost similar with fishing mortality (F = 0.42 year^{-1}). Consequently, the standing stock is not quite sustainable with the existing fishing strategy. Further, the maximum allowable exploitation rate (E_{max} = 0.471) was found a bit lower than the recorded exploitation rate (E = 0.490). Subsequently, overfishing is the most focal threat for the wild population of *P. heterolepis* in the context of Bay of Bengal, Bangladesh. The recruitment pattern was almost continuous throughout sampling period with one major peak in April-May. Finally, the MSY was assessed at 10,234.47 metric tons. The findings would be very useful to introduce appropriate fishing regulations in the Bay of Bengal ecosystem.

Contents

List of Tables

List of Figures

List of Plates

Chapter 1

General Introduction

1. GENERAL INTRODUCTION

1.1 Fisheries and Bangladesh

Bangladesh is blessed with a huge amount of open waterbody like rivers, canals, natural and man-made lakes, freshwater marshes, estuaries, brackish water impoundments, floodplains and an extensive coastline of about 710 km. Together with vast water resources; Bangladesh is rich with various fish and other aquatic species. The marine sector is considered the most vital part of Bangladesh for capturing different fish species. Hence, Bangladesh occupies third position in aquatic biodiversity in Asia after China and India with 475 coastal and marine fish species (Hussain and Mazid, 2010). In our country, fish is the main source of animal protein and contributes 60% of the daily dietary protein requirement (DoF, 2020). Besides, fisheries sector has a significant role in creating employment opportunity and earning of foreign exchange (Alam and Thomson, 2001). In 2018-19, Bangladesh exported 68.31 thousand MT of fisheries product and earned BDT 42876.40 million (FRSS, 2020). Furthermore, 17 million people directly depend on fisheries sector including 1.4 million women for their livelihoods (DoF, 2019). The contribution of fisheries sector to national GDP is 3.61% and total agricultural sector is 24.41% (FRSS, 2020). But regrettably, our marine sector is under great threat due to over-exploitation accelerated by different ecological modification and natural habitats' deterioration (Hossain et al., 2012). On the other hand, climate change is likely to badly affect both the freshwater and marine fisheries in Bangladesh (Allison et al., 2009).

At present, improved biological management is the main priority in the development policy that will limit the declination of fisheries resources and enhance production. In order to conserve our threatened fish species it is immensely important to identify critical aspects of the life histories including age, growth, reproductive biology and longevity. The knowledge of reproductive biology is the key to formulate sound fisheries management policy. King (2007) stated that information about reproductive biology of fish is vital for understanding of its population dynamics and to formulate baseline data in the management process. Effective management practice depends on knowledge of the regenerative capacity of fish populations including reproductive behavior (Tracey et al., 2007). On the other hand, growth of fish largely depends on sex, availability of feed, water quality parameters and other environmental factors (Dall et al., 1990). In addition, growth and recruitment have notable effect to uphold maximum sustainable yield of a stock.

Panna heterolepis is a popular commercial fish species in the coastal region of Bangladesh. According to the author's knowledge, only a few works including the morphometry (Sanphui et al., 2018) had been done on *P. heterolepis*. However, there is no published report on the reproductive biology, growth, age and longevity of the above mentioned species from Bangladeshi coastal water for planning appropriate management strategies of this commercially important fish species. Since *P. heterolepis* is an important marine species, there is an urgent need to manage and regulate its stocks in Bangladesh and this requires information on the population dynamics of this species.

1.2. Short Profile of *Panna heterolepis*

The Hooghly croaker *Panna heterolepis* Trewavas, 1977 is a very popular marine and brackish water fish species in Bangladesh under the family Sciaenidae. This species is locally known as *Poa* and commercially very important as a table food item in the coastal region of Bangladesh. Due to lack of culture practice, the total demand of this species is met through the capture from wild stock. As a result, overfishing is a major threat for the abundance of wild stock of *P.heterolepis*.

Systematic position

Phylum: Chordata
Class: Actinopterygii
Order: Perciformes
Family: Sciaenidae
Genus: *Panna*
Species: *Panna heterolepis*

Plate 1: Photo of *Panna heterolepis*

1.2.1. Common names

Panna heterolepis is locally known as *Poa* in Bangladesh. In India, this species is known as Hooghly croaker (Froese and Pauly, 2020).

1.2.2. Synonyms

Table 1. Synonyms of *Panna heterolepis*

Synonym	Status	Validity
Panna heterolepis Trewavas, 1977	Accepted	Yes
Panna microdon Bleeker, 1849	Misapplied	No
Sciaenoides microdon Bleeker, 1849	Misapplied	No

1.2.3. Distribution

This Sciaenid fish is distributed in Bangladesh, Myanmar, India and Sri Lanka (Sasaki, 1995).

1.2.4. Habitat

P. heterolrpis mainly inhibits in shallow marine waters and estuaries; young and juveniles occur in mangrove swamps (Talwar and Jhingran, 1991).

1.2.5. Morphology

The mouth is large, oblique and terminal and the head is with an acute snout. The body color is brownish that become lighter on belly while the fins are yellowish. Dark margin is present on dorsal and anal fins. Dorsal fin has a low notch with weak spines and the second anal spine is also weak. The body is covered with small ctenoid scale while the head is with cycloid scale (This study).

1.2.6. Fin Formula

D. 43 – 55 (VIII–X + i/34–44); P. 15 17 (i/14–16); Pv. 6 (I/5); A. 7 – 10 (II/5–8); C. 17 – 19 (ii/15–17) (This study).

1.2.7. Overall objective

The broad objective of our study is to assess the stock of *P. heterolepis* in the Bay of Bengal, Bangladesh.

1.2.8. Specific objectives

The specific objectives are:

- To estimate the morphometric relationship and meristic characteristics of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

- To determine the condition factors of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

- To determine the reproductive biology of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

- To assess the stock of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

Chapter 2

Review of Literature

2. REVIEW OF LITERATURE

It is urgent to review the former research studies for conducting a planned research experiment. Unfortunately, there is no published report on the reproductive biology, growth, age and longevity of the *P. heterolepis* for planning appropriate management strategies of this commercially important fish species. However, some related literatures are described below.

Ahamed et al. (2015) studied the size of sexual maturity of female *Puntius sophore* from Old Brahmaputra River of Bangladesh by observing the gonadosomatic index (GSI). Different morphometric parameters i.e. Fork Length (FL), Standard Length (SL), Body Weight (BW) and Gonad Weight (GW) of each individual were measured. The relationships of SL-GSI and SL-FL were used to estimate the size at first sexual maturity. Based on SL-GSI, the size at first sexual maturity for female fish was 4.2 cm standard length. Further, relative growth of FL-SL illustrated a transition point of 4 cm SL, specifying size at first sexual maturity for female fish.

Akter et al. (2020) studied the reproduction, growth, mortality and yield of the goat fish *Upeneus sulphureus* in the northern Bay of Bengal, Bangladesh. The gonadosoatic index indicated that the fish spawn twice a year during January- May and August-October. Further, the von Bertalanffy growth parameters were L_∞ = 21.80 cm, K = 0.54 per year, C = 0.05, WP = 0.1 and Rn = 0.300, respectively. The instantaneous natural mortality and fishing mortality were 1.31 and 2.86, respectively. Besides, the high exploitation rate (E = 0.69) was close to maximum exploitation level (E_{max} = 0.75) in yield–per–recruit analysis, suggesting that the species is being exploited at the MSY level. Therefore, further increase in fishing effort may reduce the wild stock in the coastal waters of Bangladesh.

Bobori et al. (2010) studied length-weight relationships of 17 different fish species collected from three natural lakes in Greece. The values of the allometric coefficient *b* varied from 2.117 ± 0.119 to 3.550 ± 0.104, with 87% of the *b* values lying between the anticipated ranges of 2.5-3.5.

Elhasni et al. (2010) observed the reproductive cycle and maturity stages of *Hexaplex trunculus* collected from Gulf of Gabès, south Tunisia. The male and female gastropods were found separate throughout the life (gonochoristic). The sex ratio varied significantly from the expected 1:1 ratio. Females were found dominant (M : F = 1:1.6). The monthly observation of gonad maturation stages, GSI (gonadosomatic index) and *K* (general condition) indicated that gametogenesis occurred throughout the year. Matured males were occurred in abundance during November to January. On the other hand, ripe females were found during February to April. The development of gonad was influenced by increasing day length and temperature of the sea water. However, the peak spawning occurred during April and May.

Goncalves et al. (2003) studied the population biology of *Diplodus vulgaris* from south west coast of Portugal. Altogether 1,086 fish specimens were collected for the experiment. Spawning season of the above mentioned species occurred from September to April. Total lengths at which 50% fish become sexually matured were 17.27 and 17.65 cm for males and females respectively. The von Bertalanfy growth parameters were $L_\infty = 27.73$ cm, $K = 0.40$ per year and $t_0 = -0.34$ year. The instantaneous mortality rate was 0.63 per year and natural mortality rate were 0.45 per year. Further, fishing mortality rate was 0.18 per year as well as exploitation rate was 0.28 per year.

Hajjej et al. (2011) observed the reproductive biology of *Euthynnus alletteratus*, which is known as little tuna in Tunisia. Altogether 1,086 fish specimens were collected for the experiment from Tunisian coastal water from January 2008 to December 2009. The experiment illustrated that the sex ratio for female was 57.77%. Spawning occurred from June to September. Fork length, at which 50% fish become sexually matured (Lm_{50}) were 43.13 and 42.12 cm for females and males, respectively.

Hossain et al. (2006) observed the length-length (LLRs) and length-weight (LWRs) relationships for eight small indigenous species from Mathabhanga River, Bangladesh, namely *Hyporamphus quoi*, *Amblypharyngodon mola*, *Macrognathus aculeatus*, *Channa punctata*, *Puntius sophore*, *Macrognathus pancalus*, *Nandus nandus*, and *Setipinna phasa*. Altogether 2,543 specimens were collected for the experiment by traditional gears for 12 months during the year 2005. The allometric coefficient '*b*' of

LWRs ranged from 2.864 to 3.397. The average value was 3.098. Further, the study revealed negative allometric growth for *M. aculeatus* while remaining species showed positive growth pattern. All LLRs were found significant ($P < 0.001$).

Hossain et al. (2009) described the length–length and length–weight relationships for ten indigenous species (SIS) in Bangladesh, namely *Puntius ticto*, *Lepidocephalus guntea*, *Ailia coila*, *Aspidoparia morar*, *Eutropiichthyes vacha*, *Amblypharyngodon mola*, *Mystus vittatus*, *Clupisoma atherinoides*, *Gudusia chapra* and *Glossogobius giuris*. Fish species were collected from lower part of Ganges by traditional gears. Altogether 2,142 specimens were collected for the experiment for 12 months from March, 2006 to February, 2007. The allometric coefficient '*b*' was found isometric (b = 3.001) for *G. giuris*. Further, the study revealed negative allometric growth for *P. ticto, E. vacha, A. coila, C. atherinoides and A. morar* while remaining species showed positive growth pattern. All LLRs were found significant ($P < 0.001$).

Hossain (2010a) studied the length-length and length-weight relationships of four small fish species namely *Aspidoparia morar*, *Amblypharyngodon mola*, *Puntius ticto* and *Lepidocephalus guntea*. Altogether 914 specimens were collected from Padma River, Bangladesh during March 2006 to February 2007. The allometric coefficient '*b*' was found isometric (≈3.000) for *A. morar* and *P. ticto*. Further, the study revealed positive allometric growth for *A. Mola* and *L. guntea*. All LLRs were found significant and highly correlated ($r^2 > 0.932$; $P < 0.001$).

Hossain et al. (2013) studied the life history traits of *Eutropiichthys vacha* from Jamuna River, Bangladesh. The experiment was conducted from March, 2010 to February, 2011. A total of 350 specimens were collected to analyze sex ratio, length-weight and length-length relationships, length frequency distribution, condition factors and form factor ($a_{3.0}$). No significant difference was found in the overall sex ratio of 1:1. The value of '*b*' (allometric coefficient) was found isometric (~*3.00*) for male and combined sexes but female showed negative allometric growth pattern. Besides, the experiment showed that length-length relationships were extremely correlated ($r^2 >$ 0.997; $P < 0.001$). Relative condition factor (K_R) indicated significant difference between both sexes (F=65.11; $P < 0.01$). However, Relative Weight (W_R) was considerably different from 100 indicating imbalance habitat for the species. The calculated form factor ($a_{3.0}$) was 0.0060 and 0.0050 for males and females, respectively.

Hossain et al. (2016a) studied the length- weight relationships (LWRs) for *Dermogenys pusilla* and *Labeo bata* from Ganges River, Bangladesh. The study extended from July, 2013 to June, 2014. For each specimen, total length (TL) was considered close to 0.01 cm and body weight was measured close to 0.01 g accuracy. Total Length ranged from 6.60 to 16.10 and 7.90 to 25.20 cm for *D. pusilla* and *L. bata*, respectively. The Body Weight (BW) ranged from 1.20 to 10.90 and 4.70 to 167.30 g for *D. pusilla* and *L. bata*, respectively. All LWRs were found statistically significant ($P < 0.001$, $r^2 \geq 0.976$).

Hossain et al. (2016b) studied the sex ratio, length-weight and length-length relationships, length frequency distribution and condition factors of *Cabdio morar* from Jamuna River, Bangladesh. The sex ratio (SR) demonstrated significant differences from the anticipated value of 1:1 (male: female). The value of '*b*' (allometric coefficient) was found positive allometric (> 3.00) for male but female showed isometric growth (~ 3.00). Length-Weight Relationships indicated significant differences between the sexes. Further, K_F indicated significant differences ($P < 0.01$) between males and females, while female performance (0.88 ± 0.14) was found better than males (0.86 ± 0.15). Besides, the spawning season of *C. morar* ranged from December to March in Jamuna River.

Hossain et al. (2017a) studied some biological aspects of *Nandus nandus* i.e. population structure, growth, condition factors, form factor ($a_{3.0}$), reproduction and natural mortality in the Ganges River (NW Bangladesh). The value of '*b*' (allometric coefficient) indicated positive growth (> 3.00) for Total Length vs. Body Weight Relationship but isometric growth (~ 3.00) for Standard Length vs. Body Weight relationship. Fulton's condition factor (K_F) was found best for this species. Relative Weight (W_R) did not vary significantly from 100 indicated a balanced habitat for the species. The calculated form factor ($a_{3.0}$) was 0.0159 indicated that the body shape of the fish was short and deep. Besides, size at sexual maturity (*Lm*) was found 9.10 cm TL (Total Length) and the natural mortality (M_W) was predicted to be 1.33 y^{-1}.

Hossen et al. (2019) observed the population parameters of *Channa punctata* from Rupsha River of southern Bangladesh through multi-models. Altogether 132 specimens were collected using different traditional gears like cast net and gill net to analyze length- weight and length-length relationships, length frequency distribution, form factor, condition factors and natural mortality of *C. punctata*. The experiment was conducted from September, 2014 to August, 2015. For each specimen, total length (TL) was considered close to 0.01 cm and body weight was measured close to 0.01 g accuracy. It was observed that 13.0-14.0 cm TL size was numerically dominant. The growth pattern was recorded positive allometric (b = 3.10). Fulton's condition factor (K_F) was documented best for describing the well-being for this species in the Rupsha River of Bangladesh. But the relative weight (W_R) denoted an imbalanced habitat with higher predators. The form factor was recorded 0.0116. Further, the natural mortality was found 1.00 $year^{-1}$.

Khatun et al. (2018) observed the sex ratio, length-weight and length-length relationships, length frequency distribution and physiological condition of *Eutropiichthys vacha* from Ganges River, Bangladesh. The sex ratio (SR) demonstrated significant differences from the anticipated value of 1:1. Female was found dominant throughout the year, except April. Total Length ranged from 6.2 to 19.9 and 6.5 to 20.6 cm for male and female, respectively. The value of '*b*' (allometric coefficient) was found negative allometric (< 3.00) for both sexes while ANCOVA indicated significant variations in LWRs. Further, all length-length relationships were found highly significant (r^2 > 0.962). The proportion of fatty fish was found higher during March and April while the proportion was recorded lowest in August.

Khatun et al. (2019) studied the reproductive biology of *Eutropiichthys vacha* from Ganges River, NW Bangladesh with special consideration of climate change. Altogether 734 female fish was collected from January to December, 2016. Total lengths at which 50% fish become sexually matured were 12.7 cm. The spawning period ranged during April to August. Peak spawning occurred in June and July. Total fecundity varied from 4,800 to 77,976 with an average 31,384±23,747. Further, total fecundity was found highly correlated with total length and body weight. Average water temperature was 31^{o}C during the spawning period. The spawning was accelerated with peak rainfall.

Manorama and Ramanujam (2011) studied the length-weight relationships of *Puntius shalynius* from Umiam River, Meghalaya, India. The value of '*b*' was found negative allometric (< 3.00) for both sexes. Length-weight relationships indicated no differences between the sexes.

Memon et al. (2016) observed the length-frequency data of *Lepturacanthus savala* (Cuvier, 1829) were collected from Pakistan waters in 2009-2010. The length ranges from 5 to 127 cm and weight ranges from 1 to 1942 g. The calculated von Bertalanffy growth parameters were L_{∞} = 133.35 cm, K = 0.130 year^{-1} and t_0 = 0.877. The estimated rate of total mortality (Z) = 0.49 year^{-1}, natural mortality (M) = 0.304 year^{-1} and fishing mortality (F) = 0.185 year^{-1}. Hence, exploitation ratio (E) was calculated as 0.377 year^{-1}. Further, the estimated value of growth performance index ($Ø'$) was 3.364. The estimated value of MSY was 26,983 tons with the estimated biomass of 110,135 tons.

Morey et al. (2003) observed length-weight relationships of 103 different fish species from western Mediterranean (Iberian coast and Balearic Islands). Seven types of fishing gear were used to collect the specimens. The experiment extended from 1991 to 2001. The allometric coefficient '*b*' ranged from 2.072 to 3.847, with an average value of 3.03.

Rahman et al. (2018a) studied population biology of the *Puntius sophore* from Padma River, Bangladesh including length-frequency distributions, length-weight relationships, sex ratio, relative weight, condition factors and fecundity. The sex ratio varied significantly from the expected 1:1 ratio. Females were found dominant throughout the year. The value of '*b*' (allometric coefficient) was found isometric for both sexes. Fulton's condition factor (K_F) was found best for this species to interpret the well-being of the population. The total fecundity ranged from 1,488 to 18,708 with an average of 5,682 ± 3,703. On the other hand, relative fecundity ranged from 205 to

1,868 with an average of 882.7±369.5. Further, total fecundity was found significantly correlated with body weight (BW), total length (TL), ovary weight, gonadosomatic index (GSI) and Fulton's condition factor.

Rahman et al. (2012) observed the sex ratio, length-weight, length-length relationships and length frequency distribution of *Macrognathus aculeatus* from Ganges River, Bangladesh. Specimens were collected using different traditional gears i.e. conical trap, cast net and gill net. Altogether 254 specimens were collected for the experiment. Total length (TL) ranged from 9.20 to 19.71cm and body weight (BW) ranged from 5.10 to 28.60 g.

Salam et al. (2005) observed the length-weight relationships and condition factor of *Puntius chola* from Islamabad, Pakistan. Altogether 52 specimens of different size were collected. The value of allometric coefficient '*b*' was found 2.80, indicating negative allometric growth pattern. Condition factor was found constant in measuring length or weight.

Solomon et al. (2011) studied the reproductive biology of *Puntius denisonii*. The observed results were based on three river systems namely Valapattannam, Chandragiri and Chaliyar. Maximum total length was 162 and 132 mm for male and female, respectively. Spawning occurred from October to March. The sex ratio varied significantly from the expected 1:1 ratio. Males were found dominant throughout the year. The total fecundity ranged from 376 to 1,098.

Yilmaz et al. (2010) studied length-length as well as length-weight relationships of *Capoeta sieboldii*. Altogether 170 specimens were collected from Hirfanli Lake of Turkey. Length-weight relationships of both sexes showed no statistical difference within or with the season and revealed isometric growth for both sexes. The correlations among total length, fork length and standard length where found highly significant ($r^2 > 0.92$, $P < 0.001$). The K value for female varied from 1.21 to 1.43 while for male it ranged from 1.12 to 1.36.

Chapter 3

Study-I

STUDY-I

Morphometric relationship and meristic characteristics of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

3.1. Abstract

The study describes the morphometric relationships and meristic counts including fin rays, monthly variation of sex ratio, the length-frequency (LFDs) distributions, length-length (LLRs) relationships, growth pattern based on length-weight (LWRs) relationships in relation to eco-climatic factors and form factor ($a_{3.0}$) of *Panna heterolepis* from the Bay of Bengal, Bangladesh. All together 1,223 specimens (male = 654 and female = 569) were collected from the fishers during January to December, 2019. Individual total length (TL) and body weight (BW) were measured by measuring board and digital balance with 0.01 cm and 0.01 g accuracy. The fin formula was: D. 43 – 55 (VIII–X + i/34–44); P. 15 17 (i/14–16); Pv. 6 (I/5); A. 7 – 10 (II/5–8); C. 17 – 19 (ii/15–17). The overall SR (male: female=1.00:0.87) varied statistically from the predictable ratio of 1:1 (df =1, $\chi2$ = 5.91, p > 0.05). The LFDs for both sexes did not pass the normality. Further, Mann-Whitney U-test showed no significant differences between sexes (p = 0.5125). Total length varied between 10.7-31.4 cm for males and 10.5-34.5 cm for females. The overall b value for both sexes indicated negative allometric growth (< 3.00) for most of the months. In addition, the LLR (TL *vs.* SL) was extremely correlated (p < 0.001), with all r^2 values ≥ 0.982. The allometric co-efficient (b) of LWRs was found significantly related with temperature for both male and female respectively. However, Rainfall, DO and pH did not reveal any significant correlation with the growth pattern for both sexes. The calculated form factor ($a_{3.0}$) was 0.0070 and 0.0071 for male and female *P. heterolepis*, respectively. The results of this study will be helpful for stock assessment and management of this fish in the Bay of Bengal, Bangladesh and neighboring countries.

Key words: *Panna heterolepis,* fin formula, sex ratio, growth pattern, eco-climatic factors, Bay of Bengal.

3.2. Introduction

The southern estuarine and marine water-bodies of Bangladesh are blessed with vast quantities of fishes that can be catch commercially may have boundless contribution to the national economy of the country (Belton et al., 2014; Hanif et al., 2015; Islam, 2003). The Hooghly Croaker (*Panna heterolepis* Trewavas, 1977) belonging to the family Sciaenidae is a tropical fish species inhabit shallow coastal waters and estuaries while young and juveniles occurs in mangrove swamps. This Sciaenid fish is distributed in Bangladesh, Myanmar, India and Sri Lanka (Sasaki, 1995). This species is popular food items and fairly common in the commercial catch that marketed fresh as well as dried salted. According to the author's knowledge, only a few works including the morphometry (Sanphui et al., 2018) had been done on *P. heterolepis*. However, there is no available published report on the detailed morphology, reproductive biology, growth, age and longevity of the above mentioned species from Bangladeshi marine water for planning proper management strategies of this commercially important fish species.

Morphometric and meristic characters are important for fish species identification and classification as well as the genetic studies (Bagenal and Tesch, 1978; Harrison et al., 2007; Jayaram, 1999). Sex ratio and length-frequency distribution provides vital evidence to estimate reproductive potential of a fish population (Khatun et al., 2018). Length-weight relationships (LWRs) are crucial for comparing the life histories of fishes among different geographic regions (Hossain et al., 2013). Furthermore, the length-length relationships (LLRs) are very important because several eco-physiological factors are more length dependent (Hossain et al., 2006). On the other hand, form factor ($a_{3.0}$) is used widely to identify the body shape of fish in any aquatic habitat (Froese, 2006).

At present, climate change is considered as an important hazard to fisheries along with other different risk such as overfishing, pollution and habitat deterioration (Rose, 2005). Climatic factors mainly temperature and rainfall has constant effect on fish growth and survival (Shoji et al., 2011). Temperature is the most significant abiotic factors regulating the progresses of larval assemblages of freshwater as well as marine species (Houde and Zastrow, 1993; Jakobsen et al., 2009). A good number of studies linked temperature fluctuations to distributional changes in marine fish stocks (Beare et al., 2004; Alheit et al., 2005; Perry et al., 2005). Similarly, rainfall is a basic climatic factor influencing the entire chain of hydrological events through runoff and river inflow (Patrick, 2016). To ensure comprehensive fish growth, it is urgent to maintain an optimum DO (dissolved oxygen) level for physiological and metabolic activities. The DO requirement increases with increasing fish size during grow out period (Abdel-Tawwab et al., 2015). Alternatively, pH indicates whether the habitat is acidic or alkaline condition. Higher level of pH (9-14) not only affects fish by denaturing cell membranes but also alter other water quality parameters (Brown and Sadler, 1989).Therefore, it is obligatory to assess the influence of eco-climatic factors on the growth pattern of fish.

3.3. Objectives

The aims of this study are to:

- Assess the morphometric and meristic traits;
- Determine the temporal variation of sex ratio;
- Determine growth pattern in relation to the eco-climatic factors;
- Assess the length-length relationships; and
- Determine the form factor.

3.4. Materials and Methods

3.4.1. Study site and sampling

The study was conducted in the Bay of Bengal, Khulna region (21.7728^{o} N; 89.5592^{o} E), Bangladesh. Altogether, 1,223 individuals (male = 654 and female = 569) of *P. heterolepis* were collected randomly from fisher's catch during January to December, 2019 through different traditional fishing gear including seine bag net (mesh size 1.5 to 3 cm) and gill net (mesh size 3 cm). The samples were chilled with ice at sampling spot and preserved in 10% formalin solution at the laboratory.

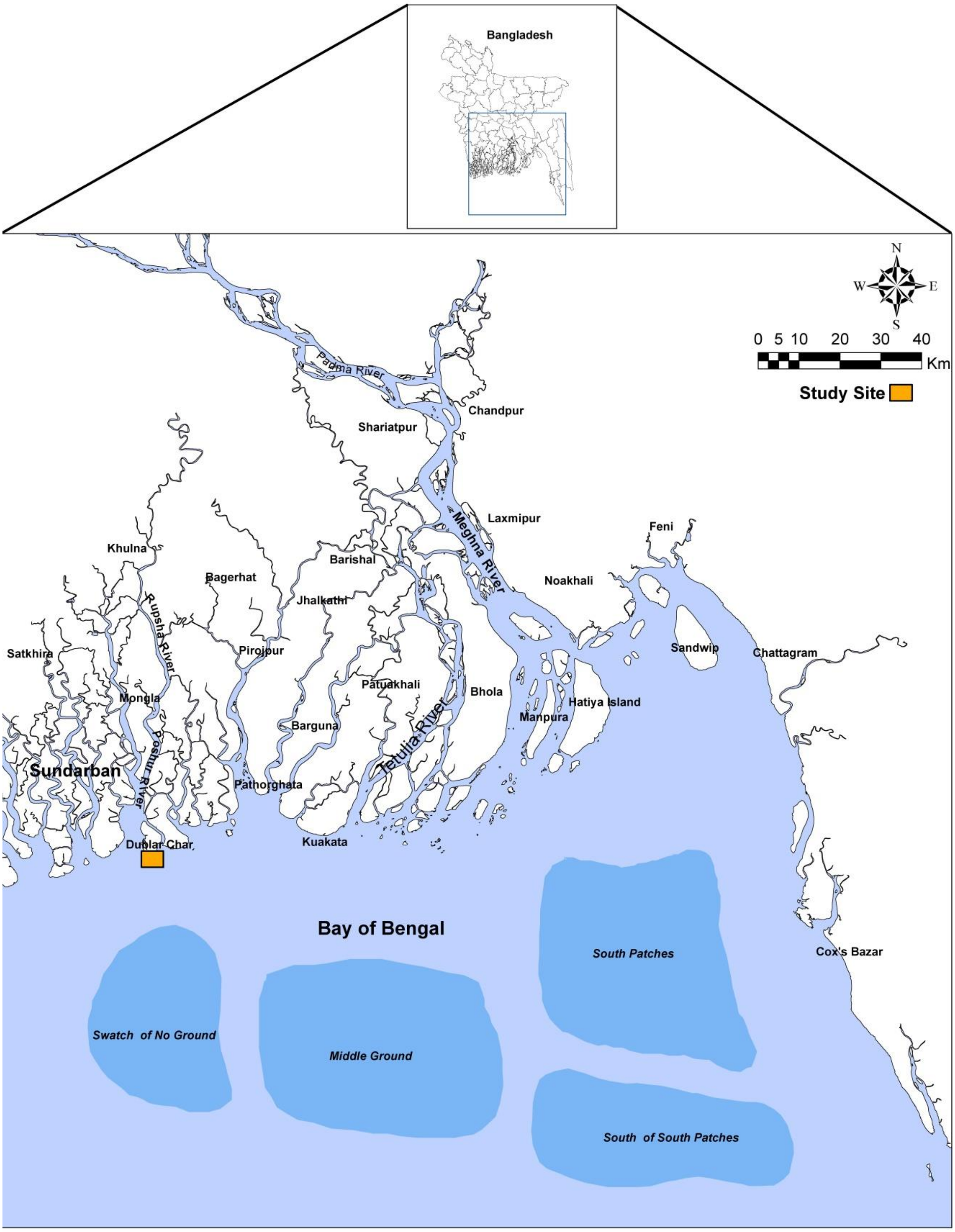


Plate 2. Sampling site in the Bay of Bengal, Bangladesh.

3.4.2. Fish measurement

Male and female individuals were identified by microscopic observation of gonads. Individual body weight (BW) for all samples was weighed with 0.01 g accuracy with electric balance and different lengths i.e. total length (TL) and standard length (SL) were measured by measuring board to 0.01 cm precision.

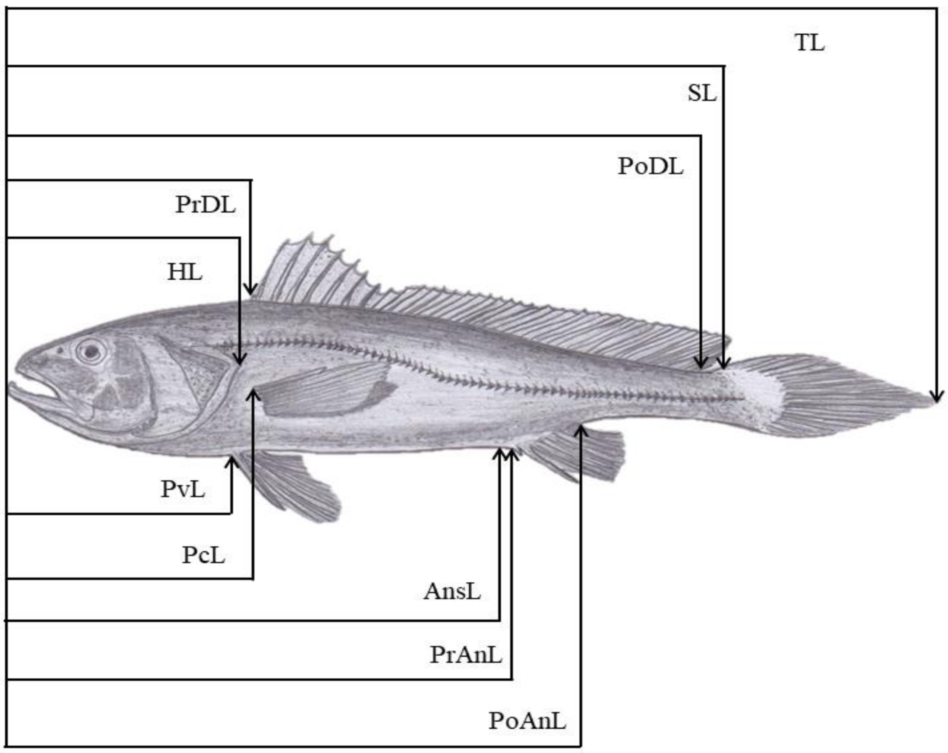


Figure 1. Morphometric measurement of *Panna heterolepis* from the Bay of Bengal, Bangladesh (**TL**= Total Length, **SL**= Standard Length, **PoDL**= Post-Dorsal Length, **PoAnL** = Post-Anal Length, **PrAnL** = Pre-Anal Length, **AnsL** = Anus Length, **PrDL** = Pre-Dorsal Length, **PcL** = Pectoral Length, **PvL** = Pelvic Length and **HL** = Head Length).

3.4.3. Meristic counts

Meristic counts (fin rays number from all fins) were done by using a magnifying glass. Different linear dimensions (Table 2 and Figure 1) were measured nearest to 0.01cm accuracy.

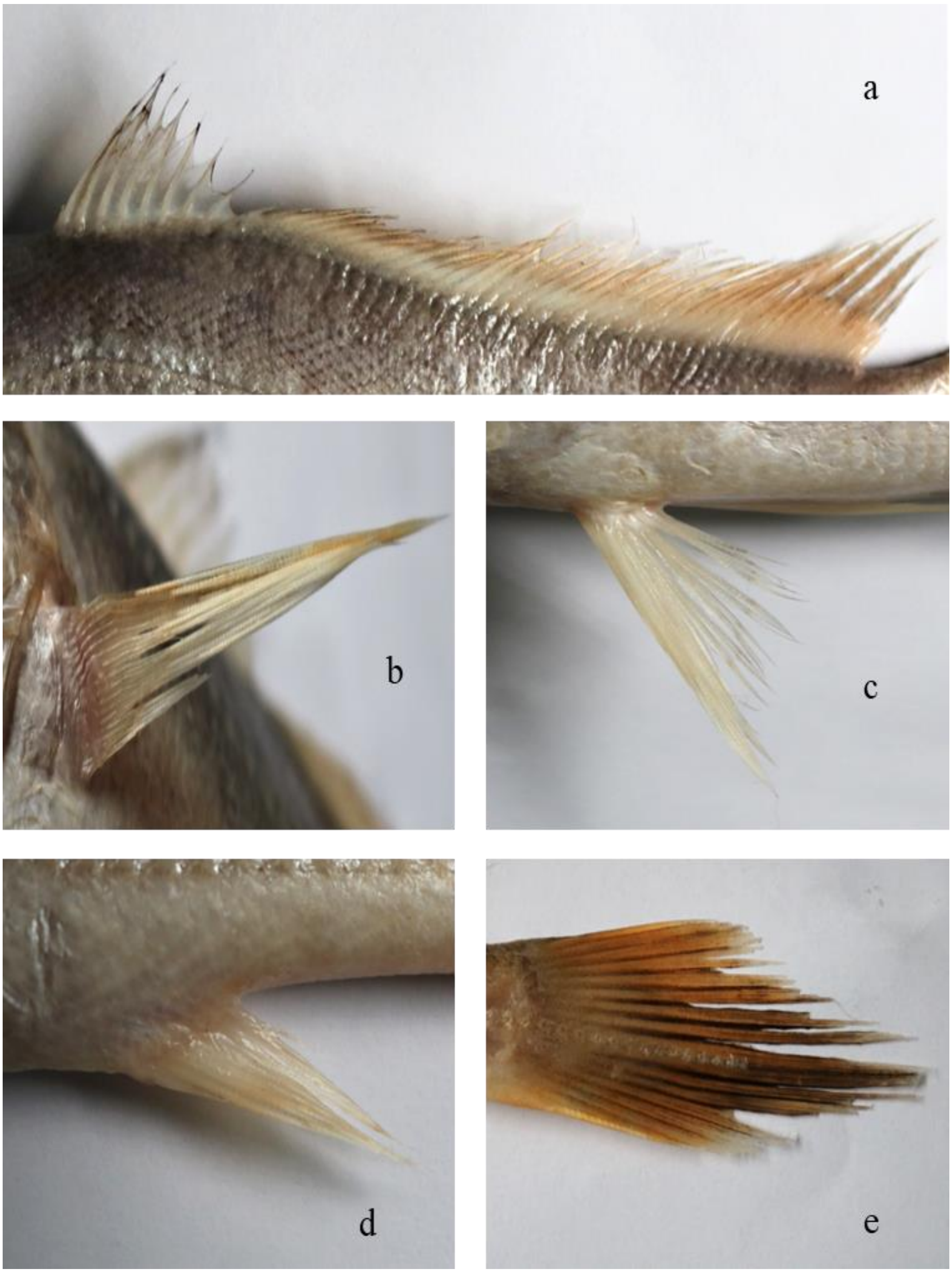


Plate 3. Different fins such as (a) Dorsal, (b) Pectoral, (c) Pelvic, (d) Anal and (e) Caudal of *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Table 2. Description of different morphometric measurements of the *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Length	Starting Point	Ending point
Head Length (FL)	Tip of the snout	Ending point of bony opercular edge
Pre-Dorsal Length (PrDL)	Tip of the snout	Anterior point of dorsal fin base
Post-Dorsal Length (PoDL)	Tip of the snout	Posterior point of dorsal fin base
Pectoral Length (PcL)	Tip of the snout	Anterior point of pectoral fin base
Pelvic Length (PvL)	Tip of the snout	Anterior point of pelvic fin base
Anus Length (AnsL)	Tip of the snout	Anterior point of anus
Pre-Anal Length (PrAnL)	Tip of the snout	Ending point of anal fin base
Post-Anal Length (PoAnL)	Tip of the snout	Posterior point of anal fin base

3.4.4. Length-frequency distributions (LFDs)

Population structure through LFDs for *P. heterolepis* was assembled using 1 cm intervals of TL.

3.4.5. Length-weight relationships (LWRs) considering the eco-climatic parameters

Growth pattern was calculated by LWRs involving the equation: $W = a \times L^b$, where W is the body weight (g) and L represents the total length (cm). The parameters *a* and *b* were assessed using linear regression study based on natural logarithms: $\ln (W) = \ln (a) + b \ln (L)$. Besides, LLR i.e. TL vs. SL was assessed with linear regression analysis (Hossain et al., 2006). In order to assess the relationship between allometric co-efficient (*b*) with habitat condition, monthly ecological parameters were also recorded from the sampling site following APHA (2005) procedures. The collected parameters were temperature (^oC), pH and dissolved oxygen (DO; mg/L). Further, the data of monthly rainfall (mm) was collected from meteorological station of Khulna, Bangladesh.

3.4.6. Form factor

The form factor ($a_{3.0}$) was measured according to Froese (2006), as $a_{3.0} = 10^{\log a\text{-}s(b\text{-}3)},$ where *a* and *b* are regression parameters of LWRs and *S* is the regression slope of *ln a vs. b*. A mean slope $S = -1.358$ was used for estimating the form factor ($a_{3.0}$) because information on LWR is not available for this species.

3.4.7. Statistical Analyses

Statistical analyses were conducted by Microsoft® Excel-add-in-DDXL and GraphPad Prism 6.5 software. Homogeneity as well as normality of data was checked by pictorial assessment of histograms and confirmed with the Kolmogorov-Smirnov test. Where test for normality assumption was not met, Mann-Whitney U-test was applied to relate the mean values between sexes as a non-parametric test. A chi-square test was executed to observe the sex ratio departure from the predictable value of 1:1 (male: female). ANCOVA was executed to confirm the difference of growth type between sexes. Besides, Spearman rank test was done to relate allometric co-efficient (*b*) with different eco-climatic factors. All statistical analyses were considered significant at 5% (P <0.05).

3.5. Results

3.5.1. Morphometric and meristic traits

The body of *P. heterolepis* is eel-like. The mouth is large, oblique and terminal and the head had a blunt snout. The body color is brownish becoming lighter on belly while the fins are yellowish. Dark margins are present on dorsal and anal fins. Dorsal fin has a low notch with weak spines and the second anal spine is also weak. The body is covered with small ctenoid scale but the head has cycloid scales. Meristic count of *P. heterolepis* was given in Table 3. All morphometric measurements are presented in Table 4. The regression parameters (*a* and *b*), with their 95% confidence intervals for LWRs, co-efficient of determination (r^2) of *P. heterolepis* are given in Table 5. All LWRs were highly significant ($p < 0.0001$). All LLRs were also highly correlated with r^2 values ≥ 0.928 are presented in Table 6.

Table 3. Meristic counts of *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Meristic data	Numbers	Spine	Unbranched	Branched
Dorsal fin rays	43 - 55	VIII - X	i	34 - 44
Pectoral fin rays	15 - 17	-	i	14 - 16
Pelvic fin rays	6	I	-	5
Anal fin rays	7 – 10	II	-	5 - 8
Caudal fin rays	17 - 19	-	ii	15 - 17

Note: Spine, upper portion of single ray is sharp & pointed; Unbranched, single fin ray; Branched, upper portion of fin is divided into several rays.

Table 4. Morphometric measurements of the *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Measurements	Min (cm)	Max(cm)	Mean ± SD	95% CL	% TL
HL (Head length)	2.3	6.5	4.04 ± 0.77	3.94 - 4.15	18.84
PrDL (Pre-dorsal length)	2.3	6.9	4.09 ± 0.84	3.97 - 4.21	20.00
PoDL (Post-dorsal length)	7.9	25.4	13.91 ± 3.29	13.46 - 14.37	73.62
PcL (Pectoral Length)	2.6	6.8	4.19 ± 0.76	4.08 - 4.29	19.71
PvL (Pelvic length)	2.7	7.5	4.43 ± 0.92	4.30 - 4.56	21.74
AnsL (Anus Length)	5.6	14.9	9.42 ± 1.90	9.16 - 9.68	43.19
PrAnL (Pre-anal Length)	6.5	15.7	10.47 ± 1.89	10.21 - 1073	45.51
PoAnL (Post-anal Length)	7.1	19.7	11.55 ± 2.39	11.21 – 11.88	57.10

Note: Min, minimum; Max, maximum; SD, standard deviation; CL, confidence limit for mean value.

Table 5. Descriptive statistics and estimated parameters of the length-weight relationships of *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Equation	Regression parameters *a*	*b*	95% CL of *a*	95% CL of *b*	r^2	GT
BW= $a \times HL^b$	0.8867	2.941	0.7606 – 1.0338	2.831 – 3.051	0.933	A-
BW= $a \times PrDL^b$	1.1359	2.743	0.9680 – 1.3329	2.629 – 2.857	0.919	A-
BW= $a \times PoDL^b$	0.0543	2.63	0.0457 – 0.0645	2.560 – 2.692	0.969	A-
BW= $a \times PcL^b$	0.4788	3.298	0.4182 – 0.5482	3.203 – 3.392	0.959	A+
BW= $a \times PvL^b$	0.7000	2.922	0.6146 – 0.7972	2.834 – 3.010	0.956	A-
BW= $a \times AnsL^b$	0.0969	2.821	0.0801 – 0.1171	2.736 – 2.906	0.956	A-
BW= $a \times PrAnL^b$	0.0400	3.069	0.0309 – 0.0517	2.958 – 3.179	0.938	I
BW= $a \times PoAnL^b$	0.0465	2.887	0.0388 – 0.0558	2.812 – 2.962	0.967	A-

Note: *a* and *b* are the regression parameters of LWRs; CL, confidence intervals; r^2, co-efficient of determination; GT, growth type; A-, negative allometric; A+, positive allometric; I, isometric.

Table 6. The estimated parameters of the length-length relationships (y = *a* + *b*× x) of *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Equation	Regression parameters *a*	*b*	95% CL of *a*	95% CL of *b*	r^2
TL = *a* + *b*× HL	-0.2871	4.858	-0.9242 – 0.3500	4.70 – 5.01	0.951
TL = *a* + b× PrDL	1.3400	4.40	0.6200 – 2.0599	4.231 – 4.576	0.928
TL = *a* + b× PoDL	3.3848	1.148	2.9579 – 3.8118	1.118 – 1.178	0.967
TL = *a* + b× PcL	-1.5854	5.001	-2.0521 - -1.1187	4.892- 5.111	0.988
TL = *a* + b× PvL	1.1413	4.111	0.6322 – 1.6504	3.999 – 4.223	0.963
TL = *a* + b× AnsL	0.5694	1.995	0.1352 – 1.0037	1.949 – 2.039	0.975
TL = *a* + b×PrAnL	-1.3730	1.980	-2.0232 - -2.0229	1.919 – 2.041	0.954
TL = *a* + b× PoAnL	0.9744	1.592	0.6580 – 1.2909	1.566 – 1.619	0.986

Note: *a* and *b* are the regression parameters of LWRs; CL, confidence intervals; r^2, co-efficient of determination.

3.5.2. Sex ratio

All together 1,223 (male = 654, Female = 569) specimens were collected for the study. The overall sex ratio differed statistically (male: female = 1:0.87) from the predicted 1:1 ratio. Further, the monthly sex ratio indicated that males were dominated in the month of June and maximum female fish were found in January (Table 7).

Table 7. Monthly sex ratio (male: female = 1:1) of the *Panna heterolepis* from the Bay of Bengal, Bangladesh.

	Number of specimens			Sex ratio	χ^2	
Month	**Male**	**Female**	**Total**	**(Male : Female)**	**(df=1)**	**Significance**
January	35	72	107	1:2.06	12.79	*
February	37	67	104	1:1.81	8.65	*
March	47	57	104	1:1.21	0.96	NS
April	50	34	84	1:0.68	3.05	NS
May	76	25	101	1:0.33	25.75	*
June	77	22	99	1:0.29	30.56	*
July	66	37	103	1:0.56	8.17	*
August	63	43	106	1:0.68	3.77	NS
September	60	42	102	1:0.70	3.18	NS
October	45	59	104	1:1.31	1.88	NS
November	42	63	105	1:1.50	4.20	*
December	56	48	104	1:0.86	0.62	NS
Overall	654	569	1223	1:0.87	5.91	*

Note: *df*, degree of freedom; ns, not significant; * significant at 5% level ($\chi^2 > \chi^2_{t\ 1,\ 0.05} = 3.84$).

3.5.3. Length-frequency distributions (LFDs)

The LFD of *P. heterolepis* revealed that the size range was 10.5 to 34.5 cm TL for combined sex. Besides, LFD indicated that 18.00 – 18.99 cm and 17-17.99 cm TL size group was numerically dominant for male and female, respectively (Figure 2). The LFD for both sexes did not pass the normality. Further, Mann-Whitney U-test showed no significant differences between males and females (p = 0.5125).

3.5.4. Total Length (TL)

The study demonstrated that total length varied between 10.7-31.4 cm for males and 10.5-34.5 cm for females (Table 8). Further, highest TL for both male and female was found during the month of August and February, respectively. On the other hand, the lowest individuals were recorded during the month of July for both sexes.

3.5.5. Standard Length (SL)

The SL of *P. heterolepis* ranged from 8.2 to 23.6 cm for male and 8.0 to 28.2 cm for female. Also, highest SL for both male and female was found during the month of August and February, respectively. Besides, the smallest SL was recorded during the month of July for both sexes (Table 9).

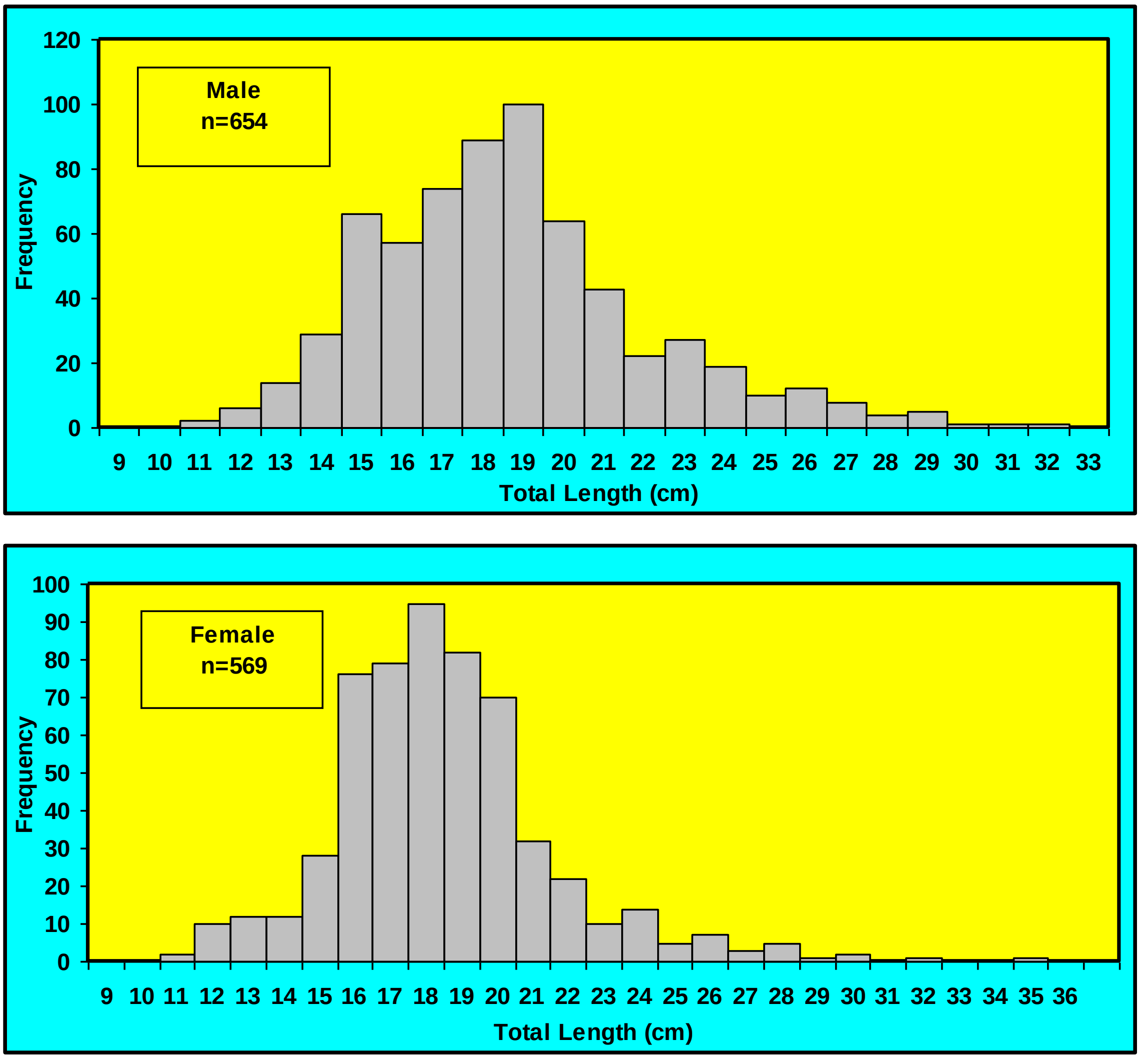


Figure 2. Length frequency distributions of male and female *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Table 8. Descriptive statistics on Total Length (TL) measurements and their 95% confidence limits of the *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Month	Sex	*n*	Total length (cm)			
			Min	Max	Mean±SD	95% CL
January	M	35	14.3	19.5	16.75±1.44	16.26-17.25
	F	72	12.0	25.9	17.46±1.90	17.01-17.91
	C	107	12.0	25.9	17.23±1.79	16.88-17.57
February	M	37	11.3	29.6	19.23±4.07	17.87-20.59
	F	67	11.0	34.5	18.41±4.55	17.30-19.52
	C	104	11.0	34.5	18.70±4.39	17.85-19.56
March	M	47	11.9	21.2	16.93±2.30	16.25-17.61
	F	57	11.1	25.7	18.25±3.19	17.41-19.10
	C	104	11.1	25.7	17.66±2.89	17.09-18.21
April	M	50	10.8	28.7	17.15±4.83	15.78-18.52
	F	34	10.5	27.5	16.27±4.48	14.42-17.83
	C	84	10.5	28.7	16.80±4.67	15.78-17.81
May	M	76	11.9	25.8	16.68±2.64	16.08-17.29
	F	25	12.7	27	17.50±3.00	16.26-18.73
	C	101	11.9	27	16.89±2.74	16.34-17.42
June	M	77	12.5	28.5	20.73±3.30	19.99-21.48
	F	22	11.5	27	16.46±3.42	14.95-17.98
	C	99	11.5	28.5	19.79±3.78	19.03-20.55
July	M	66	10.7	26	17.58±3.34	16.76-18.40
	F	37	10.5	29.5	17.73±3.94	16.42-19.05
	C	103	10.5	29.5	17.64±3.55	16.94-18.33
August	M	63	13.0	31.4	18.53±4.15	17.48-19.58
	F	43	13.6	24.8	17.76±2.54	16.98-18.55
	C	106	13.0	31.4	18.22±3.59	17.53-18.91
September	M	60	15.0	30.9	19.74±2.53	19.09-20.39
	F	42	15.0	23.8	18.66±1.94	18.06-19.26
	C	102	15.0	30.9	19.30±2.36	18.83-19.76
October	M	45	12.5	24.2	16.74±2.48	16.00-17.48
	F	59	13.6	27.2	18.71±2.62	18.03-19.39
	C	104	12.5	27.2	17.86±2.73	17.33-18.39
November	M	42	13.1	25.2	17.44±2.50	16.66-18.21
	F	63	13.5	26.4	18.30±2.41	17.69-18.91
	C	105	13.1	26.4	17.96±2.47	17.48-18.43
December	M	56	15.2	25.2	18.37±1.93	17.85-18.89
	F	48	14.7	23.5	17.62±1.95	17.05-18.19
	C	104	14.7	25.2	18.02±1.97	17.64-18.41

Note: M, Male; F, Female; *n*, Sample Size; Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, Confidence Limit of Mean.

Table 9. Descriptive statistics on Standard Length (SL) measurements and their 95% confidence limit of the *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Month	Sex	*n*	Standard length (cm)			
			Min	**Max**	**Mean±SD**	**95% CL**
January	M	35	10.8	15.2	12.84±1.11	12.46-13.23
	F	72	9.0	20.0	13.45±1.52	13.10-13.81
	C	107	9.0	20.0	13.25±1.42	12.98-13.53
February	M	37	9.2	23.3	15.28±3.25	14.20-16.36
	F	67	8.3	28.2	14.63±3.75	13.72-15.55
	C	104	8.3	28.2	14.86±3.58	14.17-15.56
March	M	47	9.2	16.6	13.22±1.81	12.69-13.75
	F	57	8.7	20.8	14.26±2.59	13.58±14.95
	C	104	8.7	20.8	13.80±2.33	13.35±14.25
April	M	50	8.3	22.9	13.42±3.93	12.30-14.53
	F	34	8.4	21.5	12.74±3.51	11.52-13.97
	C	84	8.3	22.9	13.14±3.76	12.33-13.99
May	M	76	9.3	19.9	13.13±2.05	12.67-13.60
	F	25	10.1	21.3	13.80±2.39	12.81-14.79
	C	101	9.3	21.3	13.30±2.15	12.88-13.73
June	M	77	10.2	23.1	16.58±2.76	15.95-17.20
	F	22	9.5	21.3	13.16±2.58	12.01-14.31
	C	99	9.5	23.1	15.83±3.09	15.22-16.45
July	M	66	8.2	20.8	13.72±3.34	13.07-14.37
	F	37	8.0	24.0	13.89±3.23	12.81-14.96
	C	103	8.0	24.0	13.78±2.86	13.22-14.34
August	M	63	10.4	23.6	14.44±3.43	13.58-15.30
	F	43	11.0	19.5	13.84±2.05	13.20-14.47
	C	106	10.4	23.6	14.19±2.95	13.63-14.76
September	M	60	11.2	23.5	15.24±2.02	14.71-15.76
	F	42	11.5	18.8	14.38±1.64	13.87-14.89
	C	102	11.2	23.5	14.89±1.91	14.51-15.26
October	M	45	9.5	18.6	12.94±1.86	12.38-13.50
	F	59	10.2	21.5	14.51±2.22	13.93-15.08
	C	104	9.5	21.5	13.83±2.21	13.40-14.26
November	M	42	10.4	19.7	13.66±1.97	13.05-14.28
	F	63	11.0	20.7	14.23±1.89	13.75-14.70
	C	105	10.4	20.7	14.00±1.94	13.63-14.37
December	M	56	11.3	20.3	14.27±1.63	13.83-14.70
	F	48	11.1	19.2	13.63±1.64	13.15-14.10
	C	104	11.1	20.3	13.97±1.65	13.65-14.29

Note: M, Male; F, Female; *n*, Sample Size; Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, Confidence Limit of Mean.

3.5.6. Estimation of Body Weight (BW)

The study revealed that the BW ranged from 10.02 to 203.89 g for male and 9.02 to 342.26 g for female population. The maximum body weight for male and female was recorded during the month of August and February, respectively. On the other hand, the minimum body weight for male was found in the month of April and female showed minimum body weight in February (Table 11). Besides, BW frequency distribution revealed that the males and females of *P. heterolepis* were not normally distributed (Shapiro-Wilk normality test; $P < 0.001$). Alternatively, Mann-Whitney U-test revealed that BW of both sexes were not significantly different (Two tailed, Mann-Whitney test, $P = 0.5355$).

Table 10. Descriptive statistics on weight measurements and their 95% confidence limits of the *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Month	Sex	*n*	Body weight (g)			
			Min	Max	Mean±SD	95% CL
January	M	35	20.09	52.34	34.00±8.38	31.12-36.88
	F	72	12.39	134.28	42.50±16.35	38.66-46.34
	C	107	12.39	134.28	39.72±14.75	36.89-42.55
February	M	37	12.52	182.56	59.81±39.20	46.74-72.88
	F	67	9.02	342.26	59.18±58.50	44.91-73.45
	C	104	9.02	342.26	59.41±52.25	49.24-69.57
March	M	47	12.60	73.45	38.34±16.30	33.55-43.12
	F	57	11.98	133.35	52.43±27.66	45.10-59.77
	C	104	11.98	133.35	46.06±24.17	41.36-50.76
April	M	50	10.02	175.60	48.54±42.24	36.54-60.55
	F	34	12.31	170.30	44.21±37.80	31.02-57.40
	C	84	10.02	175.60	46.79±40.32	38.04-55.54
May	M	76	11.42	134.43	39.10±20.74	34.36-43.84
	F	25	17.4	144.30	47.82±26.08	37.06-58.59
	C	101	11.42	144.30	41.26±22.36	36.85-45.68
June	M	77	14.20	174.60	69.63±31.30	62.53-76.74
	F	22	15.34	173.19	43.02±33.50	28.16-57.87
	C	99	14.20	174.60	63.72±33.53	57.03-70.41
July	M	66	11.20	124.74	43.40±25.39	37.16-49.64
	F	37	12.44	187.53	48.21±35.03	36.53-59.90
	C	103	11.20	187.53	45.13±29.14	39.43-50.82
August	M	63	17.90	203.89	51.32±41.03	40.98-61.65
	F	43	21.37	103.21	41.86±18.08	36.30-47.43
	C	106	17.90	203.89	47.48±33.86	40.96-54.00
September	M	60	24.19	165.15	53.47±21.45	47.93-59.01
	F	42	24.54	104.44	47.60±16.31	42.51-52.68
	C	102	24.19	165.15	51.05±19.63	47.19-54.91
October	M	45	13.89	96.92	35.58±15.22	31.00-40.15
	F	59	18.29	140.58	49.92±23.53	43.78-56.05
	C	104	13.89	140.58	43.71±21.48	39.53-47.89
November	M	42	18.05	102.65	39.00±16.27	33.93-44.07
	F	63	19.58	120.22	44.27±18.08	39.72-48.43
	C	105	18.05	120.22	42.16±17.49	38.78-45.55
December	M	56	25.06	117.38	44.96±16.31	40.59-49.33
	F	48	24.44	96.29	41.25±13.87	37.22-45.28
	C	104	24.44	117.38	43.25±15.28	40.28-46.22

Note: M, Male; F, Female; *n*, Sample Size; Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, Confidence Limit of Mean.

3.5.7. Length-weight relationships (LWRs) considering the eco-climatic factors

The present study stated that the overall *b* value for both sexes indicated negative allometric growth ($b < 3.00$) (Figure 3). However, males exhibited isometric growth ($b = 3$) during January to March, and December. Furthermore, females showed positive allometric growth ($b > 3$) in January while isometric growth in February and March. All LWRs were highly significant ($p < 0.001$), with all r^2 values ≥ 0.957. The monthly sample size (*n*), regression parameters (*a* and *b*) with 95% confidence limit of the LWRs and coefficient of determination (r^2) of *P. heterolepis* in the Bay of Bengal, (SW) Bangladesh are presented in Table 11. The analysis of covariance (ANCOVA) revealed no significant difference in LWRs between sexes ($p < 0.067$).

In our study, four eco-climatic factors were recorded namely temperature, rainfall, dissolved oxygen (DO) and pH. The allometric co-efficient (*b*) of length weight relationships was found significantly related with temperature for both male and female population. However, rainfall, DO and pH did not reveal any significant correlation with *b* value between sexes (Table 12). The relationship between *b* value and eco-climatic parameters are presented in Figure 6 and 7. Throughout the study, the maximum water temperature was recorded in June-July (34.4^{o}C) and the minimum was in January (19.8^{o}C). In addition, the highest rainfall was observed in August (370 mm) and no precipitation was occurred in the month of January.

3.5.8. Length-Length Relationships (LLR)

The LLR (TL *vs.* SL) were extremely correlated ($p < 0.001$), with all $r^2 \geq 0.982$ (Table 14 and Figure 5).

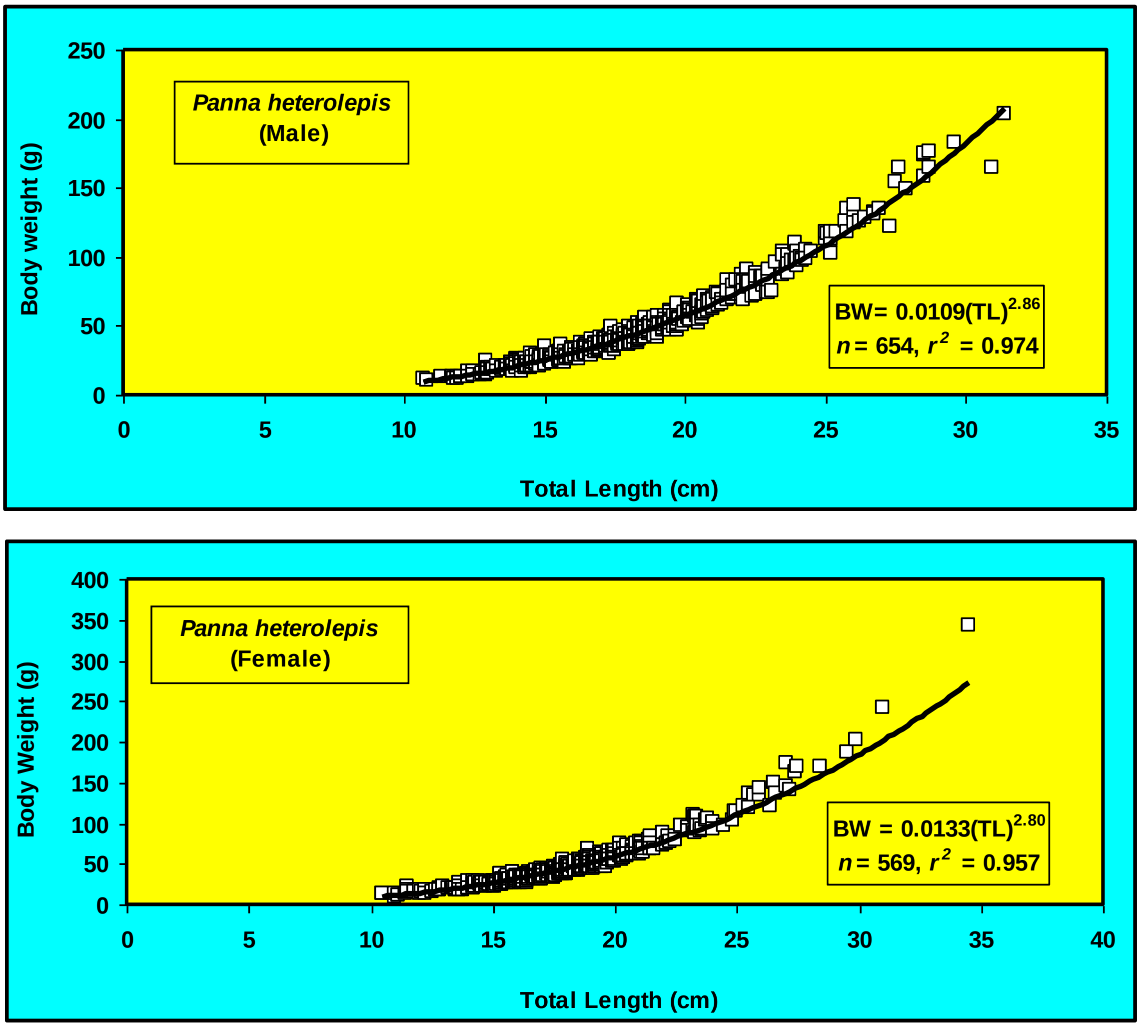


Figure 3. Relationships between total length (TL) and body weight (BW) between sexes of *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Table 11. Descriptive statistics and estimated parameters of the length-weight relationships (BW = $a \times TL^b$) of the *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Month	Sex	*n*	Regression parameters		95% CL of *a*	95% CL of *b*	r^2	GT
			a	*b*				
January	M	35	0.0086	2.93	0.0055-0.0135	2.77-3.09	0.977	I
	F	72	0.0056	3.11	0.0040-0.0079	2.99-3.23	0.974	+A
	C	107	0.0052	3.13	0.0037-0.0072	3.01-3.25	0.965	+A
February	M	37	0.0057	3.08	0.0037-0.0088	2.94-3.23	0.982	I
	F	67	0.0069	3.04	0.0045-0.0104	2.90-3.19	0.964	I
	C	104	0.0067	3.04	0.0049-0.0091	2.94-3.15	0.969	I
March	M	47	0.0058	3.09	0.0037-0.0093	2.92-3.25	0.969	I
	F	57	0.0077	3.01	0.0052-0.0113	2.88-3.14	0.974	I
	C	104	0.0063	3.07	0.0047-0.0085	2.97-3.17	0.971	I
April	M	50	0.0107	2.89	0.0081-0.0140	2.79-2.99	0.987	-A
	F	34	0.0173	2.75	0.0104-0.0286	2.56-2.93	0.967	-A
	C	84	0.0134	2.82	0.0102-0.0176	2.72-2.92	0.976	-A
May	M	76	0.0122	2.84	0.0085-0.0174	2.72-2.97	0.964	-A
	F	25	0.0145	2.80	0.0077-0.0273	2.58-3.03	0.967	-A
	C	101	0.0120	2.86	0.0087-0.0164	2.74-2.97	0.962	-A
June	M	77	0.0088	2.94	0.0067-0.0114	2.85-3.03	0.984	-A
	F	22	0.0120	2.88	0.0063-0.0226	2.65-3.11	0.972	-A
	C	99	0.0149	2.77	0.0116-0.0192	2.69-2.86	0.977	-A
July	M	66	0.0110	2.85	0.0083-0.0147	2.75-2.95	0.980	-A
	F	37	0.0169	2.72	0.0114-0.0252	2.58-2.86	0.978	-A
	C	103	0.0132	2.80	0.0104-0.0168	2.71-2.88	0.977	-A
August	M	63	0.0099	2.88	0.0073-0.0135	2.77-2.98	0.980	-A
	F	43	0.0182	2.67	0.0122-0.0271	2.54-2.81	0.974	-A
	C	106	0.0117	2.83	0.0092-0.0148	2.74-2.91	0.978	-A
September	M	60	0.0193	2.65	0.0135-0.0275	2.53-2.76	0.972	-A
	F	42	0.0081	2.95	0.0052-0.0126	2.80-3.10	0.975	-A
	C	102	0.0162	2.71	0.0121-0.0218	2.61-2.81	0.967	-A
October	M	45	0.0129	2.79	0.0088-0.0190	2.65-2.93	0.975	-A
	F	59	0.0106	2.87	0.0075-0.0150	2.75-2.99	0.976	-A
	C	104	0.0108	2.86	0.0086-0.0137	2.78-2.94	0.979	-A
November	M	42	0.0142	2.75	0.0095-0.0212	2.61-2.89	0.975	-A
	F	63	0.0153	2.73	0.0111-0.0212	2.61-2.84	0.975	-A
	C	105	0.0148	2.74	0.0116-0.0189	2.65-2.82	0.976	-A
December	M	56	0.0063	3.03	0.0044-0.0092	2.90-3.16	0.976	I
	F	48	0.0166	2.71	0.0111-0.0248	2.57-2.85	0.971	-A
	C	104	0.0114	2.84	0.0084-0.0153	2.74-2.94	0.962	-A

Note: M, Male; F, Female; *n*, Sample Size; *a*, Intercept; *b*, Slope ; CL, 95% Confidence Limit; GT, Growth Type.

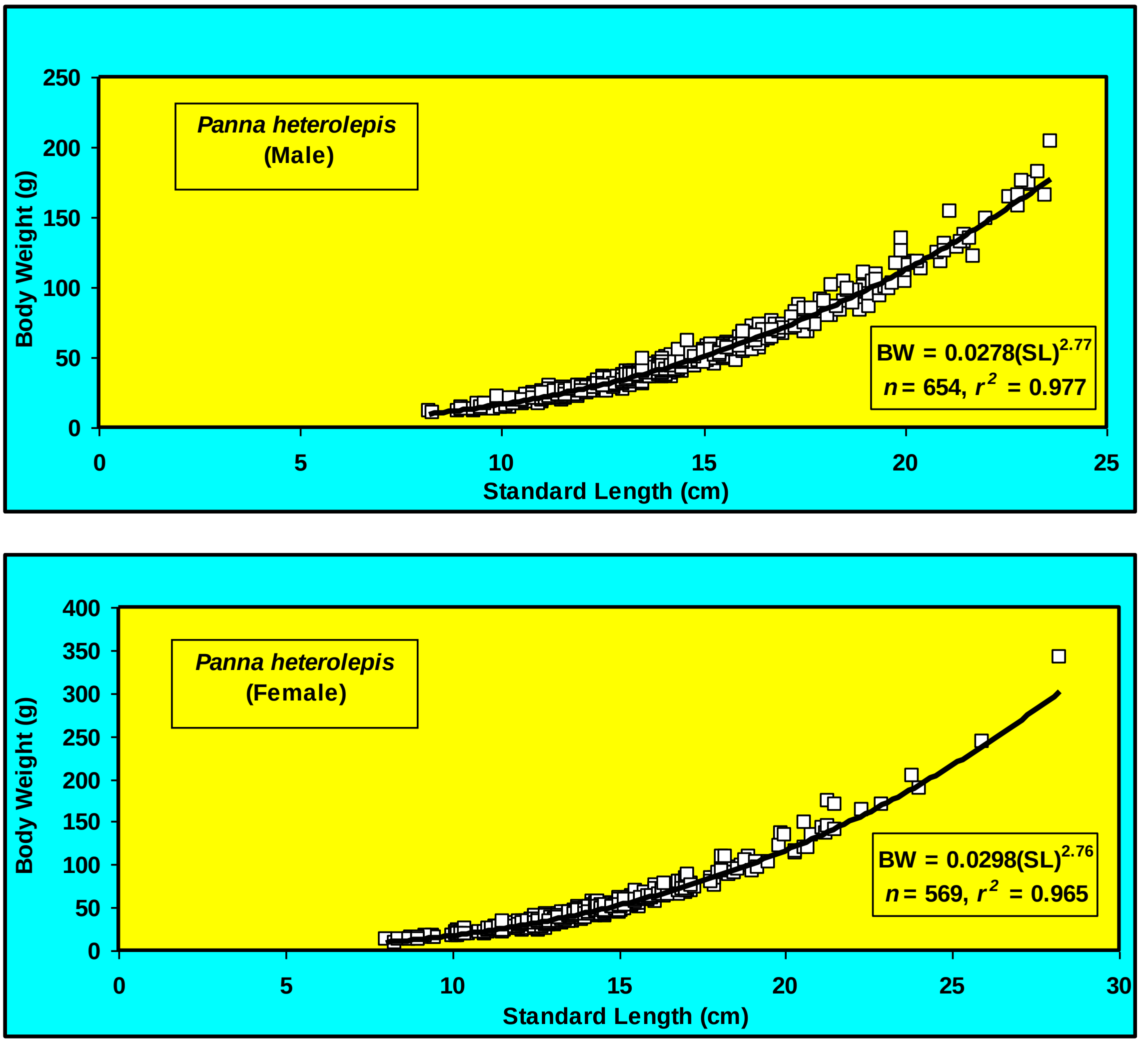


Figure 4. Relationships between standard length (SL) and body weight (BW) between sexes of *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Table 12. Relationship between allometric co-efficient (*b*) with climatic and ecological factors of *Panna heterolepis* from the Bay of Bengal, Bangladesh.

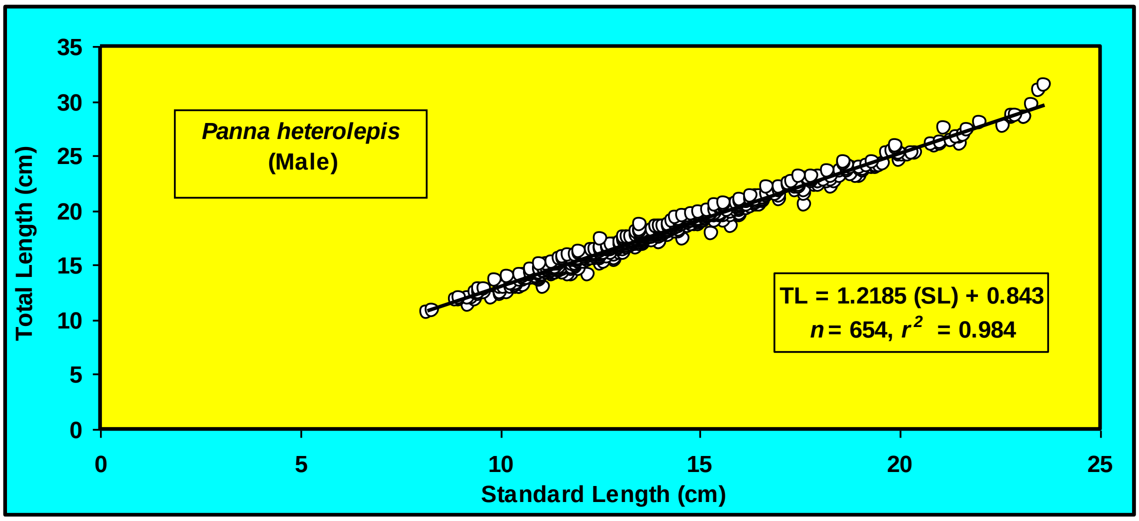
Relationships	**Sex**	r_s **values**	**95% CL of** r_s	***P* values**	**Significance**
Temp *vs. b*	**M**	-0.5534	-0.8607 to 0.04947	*P* = 0.0335	*
Rain *vs. b*		-0.5874	-0.8732 to -0.0009	*P* = 0.2489	*ns*
DO vs. *b*		0.03163	-0.5657 to 0.6072	*P* = 0.9251	*ns*
pH vs. *b*		0.2561	-0.3892 to 0.7328	*P* = 0.4182	*ns*
Temp *vs. b*	**F**	-0.6725	-0.9030 to -0.1415	*P* = 0.0189	*
Rain *vs. b*		-0.3916	-0.7965 to 0.2535	*P* = 0.2097	*ns*
DO vs. *b*		0.3550	-0.2928 to 0.7795	*P* = 0.2558	*ns*
pH vs. *b*		-0.7404	-0.9252 to -0.2715	*P* = 0.6273	*ns*

Note: M, male; F, female; C, combined sex; Temp, temperature (^{o}C); Rain; rainfall (mm); DO, dissolved oxygen (mg/l), r_s, Spearman rank correlation values; CL, confidence limit; *P*, level of significance; *ns*, not significant; *significant.

Table 13. Descriptive statistics and estimated parameters of the length-weight relationships (BW = $a \times SL^b$) of the *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Month	Sex	*n*	Regression parameters		95% CL of *a*	95% CL of *b*	r^2
			a	*b*			
January	M	35	0.0193	2.92	0.0130-0.0287	2.76-3.07	0.978
	F	72	0.0174	2.99	0.0122-0.0248	2.85-3.12	0.965
	C	107	0.0152	3.03	0.0112-0.0206	2.91-3.15	0.961
February	M	37	0.0128	3.05	0.0092-0.0177	2.93-3.17	0.987
	F	67	0.0155	3.00	0.0116-0.0208	2.89-3.11	0.979
	C	104	0.0150	3.00	0.0120-0.0188	2.92-3.09	0.980
March	M	47	0.0132	3.07	0.0084-0.0207	2.89-3.24	0.965
	F	57	0.0218	2.90	0.0157-0.0302	2.77-3.02	0.976
	C	104	0.0172	2.97	0.0131-0.0225	2.87-3.08	0.970
April	M	50	0.0275	2.80	0.0218-0.0346	2.71-2.89	0.988
	F	34	0.0307	2.79	0.0230-0.0410	2.67-2.90	0.987
	C	84	0.0296	2.78	0.0245-0.0357	2.71-2.86	0.986
May	M	76	0.0224	2.87	0.0163-0.0308	2.75-2.99	0.967
	F	25	0.0296	2.79	0.0172-0.0509	2.58-2.99	0.971
	C	101	0.0230	2.87	0.0174-0.0303	2.76-2.97	0.966
June	M	77	0.0234	2.82	0.0178-0.0308	2.73-2.92	0.978
	F	22	0.0156	3.02	0.0071-0.0344	2.72-3.33	0.955
	C	99	0.0304	2.74	0.0236-0.0393	2.64-2.83	0.972
July	M	66	0.0262	2.79	0.0194-0.0354	2.68-2.91	0.973
	F	37	0.0412	2.64	0.0284-0.0597	2.50-2.78	0.976
	C	103	0.0317	2.73	0.0250-0.0403	2.64-2.82	0.972
August	M	63	0.0298	2.74	0.0231-0.0386	2.64-2.83	0.981
	F	43	0.0434	2.60	0.0299-0.0631	2.45-2.74	0.971
	C	106	0.0327	2.70	0.0266-0.0402	2.63-2.78	0.979
September	M	60	0.0522	2.53	0.0388-0.0703	2.42-2.64	0.974
	F	42	0.0339	2.71	0.0232-0.0496	2.56-2.85	0.973
	C	102	0.0490	2.56	0.0386-0.0623	2.47-2.65	0.970
October	M	45	0.0204	2.89	0.0144-0.0288	2.76-3.03	0.977
	F	59	0.0385	2.66	0.0287-0.0517	2.55-2.77	0.976
	C	104	0.0267	2.79	0.0215-0.0331	2.71-2.88	0.978
November	M	42	0.0282	2.75	0.0211-0.0378	2.63-2.86	0.984
	F	63	0.0296	2.74	0.0218-0.0402	2.62-2.85	0.974
	C	105	0.0281	2.75	0.0227-0.0347	2.67-2.83	0.978
December	M	56	0.0287	2.75	0.0191-0.0431	2.60-2.91	0.960
	F	48	0.0564	2.51	0.0386-0.0824	2.37-2.66	0.963
	C	104	0.0438	2.60	0.0328-0.0585	2.49-2.71	0.956

Note: M, Male; F, Female; *n*, Sample Size; *a*, Intercept; *b*, Slope; CL, 95% Confidence Limit.



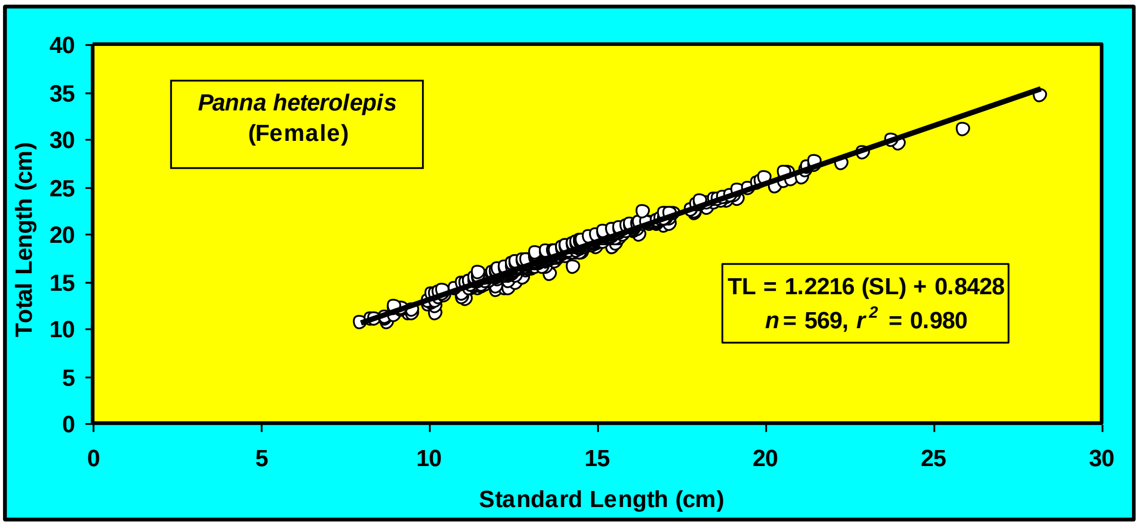


Figure 5. Overall variation of growth pattern (TL *vs.* SL) of *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Table 14. Descriptive statistics and estimated parameters of the TL *vs.* SL relationships (y = *a* +*b* × x) of the *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Month	Sex	*n*	Regression parameters		95% CL of *a*	95% CL of *b*	r^2
			a	*b*			
January	M	35	0.2992	1.2810	-0.5817 to 1.1801	1.2127-1.3494	0.978
	F	72	0.7890	1.2392	0.2057 to 1.3722	1.1961-1.2823	0.979
	C	107	0.7377	1.2442	0.2706 to 1.2048	1.2092-1.2793	0.979
February	M	37	0.2323	1.2432	-0.6037 to 1.0684	1.1896-1.2967	0.984
	F	67	0.7990	1.2036	0.2111 to 1.3869	1.1647-1.2426	0.983
	C	104	0.6366	1.2155	0.1644 to 1.1089	1.1846-1.2463	0.984
March	M	47	0.2651	1.2606	-0.4623 to 0.9926	1.2061-1.3152	0.980
	F	57	0.7521	1.2270	0.2461 to 1.2580	1.1921-1.2619	0.989
	C	104	0.6764	1.2304	0.2899 to 1.0628	1.2028-1.2580	0.987
April	M	50	0.7148	1.2250	0.2766 to 1.1530	1.1936-1.2564	0.992
	F	34	0.2478	1.2578	-0.4602 to 0.9559	1.2042-1.3114	0.986
	C	84	0.5376	1.2370	0.1638 to 0.9115	1.2096-1.2643	0.990
May	M	76	0.0075	1.2697	-0.6295 to 0.6445	1.2218-1.3176	0.974
	F	25	0.3258	1.2442	-0.7272 to 1.3787	1.1690-1.3194	0.981
	C	101	0.1118	1.2612	-0.4155 to 0.6391	1.2221-1.3004	0.976
June	M	77	1.0579	1.1867	0.4414 to 1.6744	1.1500-1.2234	0.982
	F	22	-0.6985	1.3038	-2.1156 to 0.7185	1.1980-1.4095	0.971
	C	99	0.5904	1.2127	0.0761 to 1.1046	1.1808-1.2446	0.983
July	M	66	0.4278	1.2503	-0.0307 to 0.8862	1.2175-1.2831	0.989
	F	37	0.8624	1.2149	0.3511 to 1.3738	1.1790-1.2507	0.993
	C	103	0.6309	1.2341	0.2930 to 0.9688	1.2100-1.2581	0.990
August	M	63	1.1193	1.2059	0.6226 to 1.6161	1.1724-1.2394	0.988
	F	43	0.7673	1.2282	0.1008 to 1.4338	1.1806-1.2759	0.985
	C	106	1.0302	1.2109	0.6503 to 1.4102	1.1847- 1.2372	0.988
September	M	60	0.8640	1.2389	0.1721 to 1.5559	1.1938-1.2839	0.981
	F	42	1.7704	1.1742	1.0624 to 2.4785	1.1253-1.2231	0.983
	C	102	1.1208	1.2210	0.6305 to 1.6110	1.1883-1.2536	0.982
October	M	45	-0.3632	1.3215	-1.0809 to 0.3544	1.2666-1.3764	0.982
	F	59	1.7926	1.1662	1.1408 to 2.4444	1.1218-1.2106	0.980
	C	104	0.9175	1.2249	0.4359 to 1.3991	1.1905-1.2593	0.980
November	M	42	0.2787	1.2558	-0.4490 to 1.0064	1.2031-1.3086	0.983
	F	63	0.4172	1.2572	-0.3255 to 1.1600	1.2054-1.3090	0.975
	C	105	0.2818	1.2624	-0.2424 to 0.8061	1.2253-1.2995	0.978
December	M	56	1.5931	1.1760	0.9367 to 2.2495	1.1303-1.2217	0.980
	F	48	1.5143	1.1818	0.8736 to 2.1550	1.1351-1.2248	0.983
	C	104	1.5571	1.1786	1.1155 to 1.9988	1.1472-1.2099	0.982

Note: M, Male; F, Female; *n*, Sample Size; *a*, Intercept; *b*, Slope ; CL, 95% Confidence Limit; r^2, co-efficient of determination.

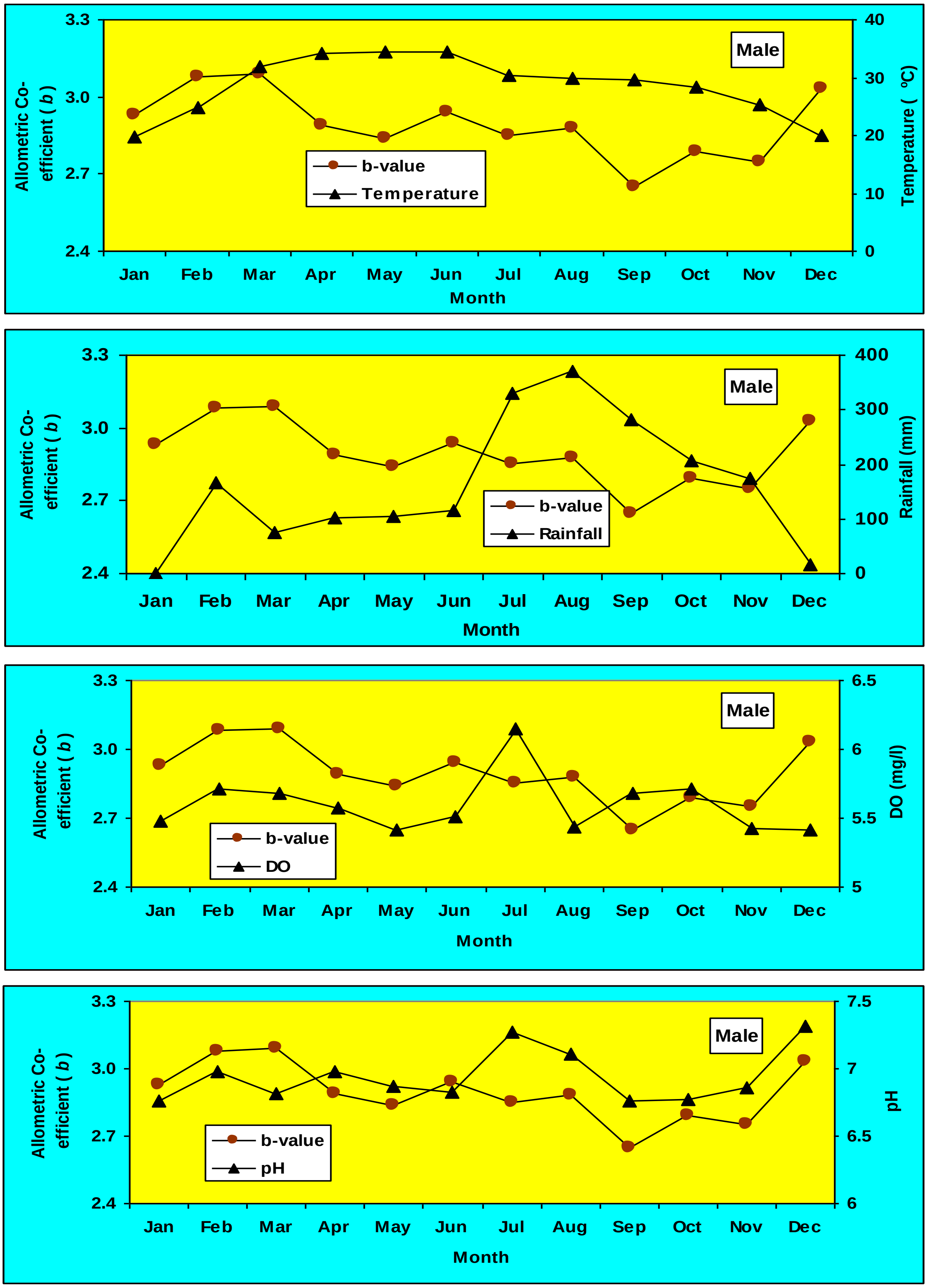


Figure 6. Relationship between allometric co-efficient (*b*) with eco-climatic factors of male *Panna heterolepis* from the Bay of Bengal, Bangladesh.

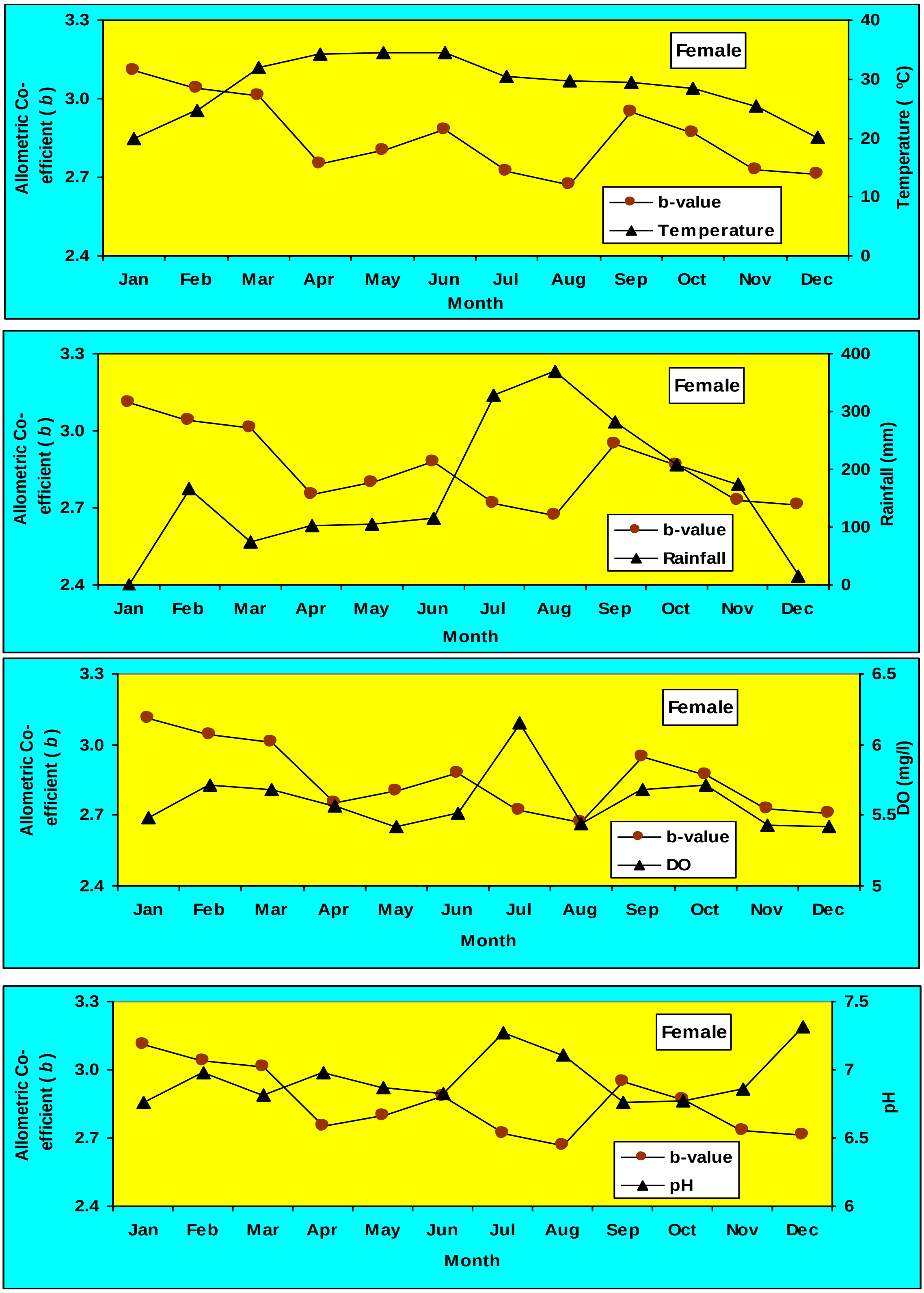


Figure 7. Relationship between allometric co-efficient (*b*) with eco-climatic factors of female *Panna heterolepis* from the Bay of Bengal, Bangladesh.

3.5.9. Form Factor

The calculated form factor ($a_{3.0}$) was 0.0070 and 0.0071 for male and female *P. heterolepis*, respectively (Froese, 2006).

3.6. Discussion

In the present study, 8-10 spine fin rays was found in dorsal fin that is similar to Shafi and Quddus (1982), Talwar and Jhingran (1991) and Rahman (2005), but the branched fin rays were more than their findings. Pectoral fin contains 15-17 fin rays with 1 unbranched ray that is more or less parallel to Rahman (2005). Observed pelvic fin rays (I/5) and anal fin rays (II/5-7) were alike with the study of Shafi and Quddus (1982), Talwar and Jhingran (1991) and Rahman (2005). Caudal fin rays (ii/15-17) were in agreements with Shafi and Quddus (1982). However, meristic counts solely unable to provide the detail information to distinguish among different populations or stocks of the same species.

Information on LFD, growth pattern and form factor of *P. heterolepis* are inadequate in literature elsewhere. Consequently, the present study is the first effort to describe LFDs, form factor as well as growth pattern of *P. heterolepis* from the Bay of Bengal, Bangladesh considering the eco-climatic parameters. Absence of individuals smaller than 10.5 cm TL during the study may be attributed to the selectivity of fishing gear or low market price or fishers did not go where smaller size of fishes exist (Hossain et al., 2016a, b; Hossen et al., 2019). The maximum TL was found 34.5 cm in favor of female. Our study revealed a length of 28.2 cm in SL specifically higher than the report (21.4 cm) of Sasaki (1995). Therefore, this study recorded the maximum length (34.5 cm in TL) for *P. heterolepis* in female population. Information about maximum length is important to assess the asymptotic length as well as growth co-efficient of fishes for formulating appropriate fisheries management policy (Ahmed et al., 2012; Khatun et al., 2018; 2019).

Carlander (1969) stated that allometric co-efficient (*b*) values may range between 2.0 to 4.0. On the other hand, Froese (2006) reported that the *b* values of LWRs should range from 2.5 to 3.5. In this study, the *b* values were found within the range of 2.5 to 3.5 (*b*

= 2.65 to 3.09 for males and *b* = 2.67 to 3.11 for females), which is comparable with the predictable range for teleost fish species (Froese, 2006). Further, the overall *b* value for both sexes indicated negative allometric growth. However, the allometric co-efficient (*b*) values may differ in the same species because of consolidation of various factors i.e. sex, development of gonad, growth variations in different body parts, physiological condition, food availability, preservation methods and variances in the observed length class of the specimens collected (Hossain et al., 2015; Le Cren, 1951; Tesch, 1968), which were excluded during the present study. Moreover, the LLR was extremely correlated, but it was difficult to make any comparisons due to lack of available information on *P. heterolepis*.

In this study, the allometric co-efficient (*b*) was found significantly related with water temperature for both male and female. Fish is a poikilothermic animal. Consequently habitat temperature controls the fish body temperature, food consumption, growth rate and various body functions (Azevedo et al., 1998; Houlihan et al., 1993). Throughout the study, the maximum water temperature was recorded in June-July (34.4^{o}C) and the minimum was in January (19.8^{o}C). For male population, the *b* value showed isometric growth pattern from December to March when the temperature is comparatively lower. Thereafter, *b* value drops with the increase of temperature but recover steadily from the month of November. For female population, *b* value was found positive allometric in the month of January and Isometric in February and March. Further, *b* value dropped with increasing temperature. However, rainfall, DO and pH did not reveal any significant correlation with growth pattern between sexes. The highest rainfall was observed in August and no precipitation was occurred in the month of January. DO is considered the most vital parameter due to its necessity for aerobic metabolism (Timmons et al., 2001). The level of DO should be above 3.5 mg/l for marine fisheries resources (EPA, 2000). Similarly, pH is also considered crucial for any aquatic ecosystem. If the pH value of any aquatic ecosystem is more acidic ($pH < 4.5$) or more alkaline ($pH > 9.5$) for long time, growth and reproduction will be diminished (Ndubuisi et al., 2015). In our study, the monthly DO level ranged from 5.42 to 6.15 mg/l and pH ranged from 6.76 to 7.32 indicating a suitable habitat for marine fisheries resources in the Bay of Bengal, Bangladesh.

The calculated form factor ($a_{3.0}$) was 0.0070 and 0.0071 for male and female *P. heterolepis*, respectively (Froese, 2006). We found no reference about the form factor of *P. heterolepis*. Therefore, it is difficult to compare the finding with other studies.

3.7. Conclusion

Our study described the length-frequency distribution, growth pattern in relation to eco-climatic factors of *P. heterolepis* from the Bay of Bengal, Bangladesh. Growth pattern was significantly correlated with temperature for both sexes. Also, this study recorded the maximum size of *P. heterolepis* from the Bay of Bengal. These findings might be a potential tool for fishery biologist to initiate stock assessment of the standing stock of *P. heterolepis* in the marine waters of Bangladesh. Moreover, the results will contribute valuable baseline for further studies within the marine and coastal ecosystems.

Chapter 4

Study-II

<u>STUDY-II</u>

Estimation of condition factors of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

4.1. Abstract

The study describes the condition factors (Fulton's, K_F; allometric, K_A; Relative, K_R and relative weight, W_R) of *P. heterolepis* from the Bay of Bengal, Bangladesh in relation to eco-climatic factors. All together 1,223 specimens (male = 654 and female = 569) were collected from the fishers during January to December, 2019. Fulton's condition factor (K_F) was found the best for assessing the well-being of this species. Moreover, K_F was found significantly related with temperature for both male and female. The W_R denoted that the ecosystem was in balanced condition. The results of this study will be helpful for future management of this fish in Bay of Bengal and surrounding ecosystems.

Key words: *Panna heterolepis*, condition factor, eco-climatic factors, Bay of Bengal.

4.2. Introduction

Condition factor is an index which is used to understand survival, maturity, health status and reproduction of fish (Le Cren, 1951). Further, it is used as an indicator of water quality and overall health of a population dwelling in a specific ecosystem (Tsoumani et al., 2006). In addition, relative weight (W_R) is the most popular index to assess the status of fish in a particular habitat considering prey-predator status (Froese, 2006; Rypel and Richter, 2008).

At present, climatic issues are considered as vibrant warning to aquatic living resources accompanied by other risks like overfishing, contamination in addition to habitat deterioration (Rose 2005). Temperature is thought to be the most imperative climatic factor influencing the distribution of larval accumulations of marine and freshwater fish species (Houde and Zastrow, 1993; Jakobsen et al., 2009). Likewise, rainfall is another important climatic factor prompting the hydrological events through runoff and river inflow (Patrick, 2016). In order to maintain inclusive fish growth, an optimum level of DO (dissolved oxygen) is necessary for their metabolic activities (Abdel-Tawwab et al., 2015). Besides, pH denotes the acidic and alkaline condition of an aquatic ecosystem. Upper pH level (9-14) affects fish physiology not only by denaturing cell membranes but also altering different parameters of an aquatic ecosystem (Brown and Sadler, 1989).

The Hooghly Croaker (*Panna heterolepis* Trewavas, 1977) is a tropical marine fish species (Talwar and Jhingran, 1991) under the family Sciaenidae. This Sciaenid fish is distributed in Bangladesh, India, Myanmar and Sri Lanka (Sasaki 1995). This species is commercially important as a fish food item for the coastal people of Bangladesh. However, total demand of this species is met through the capture from wild stock due to absence of culture practice. Consequently, overfishing is considered the notable threat for the natural stock of *P. heterolepis* in Bay of Bengal (Hossen et al., 2019). However, there is no available published literature on the growth, condition and reproductive biology of *P. heterolepis* from Bangladeshi marine water for planning proper management strategies.

4.3. Objectives

The aims of this study are to:

- Estimate the Fulton's condition factor;
- Calculate the allometric condition factor;
- Determine the relative condition factor;
- Ascertain the relative weight; and
- Establish relationship between the best condition factor with eco-climatic factors.

4.4. Materials and Methods

4.4.1. Fish measurement

Male and female individuals were identified by microscopic observation of gonads. Body weight (BW) as well as total length (TL) was assessed by digital balance and measuring board with 0.01 g and 0.01 cm accuracy.

4.4.2. Calculation of condition factors

Fulton's condition factor (K_F) was calculated by the equation: $K_F = 100\times(W/L^3)$ (Fulton, 1904), where W is the BW in g and L is the TL in cm. The scaling factor 100 was used to bring the K_F close to unit.

The allometric condition factor (K_A) was calculated using the equation: $K_A = W/L^b$ (Tesch, 1968), where W is the BW in g, L is the TL in cm and b is the LWRs parameter.

Further, relative condition factor (K_R) was assessed with the equation: $K_R = W/(a\times L^b)$ (Le Cren, 1951), where W is the BW in g, L is the TL in cm and a and b are LWRs parameters.

The relative weight (W_R) was calculated by the equation: $W_R = (W/Ws)\times 100$ (Froese, 2006), where W is the BW of a specific individual and W_S is the anticipated standard weight for the identical individual as calculated by $W_S = a\times L^b$, where a and b values were acquired from the relationships between TL and BW.

4.4.3. Eco-climatic parameters

In order to assess the relationship between the best condition factor of *P. heterolepis* with habitat status, monthly ecological parameters were also recorded from the sampling site following APHA (2005) procedures. The collected parameters were temperature (^{o}C), pH and dissolved oxygen (DO; mg/L). Further, the data of monthly rainfall (mm) was collected from meteorological station of Khulna, Bangladesh.

4.4.4. Statistical Analyses

Statistical analyses were conducted by Microsoft® Excel-add-in-DDXL and Graph Pad Prism 6.5 software. The nonparametric Mann-Whitney U test was applied to compare the condition factors between sexes. The Wilcoxon signed rank test was conducted to compare the average relative weight (W_R) and 100 (Anderson & Neumann, 1996). The Spearman's rank test was used to correlate body measurements (TL and BW) with condition factors (K_F, K_A, K_R *and* W_R) as well as to relate the best condition factor with different eco-climatic parameters. All statistical analyses were conducted with 5% significance level.

4.5. Results

4.5.1. Fulton's condition factor (K_F)

The lowest and highest K_F values for male were 0.56 and 1.12 in September and April, respectively. Besides, minimum and maximum K_F values for females were 0. 60 and 1.45 in February and April, respectively (Table 15). Further, K_F revealed significant variations between males and females (Two tailed, Mann-Whitney U-test, U= 146683, $P < 0.0001$) during the study. According to Spearman rank test, Fulton's condition factor (K_F) and TL were significantly correlated in both sexes indicating that K_F was the best allowing for the well-being of *P. heterolepis* in the Bay of Bengal (Table 19).

Table 15. Descriptive statistics on Fulton's condition factor (K_F) measurements and their 95% confidence limits of the *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Month	Sex	n	Fulton′s condition factor (K_F)			
			Min	Max	Mean±SD	95% CL
January	M	35	0.66	0.76	0.71±0.03	0.70-0.72
	F	72	0.69	0.85	0.77±0.04	0.76-0.78
	C	107	0.66	0.85	0.75±0.05	0.74-0.76
February	M	37	0.58	0.87	0.74±0.07	0.71-0.76
	F	67	0.60	1.01	0.77±0.09	0.75-0.79
	C	104	0.58	1.01	0.76±0.08	0.74-0.77
March	M	47	0.60	0.86	0.74±0.06	0.73-0.76
	F	57	0.66	0.99	0.79±0.07	0.77-0.81
	C	104	0.60	0.99	0.77±0.07	0.76-0.78
April	M	50	0.61	1.12	0.79±0.08	0.77-0.81
	F	34	0.68	1.45	0.87±0.15	0.82-0.92
	C	84	0.61	1.45	0.82±0.12	0.80-0.85
May	M	76	0.66	1.05	0.79±0.07	0.77-0.81
	F	25	0.72	1.05	0.83±0.08	0.80-0.87
	C	101	0.66	1.05	0.80±0.07	0.79-0.82
June	M	77	0.63	0.95	0.73±0.05	0.72-0.74
	F	22	0.72	1.05	0.86±0.08	0.82-0.89
	C	99	0.63	1.05	0.76±0.08	0.74-0.77
July	M	66	0.62	0.96	0.73±0.06	0.71-0.74
	F	37	0.64	1.07	0.77±0.09	0.74-0.80
	C	103	0.62	1.07	0.74±0.07	0.73-0.76
August	M	63	0.56	0.91	0.70±0.06	0.69-0.72
	F	43	0.64	0.88	0.72±0.06	0.70-0.73
	C	106	0.56	0.91	0.71±0.06	0.70-0.72
September	M	60	0.56	0.77	0.67±0.05	0.66-0.68
	F	42	0.63	0.77	0.71±0.03	0.70-0.72
	C	102	0.56	0.77	0.69±0.04	0.68-0.70
October	M	45	0.64	0.82	0.72±0.05	0.71-0.74
	F	59	0.64	0.85	0.72±0.05	0.71-0.74
	C	104	0.64	0.85	0.72±0.05	0.71-0.73
November	M	42	0.63	0.82	0.70±0.05	0.69-0.72
	F	63	0.62	0.81	0.69±0.05	0.68-0.71
	C	105	0.62	0.82	0.70±0.05	0.69-0.71
December	M	56	0.63	0.78	0.70±0.03	0.69-0.71
	F	48	0.66	0.82	0.73±0.04	0.72-0.75
	C	104	0.63	0.82	0.72±0.04	0.71-0.72

Note: M, Male; F, Female; Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, 95% Confidence Limit.

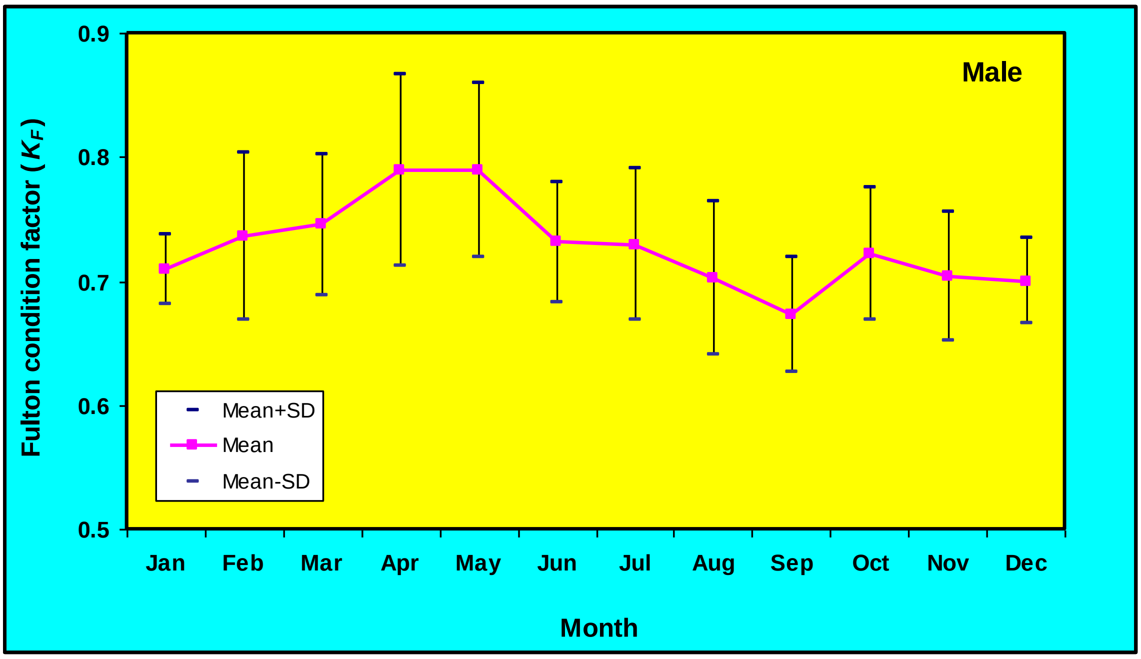


Figure 8. Monthly variations of Fulton's condition factors for male *Panna heterolepis* from the Bay of Bengal, Bangladesh.

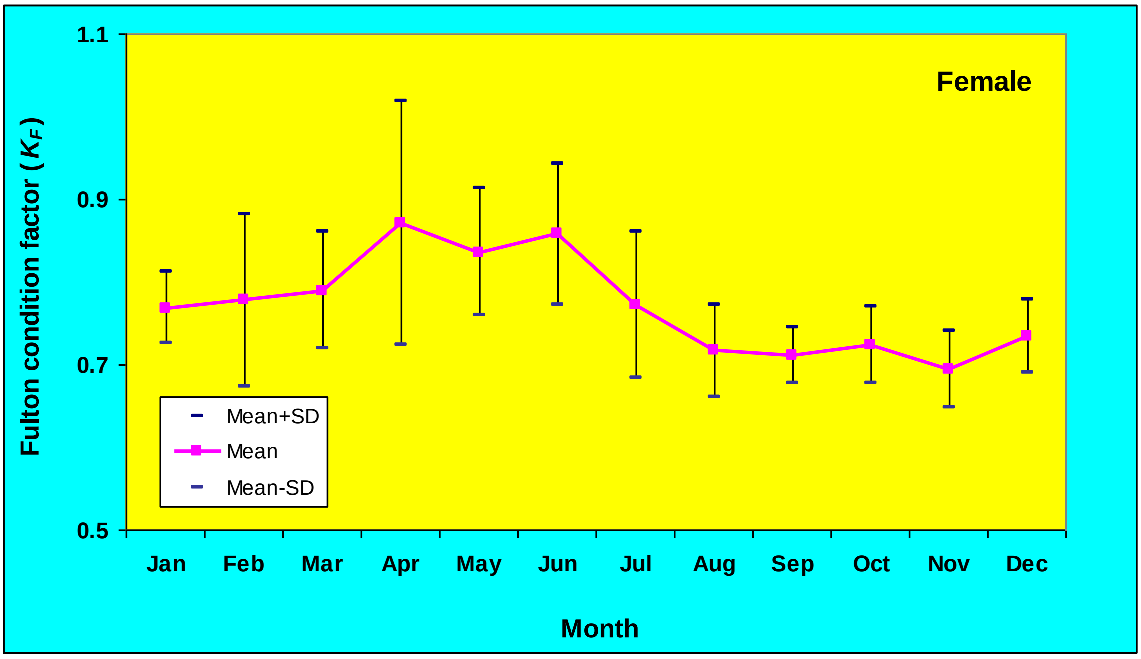


Figure 9. Monthly variations of Fulton's condition factors for female *Panna heterolepis* from the Bay of Bengal, Bangladesh.

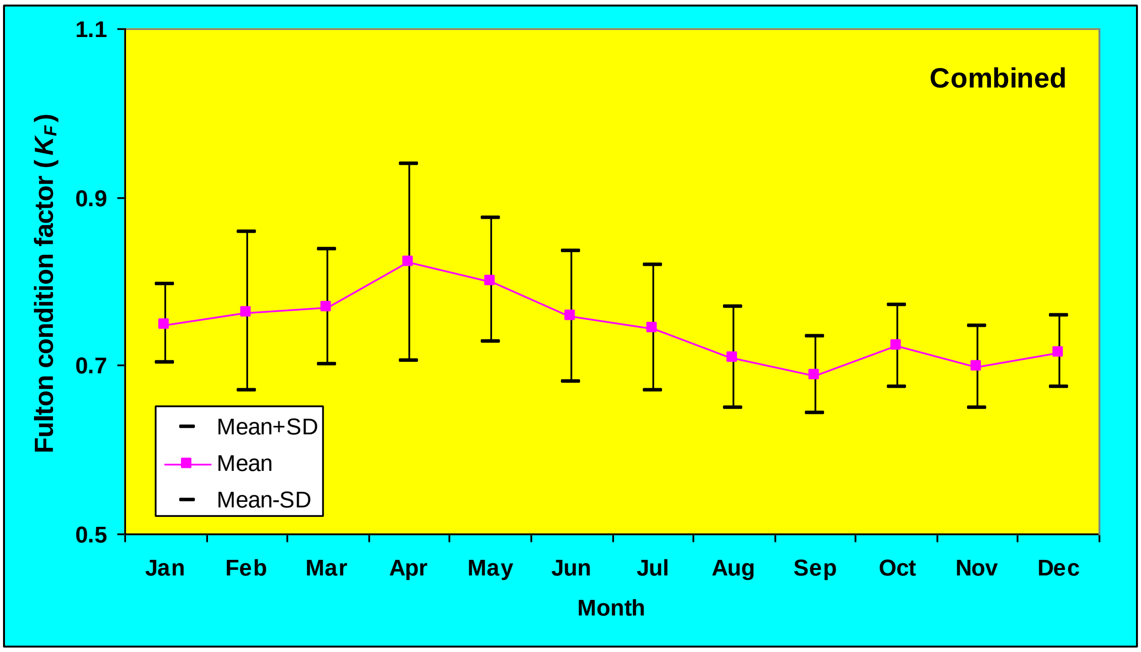


Figure 10. Monthly variations of Fulton's condition factors for combined sex of *Panna heterolepis* from the Bay of Bengal, Bangladesh.

4.5.2. Allometric condition factor (K_A)

This study indicated the minimum and maximum allometric condition factor (K_A) were 0.0047 in February and 0.0212 in September for males. On the other hand, the lowest and highest K_A values for female population were 0.0050 in January and 0.0267 in April. For combined sex, minimum and maximum K_A values were 0.0045 in January and 0.0225 in April (Table 16). The non-parametric Mann-Whitney U-test showed significant differences in the K_A between males and females (Two tailed, Mann-Whitney U = 21126, $P < 0.0001$).

Table 16. Descriptive statistics on Allometric condition factor (K_A) measurements and their 95% confidence limits of the *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Month	Sex	n	Allometric condition factor (K_A)			
			Min	Max	Mean±SD	95% CL
January	M	35	0.0079	0.0092	0.0086±0.0003	0.0085-0.0087
	F	72	0.0050	0.0063	0.0056±0.0003	0.0055-0.0057
	C	107	0.0045	0.0059	0.0052±0.0003	0.0051-0.0052
February	M	37	0.0047	0.0071	0.0058±0.0005	0.0056-0.0059
	F	67	0.0060	0.0101	0.0069±0.0009	0.0067-0.0071
	C	104	0.0056	0.0097	0.0067±0.0008	0.0066-0.0069
March	M	47	0.0048	0.0069	0.0059±0.0004	0.0058-0.0061
	F	57	0.0066	0.0099	0.0079±0.0007	0.0077-0.0081
	C	104	0.0051	0.0083	0.0065±0.0006	0.0064-0.0066
April	M	50	0.0084	0.0149	0.0107±0.0010	0.0105-0.0110
	F	34	0.0127	0.0267	0.0173±0.0025	0.0164-0.0181
	C	84	0.0103	0.0225	0.0136±0.0017	0.0132-0.0139
May	M	76	0.0100	0.0161	0.0124±0.0010	0.0121-0.0126
	F	25	0.0126	0.0181	0.0148±0.0012	0.0142-0.0153
	C	101	0.0095	0.0153	0.0119±0.0010	0.0117-0.0121
June	M	77	0.0076	0.0112	0.0088±0.0006	0.0086-0.0089
	F	22	0.0101	0.0145	0.0120±0.0011	0.0115-0.0125
	C	99	0.0127	0.0196	0.0150±0.0013	0.0147-0.0152
July	M	66	0.0094	0.0143	0.0111±0.0008	0.0109-0.0113
	F	37	0.0138	0.0206	0.0170±0.0015	0.0165-0.0175
	C	103	0.0110	0.0173	0.0132±0.0011	0.0130-0.0135
August	M	63	0.0080	0.0125	0.0100±0.0008	0.0098-0.0102
	F	43	0.0163	0.0210	0.0182±0.0011	0.0179-0.0185
	C	106	0.0093	0.0145	0.0117±0.0009	0.0115-0.0119
September	M	60	0.0173	0.0212	0.0193±0.0010	0.0190-0.0196
	F	42	0.0072	0.0090	0.0081±0.0004	0.0080-0.0083
	C	102	0.0144	0.0195	0.0163±0.0009	0.0161-0.0165
October	M	45	0.0114	0.0147	0.0130±0.0009	0.0127-0.0132
	F	59	0.0093	0.0123	0.0106±0.0006	0.0104-0.0108
	C	104	0.0096	0.0127	0.0109±0.0007	0.0107-0.0110
November	M	42	0.0128	0.0158	0.0142±0.0009	0.0140-0.0145
	F	63	0.0135	0.0171	0.0154±0.0009	0.0151-0.0156
	C	105	0.0131	0.0165	0.0148±0.0009	0.0147-0.0150
December	M	56	0.0057	0.0071	0.0064±0.0003	0.0063-0.0064
	F	48	0.0149	0.0183	0.0166±0.0008	0.0164-0.0169
	C	104	0.0102	0.0128	0.0114±0.0006	0.0113-0.0115

Note: M, Male; F, Female; Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, 95% Confidence Limit.

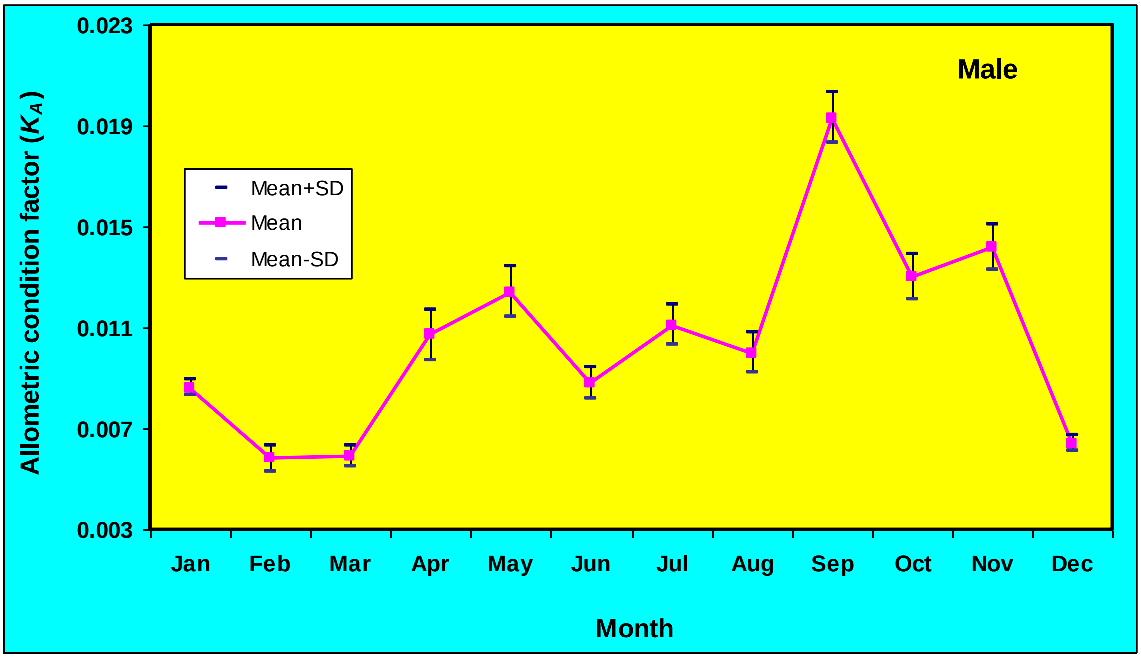


Figure 11. Monthly variations of allometric condition factor for male *Panna heterolepis* from the Bay of Bengal, Bangladesh.

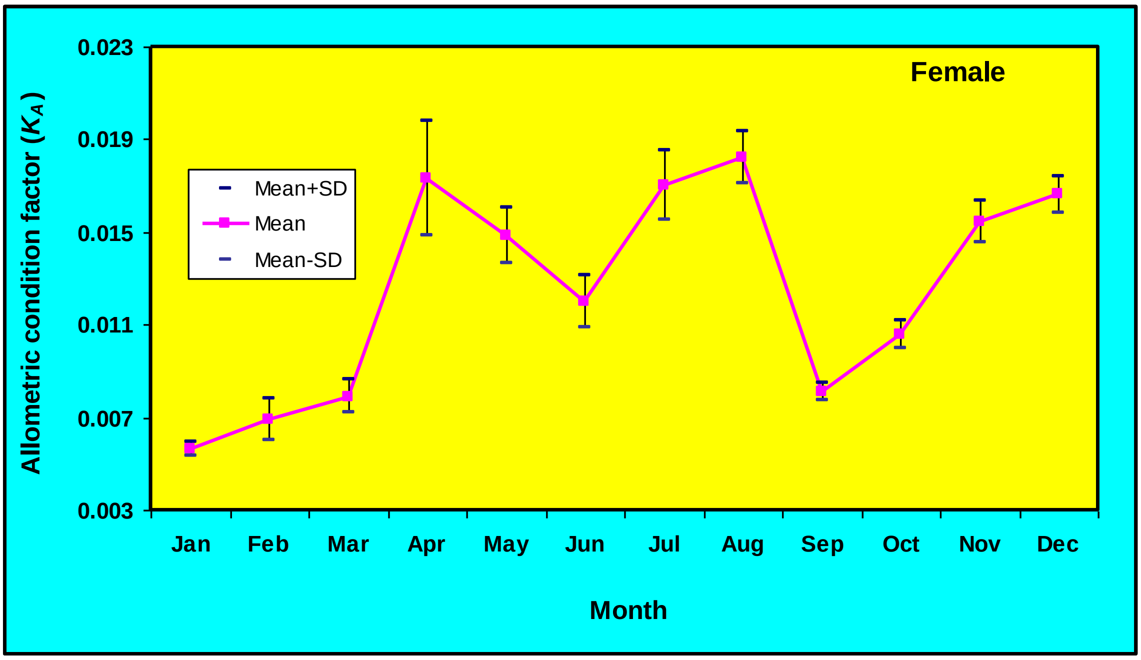


Figure 12. Monthly variations of allometric condition factor for female *Panna heterolepis* from the Bay of Bengal, Bangladesh.

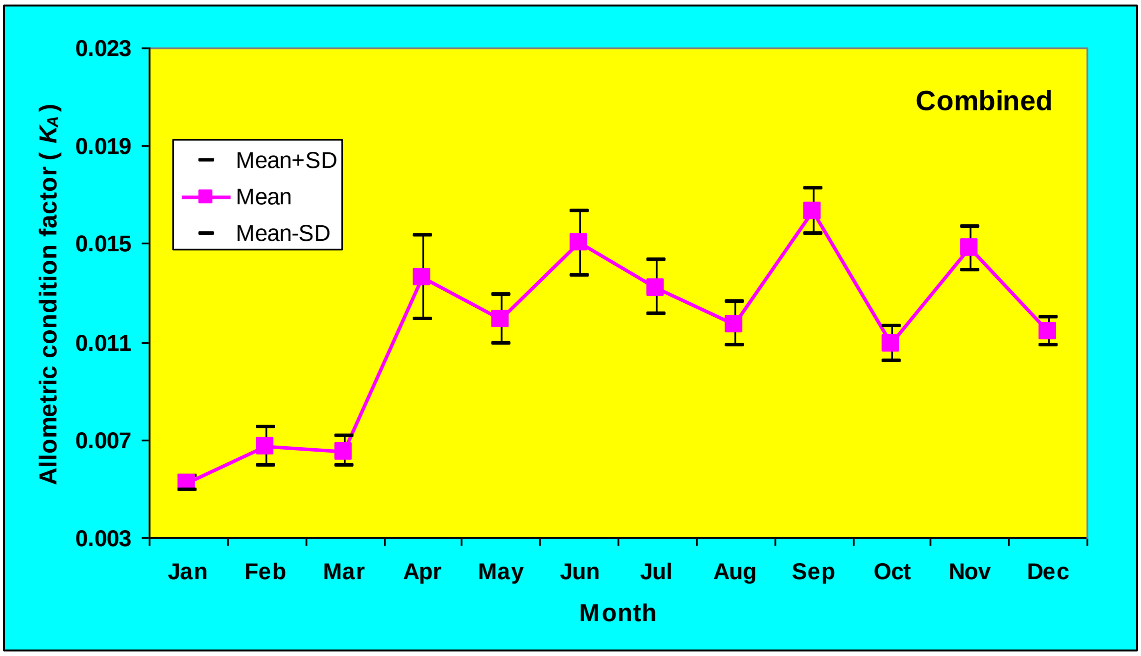


Figure 13. Monthly variations of allometric condition factor for combined sex of *Panna heterolepis* from the Bay of Bengal, Bangladesh.

4.5.3. Relative condition factor (K_R)

The study revealed the minimum and maximum relative condition factor (K_R) was 0.79 and 1.39 for males. On the other hand, the lowest and highest K_R values for female population were 0.73 and 1.55. Minimum and maximum values for both male and female populations were recorded in April. For combined sex, minimum and maximum K_R values were 0.77 in February and 1.68 in April (Table 17). The non-parametric Mann-Whitney U-test showed no significant differences in the K_R between males and females (Two tailed, Mann-Whitney U = 177488, P = 0.1641).

Table 17. Descriptive statistics on Relative condition factor (K_R) measurements and their 95% confidence limits of the *Panna heterolepis* from Bay of Bengal, Bangladesh.

Month	Sex	n	Relative condition factor (K_R)			
			Min	**Max**	**Mean±SD**	**95% CL**
January	M	35	0.92	1.07	1.00±0.04	0.99-1.02
	F	72	0.90	1.12	1.00±0.05	0.99-1.01
	C	107	0.86	1.14	0.99±0.06	0.98-1.00
February	M	37	0.82	1.24	1.01±0.09	0.98-1.04
	F	67	0.78	1.31	1.00±0.12	0.97-1.03
	C	104	0.77	1.34	1.00±0.11	0.98-1.02
March	M	47	0.83	1.20	1.02±0.08	1.00-1.05
	F	57	0.85	1.29	1.03±0.09	1.00-1.05
	C	104	0.81	1.32	1.03±0.09	1.01-1.05
April	M	50	0.79	1.39	1.00±0.09	0.98-1.03
	F	34	0.73	1.54	1.00±0.14	0.95-1.05
	C	84	0.77	1.68	1.01±0.13	0.98-1.04
May	M	76	0.82	1.32	1.01±0.08	0.99-1.03
	F	25	0.87	1.25	1.02±0.09	0.98-1.05
	C	101	0.79	1.28	0.99±0.09	0.97-1.01
June	M	77	0.86	1.28	1.00±0.06	0.98-1.01
	F	22	0.84	1.21	1.00±0.09	0.95-1.04
	C	99	0.85	1.31	1.00±0.09	0.99-1.02
July	M	66	0.85	1.30	1.01±0.08	0.99-1.03
	F	37	0.82	1.22	1.01±0.09	0.98-1.04
	C	103	0.83	1.31	1.00±0.09	0.99-1.02
August	M	63	0.80	1.27	1.01±0.08	0.99-1.03
	F	43	0.89	1.16	1.00±0.06	0.98-1.02
	C	106	0.79	1.24	1.00±0.08	0.98-1.01
September	M	60	0.90	1.10	1.00±0.05	0.99-1.01
	F	42	0.89	1.11	1.00±0.05	0.99-1.02
	C	102	0.89	1.20	1.00±0.06	0.99-1.02
October	M	45	0.89	1.14	1.01±0.07	0.99-1.03
	F	59	0.87	1.16	1.00±0.06	0.99-1.02
	C	104	0.88	1.18	1.01±0.06	0.99-1.02
November	M	42	0.90	1.11	1.00±0.06	0.98-1.02
	F	63	0.89	1.12	1.00±0.06	0.99-1.02
	C	105	0.88	1.12	1.00±0.06	0.99-1.01
December	M	56	0.91	1.13	1.01±0.05	1.00-1.02
	F	48	0.90	1.10	1.00±0.05	0.99-1.02
	C	104	0.89	1.12	1.00±0.06	0.99-1.01

Note: M, Male; F, Female; Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, 95% Confidence Limit.

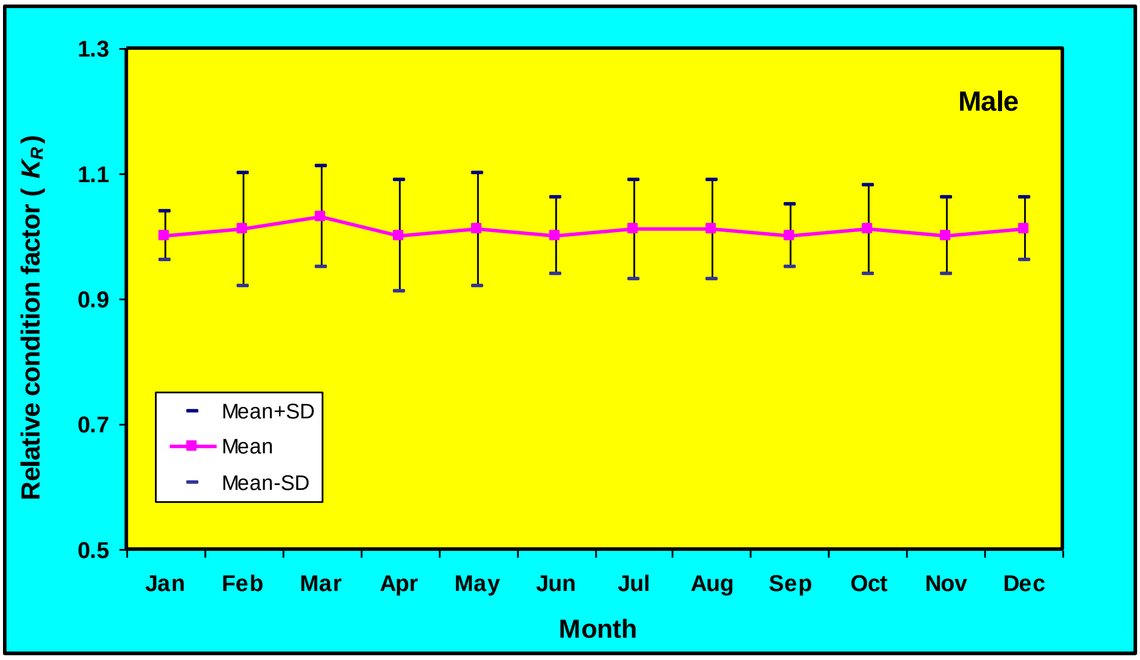


Figure 14. Monthly variations of relative condition factors for male *Panna heterolepis* from the Bay of Bengal, Bangladesh.

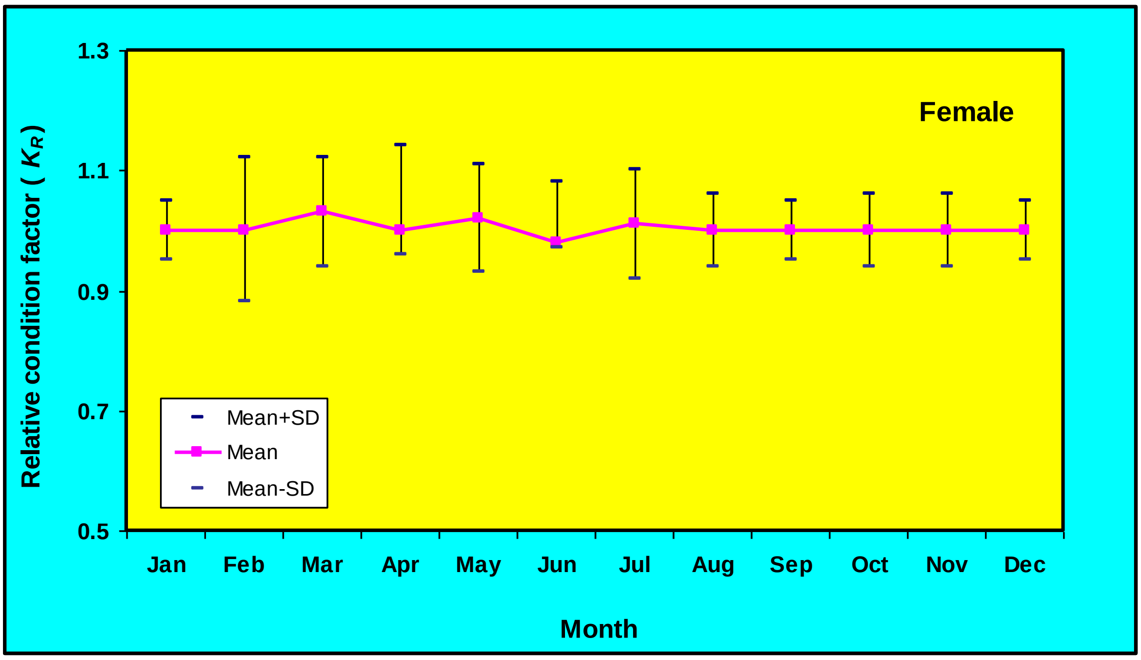


Figure 15. Monthly variations of Relative condition factors for female *Panna heterolepis* from the Bay of Bengal, Bangladesh.

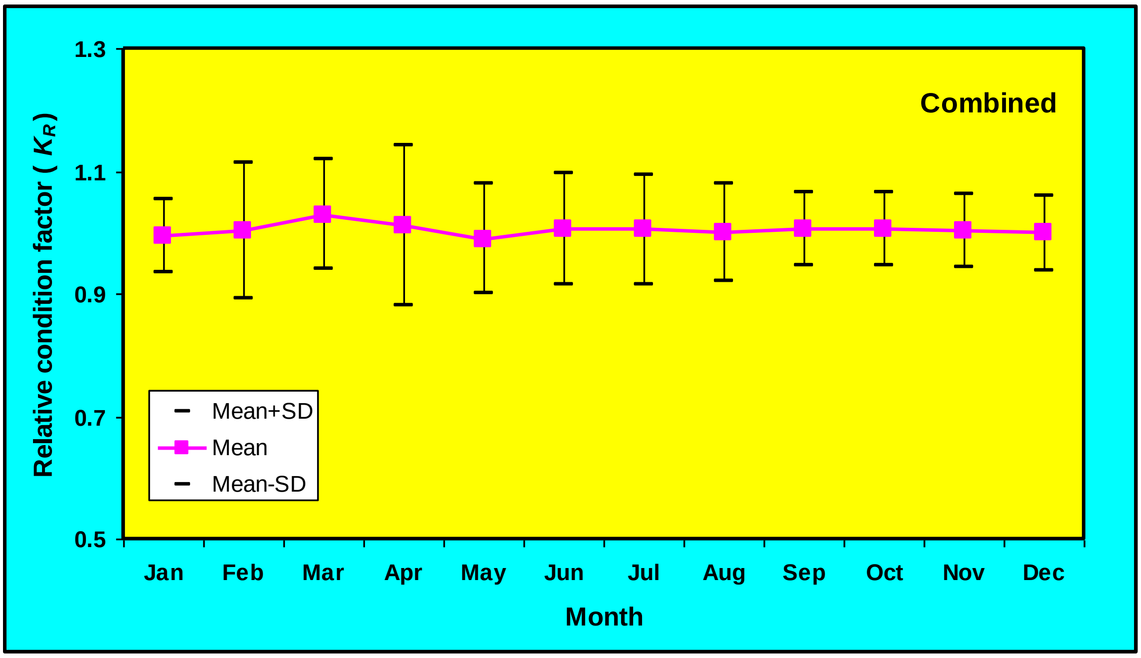


Figure 16. Monthly variations of Relative condition factors for combined sex of *Panna heterolepis* from the Bay of Bengal, Bangladesh.

4.5.4. Relative weight (W_R)

The lowest and highest W_R values for male were 78.55 and 139.24, respectively. Besides, minimum and maximum W_R values for females were 73.24 and 154.47. Minimum and maximum values for both males and females were recorded in April (Table 18). According to Wilcoxon sign rank test, W_R showed no significant differences from 100 for both males (P = 0.3348) and females (P = 0.4821).

Table 18. Descriptive statistics on Relative Weight (W_R) measurements and their 95% confidence limits of the *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Month	Sex	n	Relative Weight (W_R)			
			Min	**Max**	**Mean±SD**	**95% CL**
January	M	35	92.25	107.20	100.28±8.36	98.95-101.61
	F	72	90.14	111.69	100.04±5.44	98.76-101.32
	C	107	86.38	113.54	99.28±6.10	98.11-100.45
February	M	37	81.71	124.48	101.15±9.16	98.10-104.21
	F	67	76.24	134.77	100.17±13.46	96.88-103.45
	C	104	77.42	138.15	100.62±12.50	98.19-103.05
March	M	47	82.85	119.75	102.75±7.73	100.19-104.75
	F	57	85.17	128.98	102.53±9.12	100.11-104.95
	C	104	80.60	132.16	102.86±9.04	101.10-104.61
April	M	50	78.55	139.24	100.40±9.22	97.78-103.02
	F	34	73.24	154.47	99.92±14.20	94.96-104.88
	C	84	76.87	168.09	101.15±12.82	98.37-103.94
May	M	76	81.97	132.11	101.29±8.47	99.35-103.23
	F	25	86.77	124.50	101.74±8.62	98.18-105.29
	C	101	79.21	127.73	98.91±8.74	97.19-100.64
June	M	77	86.17	127.56	99.54±6.42	98.08-100.99
	F	22	83.99	120.95	99.66±9.49	95.45-103.87
	C	99	84.90	131.49	100.49±8.69	98.76-102.22
July	M	66	85.30	130.25	100.67±7.71	98.77-102.57
	F	37	81.93	122.05	100.58±8.89	97.61-103.54
	C	103	83.13	131.09	100.38±8.71	98.67-102.08
August	M	63	80.47	126.54	100.64±8.38	98.52-102.75
	F	43	89.37	115.52	99.99±6.08	98.11-101.86
	C	106	79.24	123.53	99.88±7.64	98.41-101.36
September	M	60	89.85	109.84	100.06±5.36	98.68-101.45
	F	42	88.98	110.87	100.42±4.80	98.92-101.91
	C	102	88.92	120.47	100.43±5.77	99.30-101.56
October	M	45	88.70	113.82	100.60±6.63	98.61-102.59
	F	59	87.41	116.42	100.11±5.96	98.56-101.67
	C	104	88.43	117.73	100.59±6.34	99.36-101.83
November	M	42	90.16	111.35	100.28±6.24	98.34-102.23
	F	63	88.54	111.70	100.38±5.61	98.96-101.79
	C	105	88.41	111.60	100.18±5.83	99.05-101.31
December	M	56	91.27	112.57	100.88±4.85	99.59-102.18
	F	48	90.00	110.12	100.10±5.07	98.62-101.57
	C	104	89.06	112.41	99.81±5.57	98.73-100.89

Note: M, Male; F, Female; Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, 95% Confidence Limit.

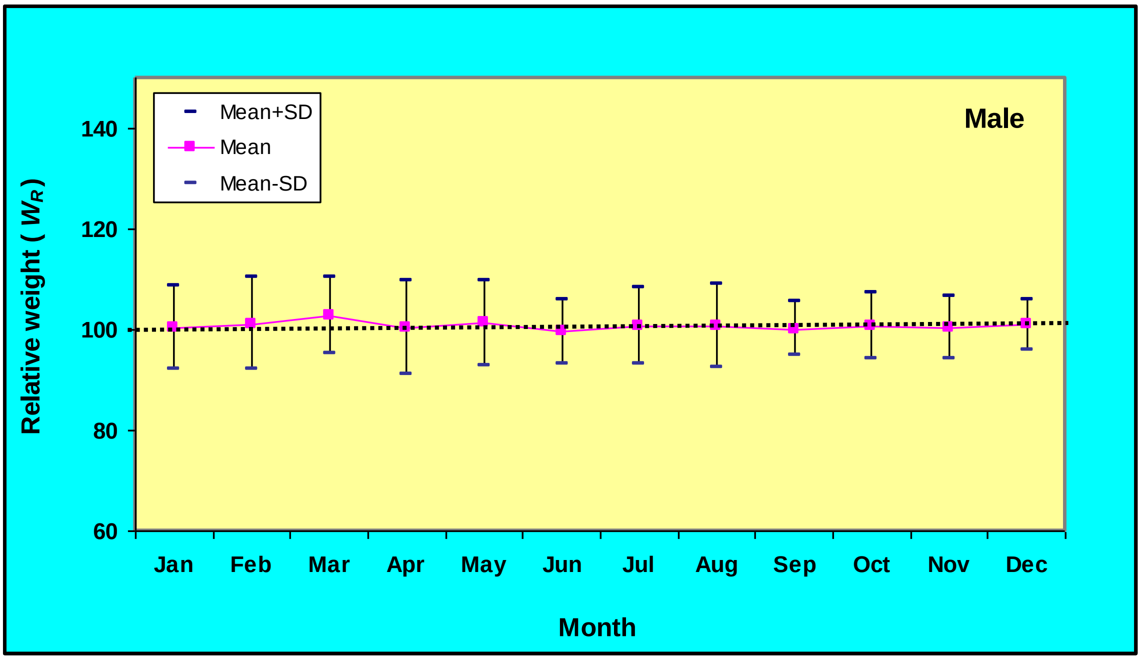


Figure 17. Monthly variations of relative weight for male *Panna heterolepis* from the Bay of Bengal, Bangladesh.

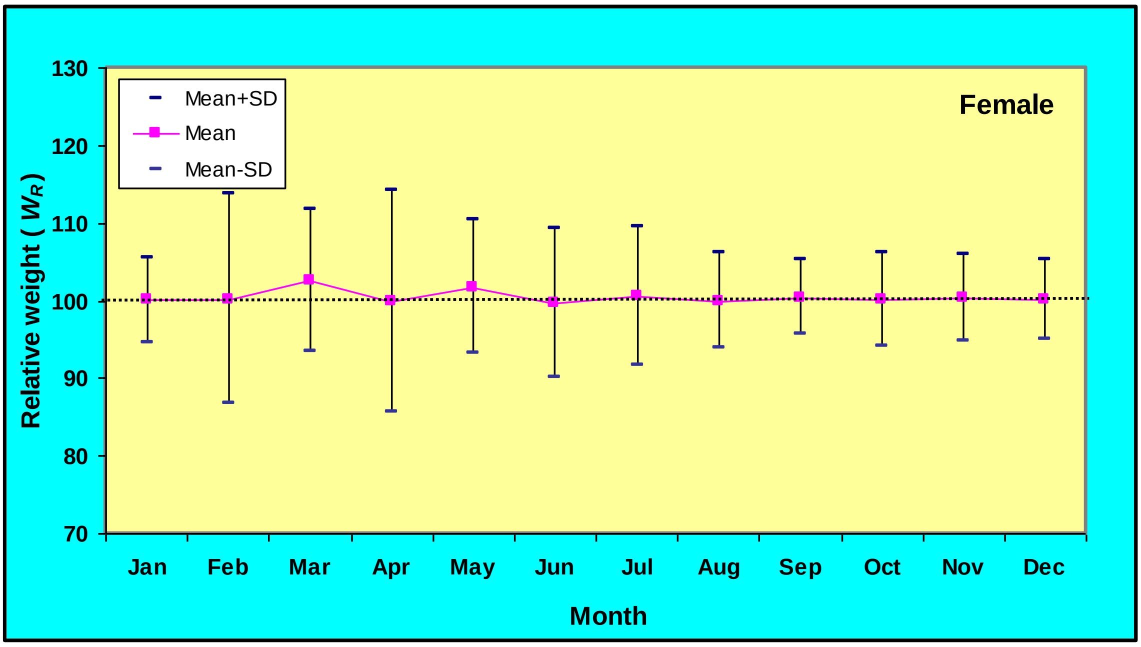


Figure 18. Monthly variations of relative weight for female *Panna heterolepis* from the Bay of Bengal, Bangladesh.

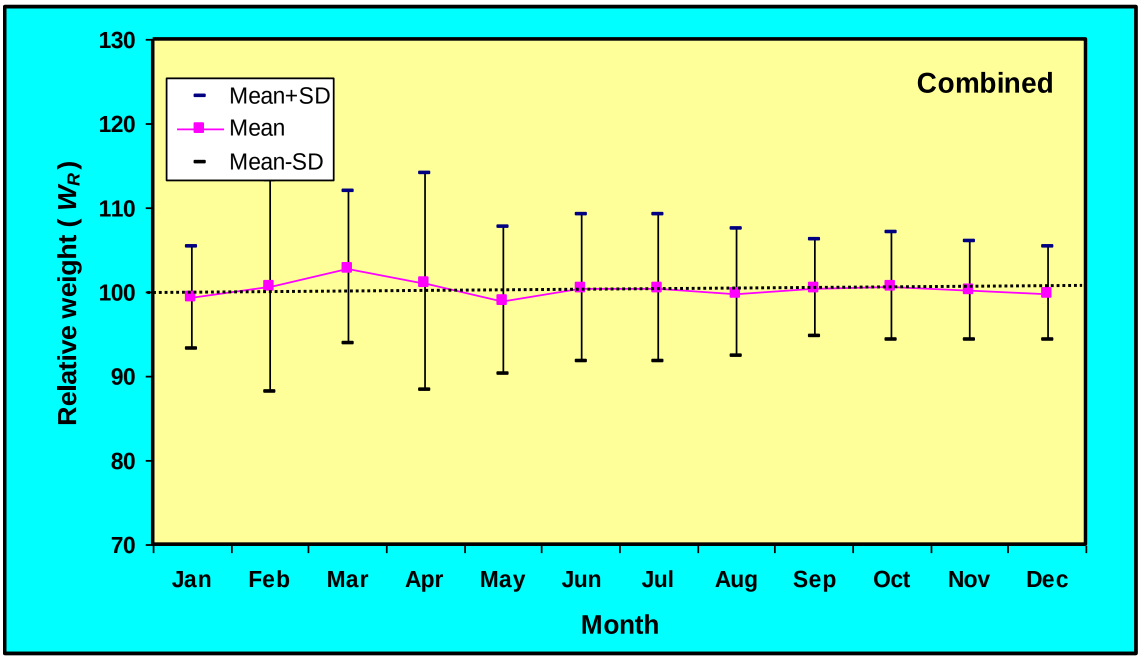


Figure 19. Monthly variations of relative weight for combined sex of *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Table 19. Relationships of condition factor with total length and body weight of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

Relationships	Sex	r_s values	95% CL of r_s	*P* values	Significance
TL *vs.* K_F	M	-0.2500	-0.3226 to -0.1746	$P < 0.001$	*
TL *vs.* K_A		0.0324	-0.0466 to 0.1111	$P = 0.2038$	*ns*
TL *vs.* K_R		0.0324	-0.0467 to 0.1111	$P = 0.2041$	*ns*
TL *vs.* W_R		0.0324	0.0467 to 0.1111	$P = 0.2041$	*ns*
BW *vs.* K_F		-0.1001	-0.1777 to -0.0214	$P = 0.0104$	*
BW *vs.* K_A		0.1827	0.1053 to 0.2579	$P < 0.0001$	***
BW *vs.* K_R		0.1827	0.1053 to 0.2579	$P < 0.0001$	***
BW *vs.* W_R		0.1827	0.1053 to 0.2579	$P < 0.0001$	***
TL *vs.* K_F	F	-0.2466	-0.3245 to -0.1654	$P < 0.0001$	***
TL *vs.* K_A		0.0401	-0.0447 to 0.1243	$P = 0.3396$	*ns*
TL *vs.* K_R		0.0401	-0.0447 to 0.1243	$P = 0.3393$	*ns*
TL *vs.* W_R		0.0402	-0.0446 to 0.1244	$P = 0.3391$	*ns*
BW *vs.* K_F		-0.0566	-0.1406 to 0.0282	$P = 0.1776$	*ns*
BW *vs.* K_A		0.2280	0.1462 to 0.3067	$P < 0.0001$	***
BW *vs.* K_R		0.2280	0.1462 to 0.3067	$P < 0.0001$	***
BW *vs.* W_R		0.2280	0.1462 to 0.3068	$P < 0.0001$	***

Note: *ns*, not significant; * significant; ***highly significant

4.5.5. Eco-climatic parameters

In our study, four eco-climatic parameters were recorded namely temperature, rainfall, DO and pH. The Fulton's condition factor (K_F) was found significantly related with temperature for both male ($P = 0.0378$) and female ($P = 0.0352$). However, Rainfall, DO and pH did not reveal any significant correlation with K_F (Table 20). The relationship between K_F and eco-climatic parameters are presented in Figure 20 and 21.

Table 20. Relationship between eco-climatic factors with Fulton's condition factor of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

Relationships	**Sex**	**r_s values**	**95% CL of r_s**	***P* values**	**Significance**
Temp. *vs.* K_F	**M**	0.6123	0.0397 to 0.8821	P = 0.0378	*
Rainfall *vs.* K_F		-0.3117	-0.7596 to 0.3367	P = 0.3154	*ns*
DO vs. K_F		0.1813	-0.4538 to 0.6943	P = 0.5679	*ns*
pH vs. K_F		0.0685	-0.5400 to 0.6300	P = 0.8310	*ns*
Temp. *vs.* K_F	**F**	0.6200	0.0521 to 0.8849	P = 0.0352	*
Rainfall *vs.* K_F		-0.4685	-0.8278 to 0.1631	P = 0.1275	*ns*
DO *vs.* K_F		0.0984	-0.5183 to 0.6478	P = 0.7606	*ns*
pH *vs.* K_F		0.1474	-0.4811 to 0.6758	P = 0.6459	*ns*

Note: *ns*, not significant; * significant

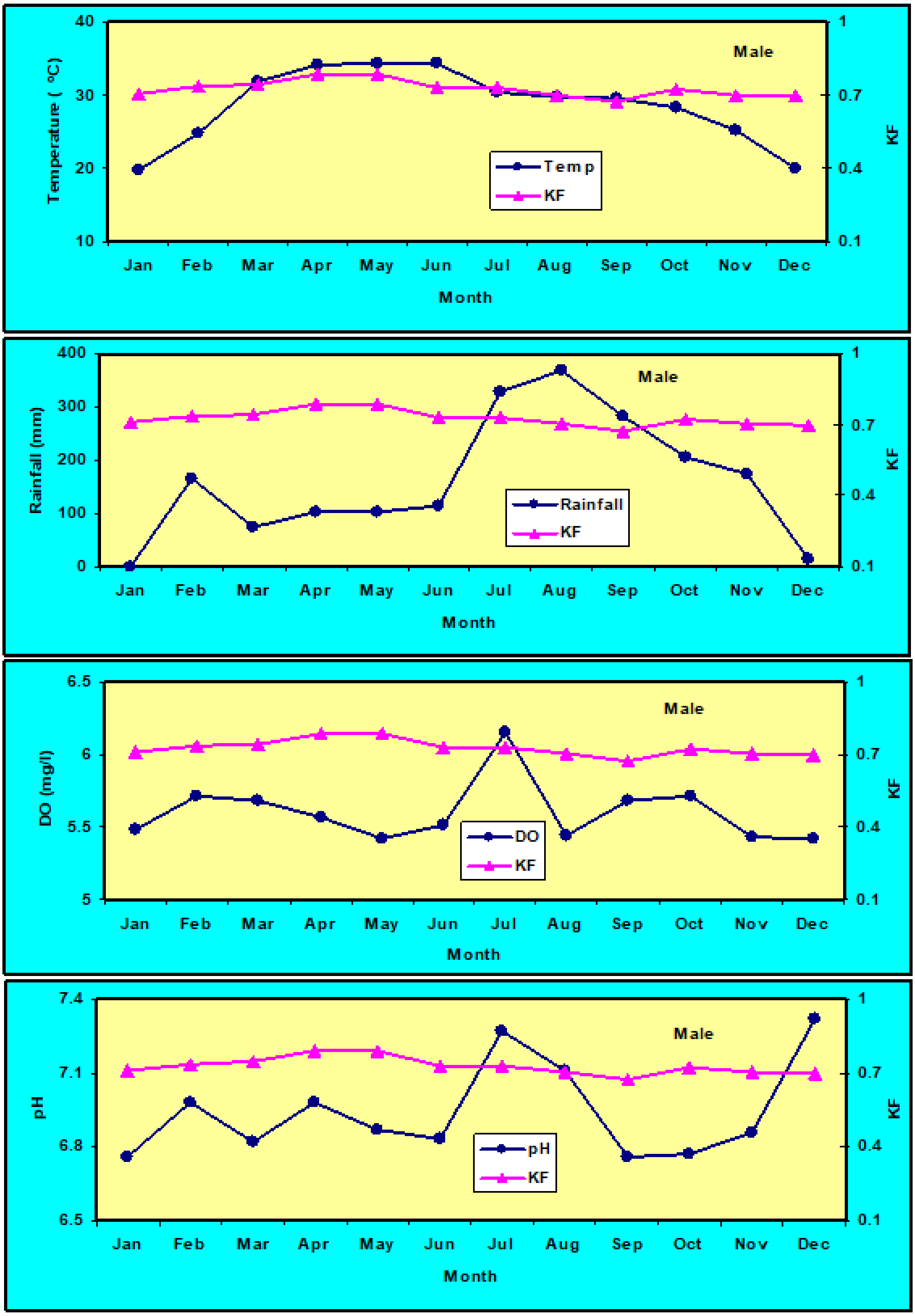


Figure 20. Relationship between Fulton's condition factor with eco-climatic factors of male *Panna heterolepis* in the Bay of Bengal, Bangladesh.

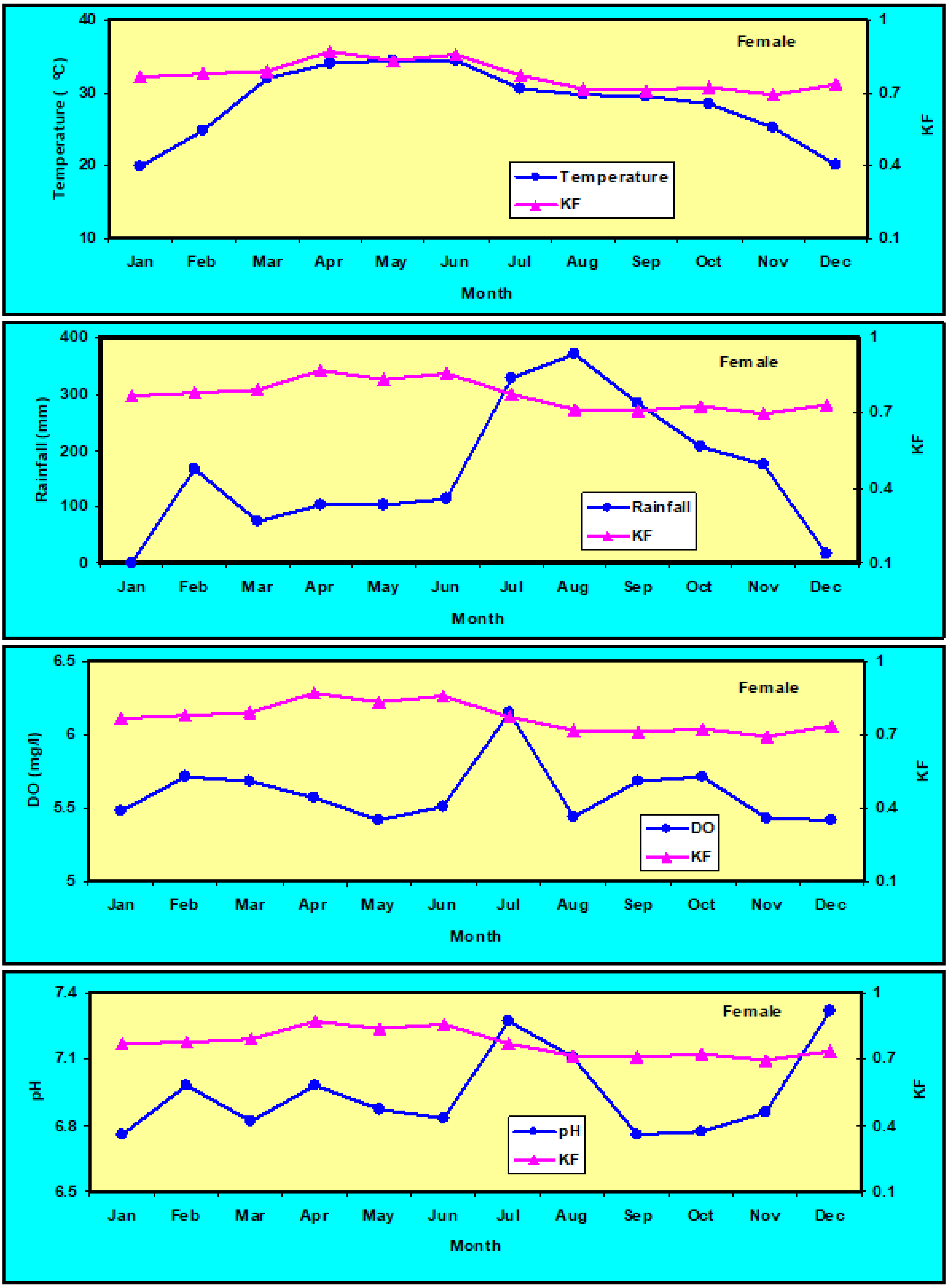


Figure 21. Relationship between Fulton's condition factor with eco-climatic factors of female *Panna heterolepis* in the Bay of Bengal, Bangladesh.

4.6. Discussion

Condition factor indicates the degree of well-being of a fish population in their natural ecosystem. The higher value of condition factor indicates that the fish are in better condition (Maurya et al., 2018). Information on condition factor of *P. heterplepis* is scarce in literature. Therefore, the present study is the first effort to describe condition factor along with relative weight of *P. heterolepis* from Bay of Bengal, Bangladesh. A total of 1,223 individuals of various body sizes were sampled using local gears for successive twelve months. To assess the overall health and productivity of *P. heterolepis,* several condition factors including Fulton's (K_F), allometric (K_A), relative (K_R) as well as relative weight (W_R) were used in the present study. According to Spearman rank test, Fulton's condition factor (K_F) and TL were significantly correlated in both sexes denoting that K_F was the best allowing for the well-being of *P. heterolepis* in the Bay of Bengal.

The W_R declining below 100 for a population indicates lower prey or high predator density; whereas values above 100 indicate a prey surplus or lower predator (Froese, 2006). In our study, the mean W_R revealed no significant difference from 100 for both male and female populations of *P. heterolepis* indicating the habitat was in balanced condition. We found no reference about the condition factor and relative weight of *P. heterolepis* elsewhere. Therefore, it is difficult to compare the finding with other studies.

Further, the Fulton's condition factor (K_F) was found significantly related with water temperature for both male and female. Fish is a poikilothermic animal. Consequently, habitat temperature controls the fish body temperature, food consumption, growth rate and various body functions (Houlihan et al., 1993; Azevedo et al., 1998). Throughout the study, the maximum water temperature was recorded in June-July (34.4^{o}C) and the minimum was in January (19.8^{o}C). The K_F value showed a positive correlation with temperature. However, rainfall, DO and pH did not reveal any significant correlation with K_F between sexes.

4.7. Conclusion

Our study describes the condition factors of *P. heterolepis* considering the eco-climatic factors from the Bay of Bengal, Bangladesh. Fulton's condition factor (K_F) was found the best for assessing the wellbeing of the above mentioned species. Further, K_F value showed a positive correlation with temperature for both sexes. The findings of the study might be a potential tool for fishery biologist to initiate stock assessment of the standing stock of *P. heterolepis* in the marine and coastal waters of Bangladesh.

Chapter 5

Study-III

STUDY-III

Reproductive Biology of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

5.1. Abstract

This study highlights the reproductive biology of *P. heterolepis*, which is a dominant fish in the Bay of Bengal, Bangladesh, based on monthly sampling of 569 female individuals from January to December, 2019. We observe the effect of different environmental factors (temperature, rainfall, dissolved oxygen and pH) on the reproduction of *P. heterolepis*. Measurement of each individual like as total length (TL) and body weight (BW) were taken by means of measuring board and digital balance. Gonads were removed cautiously through ventral dissection from female specimens and weighed to 0.01 g accuracy. To assess the size at sexual maturity (TL_m), spawning season and peak - spawning season; the GSI (gonadosomatic index in %), MGSI (modified gonadosomatic index in %) and DI (Dobriyal index) were considered. Based on these indices, the L_m was documented 15.0 cm in TL. Moreover, the TL_{50} was predicted by logistic calculation as 15.0 cm in TL. Further, the greater values of GSI, MGSI and DI denoted that the spawning season was extended from January to July, with a peak in February for *P. heterolepis* in the Bay of Bengal. In addition, GSI was recorded statistically correlated with temperature. However, other environmental factors (rainfall, dissolved oxygen and pH) did not show any significant relation with GSI. Finally, the outcomes of our study might be useful to carry out specific management program for *P. heterolepis* in the Bay of Bengal and connected ecosystem.

Keywords: Size at sexual maturity, environmental factors, spawning season, *Panna heterolepis*, Bay of Bengal.

5.2. Introduction

The Hooghly Croaker (*Panna heterolepis* Trewavas, 1977) is found profusely in Bangladesh, Indian, Myanmar and Sri Lanka (Sasaki, 1995). This species is a representative of the family Sciaenidae inhibits coastal and marine waters (Talwar and Jhingran, 1991). The *P. heterolepis* is very famous among the three representative species under the genus *Panna* in the Indian Ocean together with *P. microdon* and *P. perarmatus* (Froese and Pauly, 2020). This species is locally called *Poa* and commercially significant as a popular fish food item for the coastal people of Bangladesh because of their outstanding flesh quality. Consequently, overfishing is considered the most focal threat for the wild population of *P. heterolepis* in the context of Bangladesh (Hossen et al., 2019). Besides, this species is a profitable source of large scale and subsistence fishers who use a number of traditional gears including Seine bag net and Gill net (Hossain et al., 2012). Further, this species is considered as least concern worldwide (Akhilesh et al., 2020).

The government of Bangladesh usually enforces yearly fishing ban for a period of 65 days from 20 May to 23 July to promote the spawning of depleted fish and crustacean stocks in Bay of Bengal since 2019 (DoF, 2019). However, the peak spawning season for the marine fish and crustacean stocks is not yet determined. Alternatively, the coastal fishermen protest against the banning period, as marine fishing is the only source of their livelihood. Further, the peak fishing season is extended from the month of June to September in Bay of Bengal. Without supplementary income options, this imposed ban period would drive them into more destitution condition.

In order to formulate sound fisheries management policy, the knowledge of reproduction is an important concern. Information about reproductive biology of fish is essential for understanding of its population dynamics as well formulating baseline data in the management process (King, 2007). Effective management practice for conserving the commercially important fish species depends on understanding the regenerative capacity of fish populations including their reproductive behavior (Tracey et al., 2007) whose spawning accretions are extremely harmed by commercial fishers (Hardie et al., 2007). Besides, conscientious evaluation of reproductive behavior suggests about dynamic causes that may influence survival in addition to recruitment of different fish species (Khatun et al., 2019). Fish population replenishment as well as individual potency is mostly dependent on fruitful reproduction (Hossain et al., 2017b). Above and beyond, stock assessment models largely depend on the understanding of reproduction of fish stocks for sustainable management (Nitschke et al., 2001; Tracey et al., 2007). Consequently, the knowledge of GSI, size at first maturation and spawning season are considered useful methods in fish reproduction research (Hossain et al., 2013).

At present, changes of environmental factors are vital threat to fisheries resources together with additional risks such as contamination and overfishing (Rose, 2005). Moreover, assessment of environmental and biological onsets of fish reproduction is the foremost important to recognize the interactions between population and environment as well as denoting vulnerability of a fish population in relation to climate change (Khatun et al., 2019). Environmental issues largely temperature and rainfall have continuous effect on fish growth and reproduction (Shoji et al., 2011). The temperature is considered as the key to control every phase of fish reproduction (Pankhurst and Porter, 2003). Fluctuations of temperature represent a vital arena for understanding the reproductive potency of fish population in any ecosystem because of its direct effect on gametogenesis process and spawning timing (Pankhurst and Mundy, 2011). Besides, temperature is the basic abiotic factor controlling the movements of larval assemblages (Houde and Zastrow, 1993) of freshwater along with marine species (Jakobsen et al., 2009). Similarly, rainfall is another important factor prompting the total chain of hydrological events via river inflow and runoff (Patrick, 2016). Spawning rhythm of fish is frequently reduced due to lack of sufficient rainfall (Owiti and Dadzie, 1989). Rainfall supports fish spawning by decreasing the water temperature and enhancing dissolved oxygen. Besides, it stimulates natural spawning by offering available hydration for reproductively mature fish (Ahamed et al., 2018). Further, the reproductive biology of fish in a particular aquatic habitat is greatly influenced by different ecological factors such as pH, salinity, dissolved oxygen and photoperiod. To confirm inclusive fish reproduction, it is necessary to uphold an optimal DO (dissolved oxygen) level for metabolic activities. On the other hand, pH specifies the acidic or alkaline condition of a particular ecosystem. Upper pH level (9-14) affects fish physiology by denaturing cell membranes as well as changing different parameters of an aquatic ecosystem (Brown and Sadler, 1989).

Nevertheless, only a few studies including morphometry (Sanphui et al., 2018) had been completed on *P. heterolepis*. Consequently, our objective is to discover the reproductive biology of *P. heterolepis* considering the environmental changes from the Bay of Bengal, Bangladesh.

5.3. Objectives

There is no available published report on the reproductive biology of *P. heterolepis*. Therefore, the main purpose of this study is to

- Determine the size at first sexual maturity;
- Estimate the spawning and peak spawning season; and
- Identify the effect of environmental factors on the GSI.

5.4. Materials and Methods

5.4.1. Fish measurement

Male and female individuals were identified by microscopic observation of gonads. Only female fish were used in this study. Each specimen were washed with water and kept open to air for drying before weighing. Blotting paper was used to remove excess moisture from the specimens. Individual body weight (BW) for each sample was weighed with 0.01 g accuracy with an electric balance and a measuring board was used to measure the total length (TL) with 0.01 cm precision. Subsequently, gonads (ovaries) were removed carefully through ventral side dissection from each female specimen and weighed (GW) to the nearest 0.01 g accuracy. Further, the gonads were examined microscopically to distinguish the maturity status of fish specimens.

Plate 4. Dissecting view of Gonad with sharp scissor

5.4.2. Size at first sexual maturity (TL_m)

The TL_m was determined with three indices (i) gonadosomatic index (GSI) vs. TL; (ii) modified gonadosomatic index (MGSI) vs. TL; and (iii) Dobriyal index (DI) vs. TL. The Gonadosomatic index was measured using the equation: GSI (%) = (GW/BW) × 100 (Nikolsky, 1963). Modified gonadosomatic index was determined by the equation: MGSI (%) = (GW/BW-GW) × 100 (Nikolsky, 1963). Dobriyal index was calculated by the equation: DI= $\sqrt[3]{GW}$ (Dobriyal et al., 1999). Further, the specimens having GSI ≥ the critical GSI value (GSI at smallest size at sexual maturity) were nearly recognized as mature female for *P. heterolepis* (Fontoura et al., 2009; Hossain et al., 2012; Rahman et al., 2018b).

Moreover, TL_{50} denoted the minimum length break wherein 50% of the individual specimens were matured. In order to analysis of TL_{50}, a logistic curve following King (2007) was applied for the data by plotting the percentage of mature individuals (PMI) against TL class as PMI = 100/[1+ exp{-f (TL_m -TL_{50})}] where, f is the growth coefficient and TL_m is the median value of each TL class. However, all mature individuals in a population do not continue in a reproductive cycle at the same time. Consequently, PMI was not more than 100% even in the largest TL class. Therefore, following the established method of King (2007), the data were adjusted to overcome an unreasonably high estimate of TL_{50}.

5.4.3. Spawning season

To determine the spawning season of this Sciaenid fish monthly gonadal changes were observed. Consequently, spawning and peak spawning season were estimated using three indices including GSI, MGSI as well as DI.

5.4.4. Environmental factors

Monthly water quality parameters were collected from the sampling spot through APHA (2005) procedures to assess the impact of environmental factors on GSI of female *P. heterolepis*. The parameters were water temperature (^oC), dissolved oxygen (DO; mg/L) and pH. A fixed sampling hour was maintained strictly (between 9.00 to 10.00 am) throughout the sampling months to confirm the comparability of the collected parameters with time and space. Further, monthly rainfall (mm) data were documented from the meteorological station of Khulna, Bangladesh.

5.4.5. Statistical Analyses

Statistical analyses were done by GraphPad Prism 6.5 and Microsoft ® Excel-add-in-DDXL software with 5% significance level. Normality of the data was confirmed with Kolmogorov-Smirnov test. Besides, Spearman rank test was performed to correlate the environmental factors with GSI for detecting the vital influence of environmental factors on gonadal maturity and spawning.

5.5. Results

A total 569 female specimens were collected from January to December 2019, where total length (TL) was extended from 10.50 to 34.50 cm and body weight (BW) was varied between 9.02 to 342.26 g. Besides, gonad weight (GW) was ranged between 0.03 to 20.63 g. Lowest, highest and mean total length, body weight and gonad weight are shown in Table 21.

Table 21. Descriptive statistics on the total length (cm), body weight (g) and gonad weight (g) measurements of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

Characters	*n*	Min	Max	Mean ± SD	95% CI
Total length; TL (cm)		10.5	34.5	17.91±3.11	17.65-18.17
Standard length; SL (cm)	569	8.0	28.2	13.97±2.52	13.76-14.18
Body weight; BW (g)		9.02	342.26	47.25±29.91	44.79-49.72
Gonad weight; GW (g)		0.03	20.63	2.29±2.79	2.06-2.52

Note: *n*, sample size; Min, minimum; Max, maximum, SD, standard deviation; CI, confidence intervals.

5.5.1. Size at first sexual maturity (TL_m)

The relationship between TL vs. GSI, MGSI and DI of female *P. heterolepis* are specified in Figure 22. The GSI and MGSI values were lower (< 5.4% and < 5.6% respectively) for females smaller than 15.0 cm TL. Also, DI was low (< 1.0) at the length of 15.0 cm. Further, the GSI (≥ 5.4%), MGSI (≥ 5.6%) and DI (≥ 1.0) rose intensely at 15.0 cm TL for maximum of the female specimens. Consequently, TL_m may be considered being 15.0 cm in TL for female *P. heterolepis* in the Bay of Bengal, Bangladesh. Further, the relationship between TL and the percentage of mature individuals were expressed with the logistic functions of mature *P. heterolepis* female for each length class (TL) group (Figure 23). The projected total length at sexual maturity (TL_{50}) was 15.0 cm TL in the Bay of Bengal, Bangladesh.

5.5.2. Spawning season

Monthly variations of GSI, MGSI and DI for the female *P. heterolepis* are presented in Figure 24. The lower values of GSI, MGSI and DI were recorded during August to December. Further, the higher GSI, MGSI and DI values were recorded from January to July, which designated the extended reproductive effort of the fish. In addition, peak values of GSI, MGSI and DI were found in the month of February. Therefore, February is the peak spawning season for *P. heterolepis* in the Bay of Bengal, Bangladesh.

5.5.3. Environmental factors

In the present study, four important factors specifically temperature, rainfall, DO and pH were documented to observe the impact on gonadal maturation of *P. heterolepis*. However, temperature was recorded significantly related with GSI. Alternatively, other factors did not reveal any statistical correlation with GSI (Table 22; Figure 25).

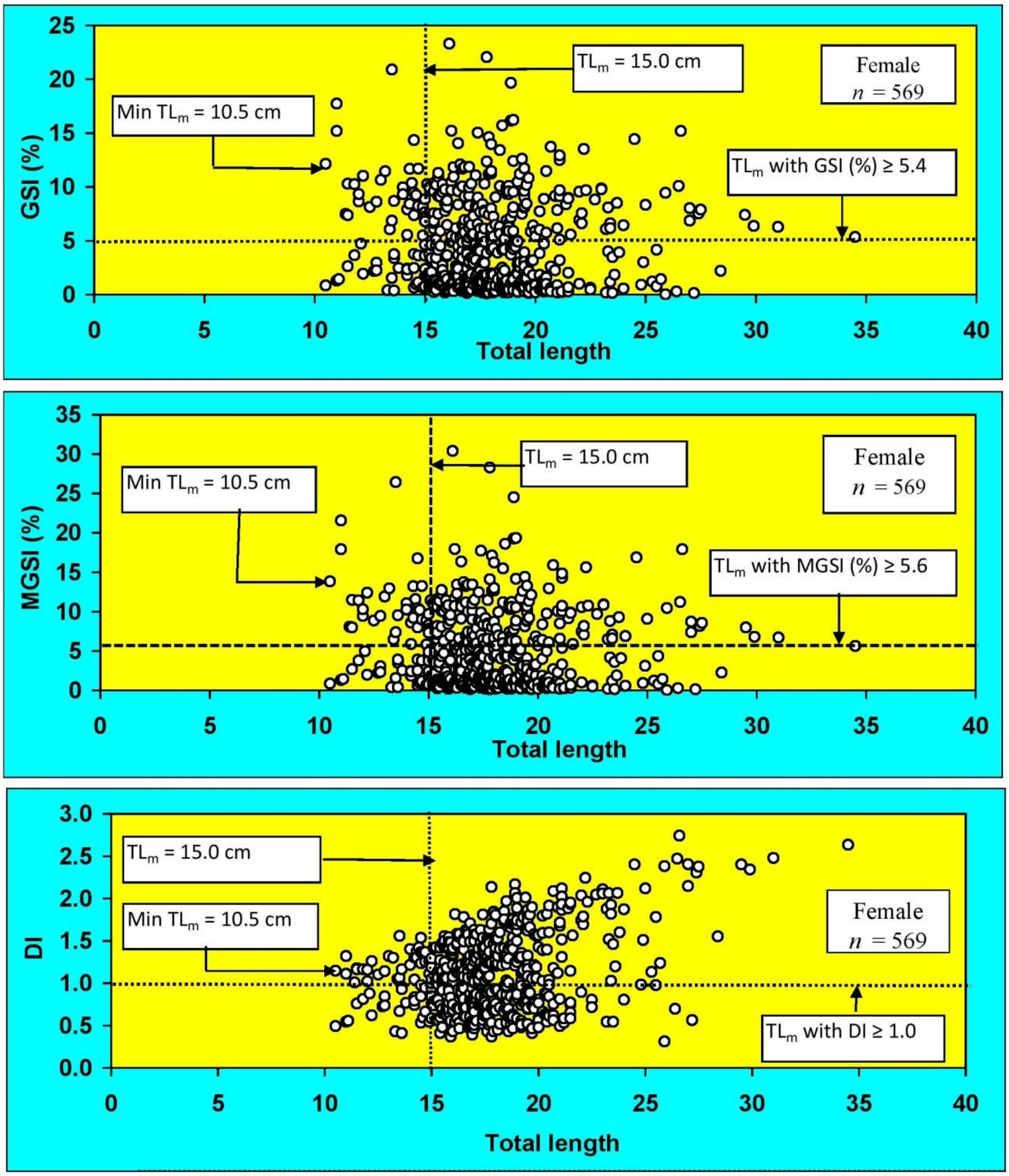


Figure 22. Relationship between gonadosomatic index (GSI), modified gonadosomatic index (MGSI) and Dobriyal index (DI) with total length of female *Panna heterolepis* in the Bay of Bengal, Bangladesh.

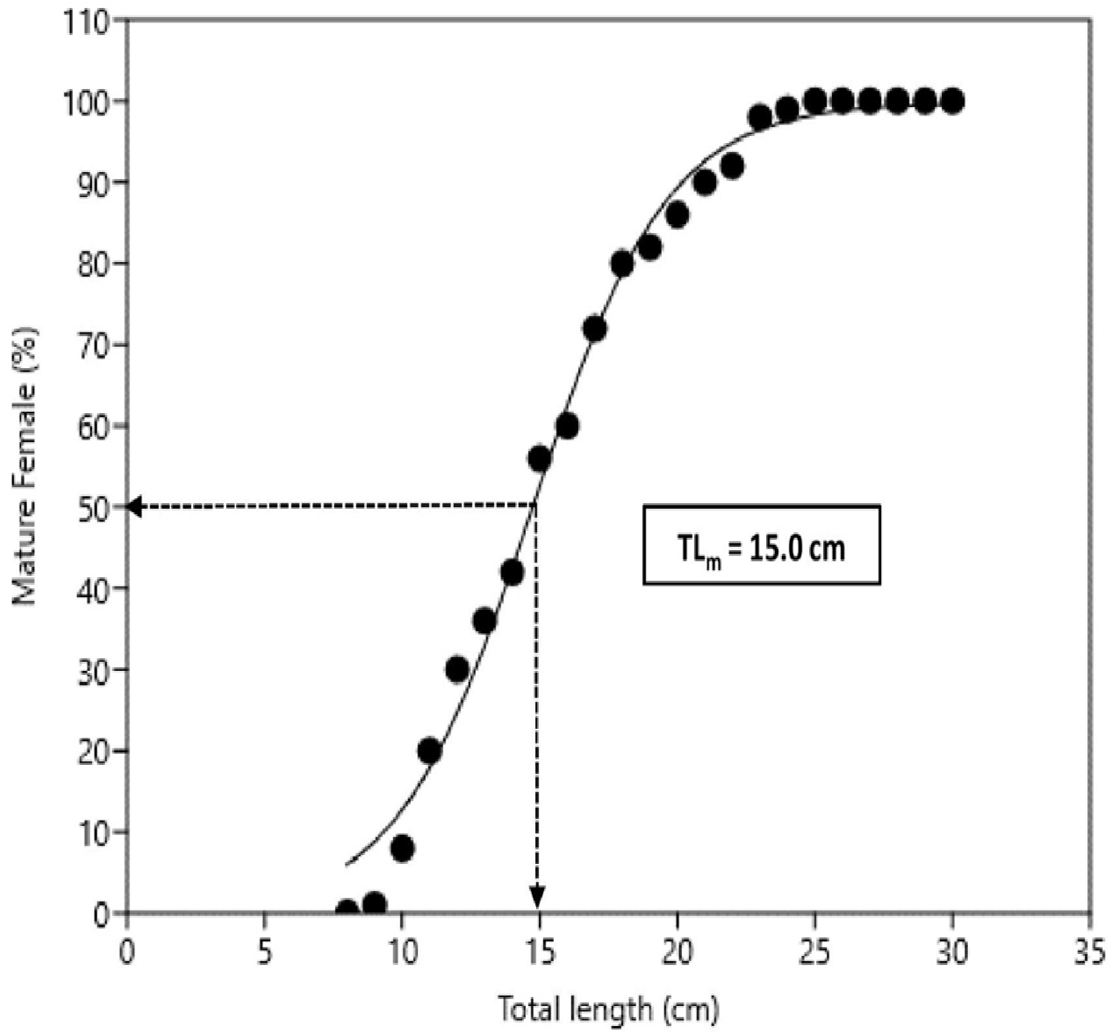


Figure 23. Adjusted percentage of mature females of *Panna heterolepis* versus total length showing the logistic curve fitted to the data.

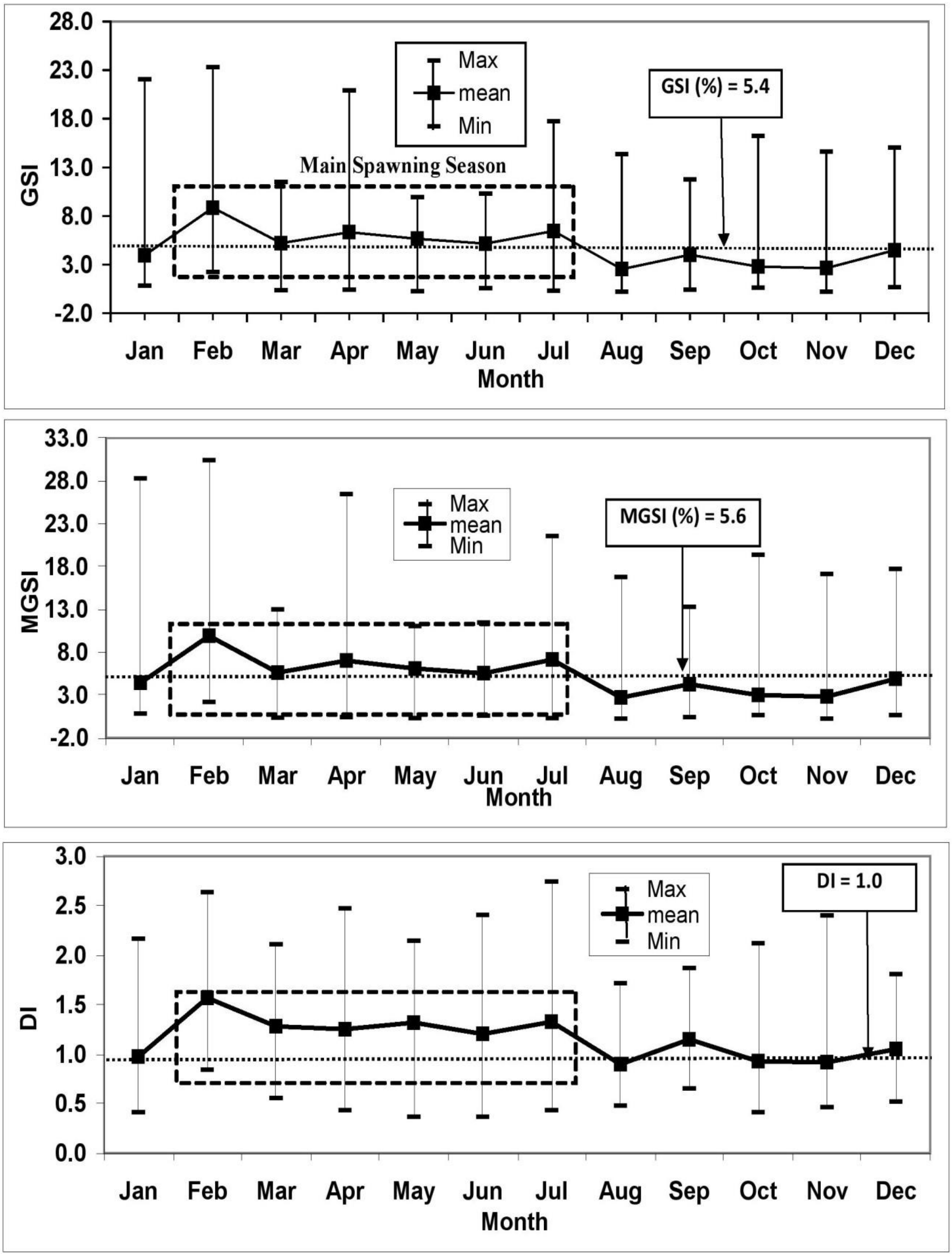


Figure 24. Monthly variations of gonadosomatic index (GSI), modified gonadosomatic index (MGSI) and Dobriyal index (DI) with maximum and minimum values of female *Panna heterolepis* in the Bay of Bengal, Bangladesh.

Table 22. Relationship between environmental factors with GSI of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

Relationship	**r_s value**	**95% CL of r_s**	***p* values**	**Significance**
Temperature *vs*. GSI	-0.5433	-0.8067 to 0.7741	0.0421	*
Rainfall *vs*. GSI	-0.2098	-0.7093 to 0.4300	0.5137	*ns*
DO *vs*. GSI	0.4042	-0.2394 to 0.8010	0.1922	*ns*
pH *vs*. GSI	0.3333	-0.3151 to 0.7696	0.2874	*ns*

Note: GSI, Gonadosomatic index; DO, Dissolved Oxygen; r_s, Spearman rank correlation values; CL, confidence limit; *p*, level of significance; *ns*, not significant; * significant ($p \leq 0.05$).

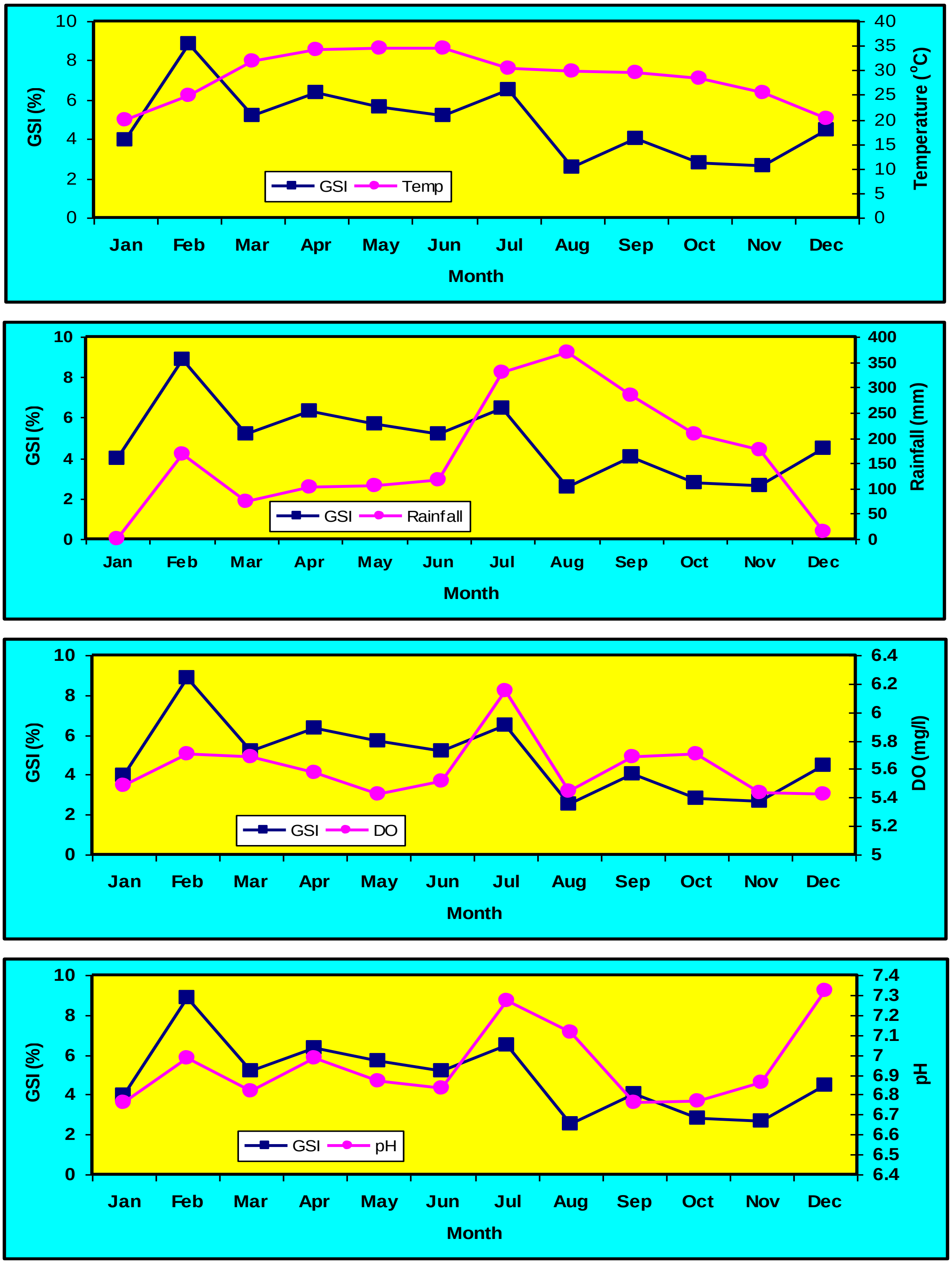


Figure 25. Relationship between Gonadosomatic index (GSI) with environmental factors of female *Panna heterolepis* in the Bay of Bengal, Bangladesh.

5.6. Discussion

Appropriate management of exploited stocks is significantly dependent on careful assessment of the maturity status of fish (Rahman et al., 2018b). Where histological observation facilities are scarce, different macroscopic and biological index are normally used as rather easy and cost- effective technique for describing ripeness status of fish (Khatun et al., 2019; West, 1990). Further, GSI was used effectively by a good number of researchers to assess the maturity status of fish (Fontoura et al., 2009; Hossain et al., 2012, 2017b; Rahman et al., 2018b). Knowledge of reproductive biology is vital to assess the life cycle and stocks of an individual fish population (Hossain et al., 2017b). Information on reproductive biology of *P. heterolepis* is insufficient elsewhere. Therefore, this study explains sexual maturity in addition to spawning season of *P. heterolepis* together with the consideration of environmental factors from Bay of Bengal, Bangladesh.

Determining size at first sexual maturity (TL_m) is critical simultaneously for differentiating among diverse populations of an identical species and for anticipating a basis that ultimate changes in length at first maturity are due to fisheries pressure or other reasons (Hossain et al., 2010b,c). Further, it is essential for fisheries biologist to manage and conserve of a particular fish population in any aquatic ecosystem (Lucifora et al., 1999). Our study revealed that the TL_m of female *P. heterolepis* was 15.0 cm in TL based on GSI, MGSI and DI values. Besides, precise estimations of first sexual maturity size (TL_{50}) are highly convenient for management of a particular fish stock (Rahman et al., 2018b). The GSI data accompanied by a logistic function with variable asymptote is durable and constant enough to be functional to a fish population with divergent life histories (Fontoura et al., 2009). Following the logistic equation, TL_{50} for female *P. heterolepis* was determined to be 15 cm. The maturity size may differ according to habitat characteristics accompanied by diverse environmental factors (Sinovcic and Zorica, 2006). However, absence of information on maturity prohibits substantial comparisons with our findings. Further, the study denotes the first widespread information on sexual maturity size of *P. heterolepis* that could be supportive for determining the mesh size to limit catching mature smaller individuals to provide them opportunity to spawn (Rahman et al., 2018b).

It was mentioned earlier that a yearly fishing ban is exposed by the government of Bangladesh from 20 May to 23 July in the Bay of Bengal to conserve the depleted marine fish stocks and allow them to spawn freely (DoF, 2019). However, the spawning and peak spawning season for most of the marine fish stocks are not yet been investigated scientifically. On the other hand, the prolonged fishing ban reveals a negative impact on the livelihoods of the poor coastal fishers. The income of the subsistence fisher folks has reduced to a great extent. Therefore, it is necessary to justify the exact spawning and peak spawning period of different fishes dwelling in the Bay of Bengal. Spawning season is crucial to assess spawning time and migration of a fish population for spawning purpose (Khatun et al., 2019). According to monthly GSI, MGSI and DI values, female *P. heterolepis* showed a prolonged spawning period from January to July. But peak spawning occurred in February. Consequently, all types of fishing ought to be banned during the peak spawning period to ensure sustainable management of this species in their interminable habitat and allow the coastal fisher folks to continue fishing during the June-September monsoon, which is the ultimate fishing season in the Bay of Bengal.

Further, it was noticed that the reproductive behavior of female *P. heterolepis* was influenced by water temperature. Throughout the study, the maximum water temperature was recorded in May-June (34.4^{o}C) and the lowest temperature was noted in January (19.8^{o}C). Besides, the highest GSI (peak spawning period) was detected in the month of February when the water temperature is comparatively lower (24.7^{o}C). Alternatively, reproductive behavior was not significantly influenced by rainfall, DO and pH in Bay of Bengal, Bangladesh. The maximum rainfall was recorded in August (370 mm) and no rainfall was ensued in January. DO is an important parameter for aerobic metabolism of fish (Timmons et al., 2001). The optimum DO level must exceed 3.5 mg/l for marine fisheries resources (EPA, 2000). Similarly, pH is considered as an essential ecological factor for any aquatic habitat. If an aquatic ecosystem is more acidic (pH < 4.5) or more alkaline (pH > 9.5) for extended time, growth and reproduction will be reduced (Ndubuisi et al., 2015). In our study, the monthly DO level ranged from 5.42 to 6.15 mg/l and pH ranged from 6.76 to 7.32 indicating an appropriate habitat for marine fisheries resources in the Bay of Bengal, Bangladesh.

5.7. Conclusion

The length at sexual maturity of *P. heterolepis* was established to fix suitable capture size, thus providing them opportunity to spawn. Further, the spawning season of the above mentioned species was extended from January to July with a peak in the month of February. Therefore, it is highly recommended that the adults must be conserved during the peak spawning season to maintain sustainable exploitation of this species. GSI value displayed a statistically significant correlation with temperature. Thus temperature should be considered in the future management policy. The outcomes of our study might be advantageous for the suitable management of *P. heterolepis* in the Bay of Bengal (Bangladesh) as well as surrounding ecosystem.

Chapter 6

Study-IV

STUDY-IV

Stock assessment of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

6.1. Abstract

The study provides a complete information on growth pattern, growth parameter, mortality, recruitment pattern, exploitation rate (*E)* and maximum sustainable yield (MSY) of *Panna heterolepis* based on monthly sampling of 1,223 specimens from the Bay of Bengal, Bangladesh, from January to December, 2019. Length–frequency data were analyzed with FAO-ICLARM Stock Assessment Tool. The allometric co-efficient (*b*) value indicated negative allometric growth (< 3.00) for *P. heterolepis* population. The von Bertalanffy growth function revealed growth coefficient (K = 0.13 year^{-1}), growth performance index ($Ø'$ = 2.30) and life-span (t_{max} = 3.85 year). Further, *P. heterolepis* was found to grow rapidly with an asymptotic length (L_{∞}) of 39.08 cm. We found that the natural mortality (M =0.44 year^{-1}) rate is almost similar with fishing mortality (F = 0.42 year^{-1}). Consequently, the standing stock is not quite sustainable with the existing fishing strategy. Further, the maximum allowable exploitation rate (E_{max} = 0.471) was lower than the recorded exploitation rate (E=0.490). Subsequently, overfishing is the most focal threat for the wild population of *P. heterolepis* in the context of Bay of Bengal, Bangladesh. The recruitment pattern was almost continuous throughout sampling period with a major peak in April-May. Finally, the MSY was assessed at 10234.47 metric tons. The findings would be very useful to introduce appropriate fishing regulations in the Bay of Bengal ecosystem.

Keywords: Stock assessment, *Panna heterolepis*, Bay of Bengal, Bangladesh.

6.2. Introduction

Fish and fisheries products are the most significant protein source for global population (Roy et al., 2020). The increasing demand for fisheries products creates massive fishing pressure on natural stock, especially in the open-water ecosystem (Panhwar et al., 2013). Consequently, fish are considered as limited renewable resource (Gulland, 1982). Therefore, it is essential to assess the life-history traits (growth, reproductive characteristics, recruitment pattern and mortality) of fish population to ensure sustainable management practice to conserve the wild stock (Foster and Vincent, 2004). Further, the lack of information about such traits on marine fisheries resources is a barrier to implement suitable fishing strategy in the marine ecosystem (Dinh et al., 2009) and this demands quick investigation.

Length- frequency distribution (LFD) is an important biometric index to detect the dynamic rates of recruitment, growth, mortality, yields and stock biomass in a particular ecosystem (Neuman and Allen, 2001) through dynamic mathematical models (Beverton and Holt, 1979). Nevertheless, knowledge on growth, recruitment, mortality, exploitation rate and maximum sustainable yield is important for developing such models (Hossain et al., 2017a). Likewise, growth pattern is essential to detect the temporal variation of fish growth (Hossain and Ohtomi, 2010b). Growth of fish and other aquatic organisms largely depend on sex, maturity status and environmental factors (Dall et al., 1990). Fast growth rate of fish is advantageous in many ways. Rapid growth rate of fish not only gives the fish immunity from predators but also allow carrying large number of eggs, also produce larger eggs with higher chances of larval survival (Hossain et al. 2017a). In addition, growth and recruitment have remarkable effect to maintain maximum sustainable yield of a stock (Ahmed et al., 2012).

The Hooghly Croaker (*Panna heterolepis* Trewavas, 1977) is found profusely in Bangladesh, Indian, Myanmar and Sri Lanka (Sasaki, 1995). This species is a representative of the family Sciaenidae inhibits coastal and marine waters (Talwar and Jhingran, 1991). The *P. heterolepis* is very famous among the three representative species under the genus *Panna* in the Indian Ocean together with *P. microdon* and *P. perarmatus* (Froese and Pauly, 2020). This species is locally called *Poa* and commercially significant as a popular fish food item for the coastal people of

Bangladesh because of their outstanding flesh quality. However, total demand of this species is met through the capture from wild stock due to absence of culture practice. Consequently, overfishing is considered the most focal threat for the wild population of *P. heterolepis* (Hossen et al., 2019). However, only a few studies with the morphometry (Sanphui et al., 2018) had been completed on *P. heterolepis*. Consequently, our objective is to assess the stock of *P. heterolepis* in the Bay of Bengal, Bangladesh.

6.3. Objectives

There is no available published report on the stock assessment of *P. heterolepis*. Consequently, the main objectives of this study are to

- Determine growth pattern;
- Calculate the growth parameters;
- Estimate recruitment pattern;
- Estimate mortality and exploitation rate; and
- Determine maximum sustainable yield (MSY).

6.4. Materials and Methods

6.4.1. Sampling site and sampling

In total, 1,223 individuals of *P. heterolepis* were collected during January to December, 2019 through different traditional gears including seine bag net (mesh size 1.5 to 3 cm) and gill net (mesh size 3 cm) from Bay of Bengal, Khulna region, Bangladesh.

6.4.2. Fish measurement

Individual body weight (BW) for each sample was weighed with 0.01 g accuracy with an electric balance and a measuring board was used to measure the total length (TL) as well as standard length (SL) with 0.01 cm precision. Only TL is considered to assess the stock.

6.4.3. Growth pattern

Growth pattern was calculated by LWRs involving the calculation: $W = a \times L^b$. The regression coefficient a and b were assessed using the formula: $\ln(W) = \ln(a) + b \ln(L)$. A t-test was executed to approve whether the b value was statistically dissimilar from isometric value ($b = 3$).

6.4.4. Estimation of growth parameters

Monthly length-frequency data were analyzed with FiSAT software version 1.1 (Gayanilo and Pauly, 1997). The asymptotic length (L_∞) and growth constant (K) were determined through von Bertalanffy Growth Function (VBGF) (Gayanilo et al., 2002). The life-span (t_{max}) was determined using the formula of log (t_{max}) = 0.5496 + 0.957*log(t_m) (Froese and Binohlan, 2005), where t_m indicates the age of first sexual maturity. Age at zero length (t_0) was determined with the calculation of log ($-t_0$) = -0.3922 - 0.2752 log L_∞ - 1.038 log K (Pauly, 1980) and growth performance index was calculated as $\varnothing' = \log_{10}K + 2\log_{10}L_\infty$ (Pauly and Munro, 1984).

6.4.5. Estimation of mortality and exploitation

Total mortality (Z) was calculated by the length-converted catch curve method (Gayanilio et al., 2002). Natural mortality (M) was assessed as $\log_{10}M$ = -0.0066 – 0.279$\log_{10}$ L_∞ + 0:6543$\log_{10}K$ + 0:0463$\log_{10}$T; where T indicates the average temperature of the habitat (28.5^{o}C). The fishing mortality (F) was estimated as Z-M. Besides, exploitation rate (E) was determined as: $E = F/Z = F / (F + M)$ (Gulland, 1983). Consequently, exploitation rate producing maximum yield (E_{max}), exploitation rate at which the secondary increase of Y'/R is 10% its virgin biomass ($E_{0.1}$) and the exploitation rate under which the stock is reduce to half its virgin biomass ($E_{0.5}$) were calculated following the knife-edge selection (Beverton and Holt,1979).

6.4.6. Recruitment rate

Recruitment rate of *P. heterolepis* was assessed from the analysis of the total time series of LFDs and growth parameters using VBGF models.

6.4.7. Relative yield-per-recruit (Y'/R), steady state biomass (SSB) and maximum sustainable yield (MSY)

The Beverton and Holt (1979) model was used to determine the *Y'/R* of *P. heterolepis* in the Bay of Bengal, Bangladesh. The recommended length at first capture (L_c) was predicted at $E_{0.5}$ level. The steady state biomass (SSB) was calculated using the length-structured virtual population analysis (VPA) routine in FiSAT II. Subsequently, MSY of *P. heterolepis* was calculated as MSY = 0.5*SSB*Z (Gulland, 1983).

6.5. Results

6.5.1. Growth pattern

LFD revealed that the TL varied from 10.5 to 34.5 cm and BW ranged from 9.02 to 342.26 g (Table 23). The regression coefficients *a* and *b* for *P. heterolepis* were assessed from the length and weight data and calculated as W = $0.012\text{TL}^{2.83}$ (P < 0.001; r^2 = 0.966; Figure 26).

6.5.2. Growth parameters

The study revealed an L_∞ of 39.08 cm TL. Further, the value of *K* was recorded as 0.13 year^{-1} for the unique data set (Figure 27 and 28; Table 24). The length–frequency histograms and the von Bertalanffy Growth curve were shown in Figure 29. The *Ø′*, t_{max} and t_0 was found 2.30, 3.85 year and 0.108 year, respectively (Table 24).

6.5.3. Mortality

Total mortality (*Z*) was recorded 0.86 year^{-1} (Figure 30). Further, natural mortality (*M*) as well as fishing mortality (*F*) were calculated 0.44 and 0.42 year^{-1}, respectively (Table 24).

Table 23. Descriptive statistics on the total length (cm) and body weight (g) measurements of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

		TL				BW			
Month	***n***	**Min**	**Max**	**Mean ± SD**	**95% CL**	**Min**	**Max**	**Mean ± SD**	**95% CL**
Jan	107	12.0	25.9	17.23±1.79	16.88 to 17.57	12.39	134.28	39.72±14.75	36.89 to 42.55
Feb	104	11.0	34.5	18.70±4.39	17.85 to 19.56	9.02	342.26	58.74±51.08	48.80 to 68.67
Mar	104	11.1	25.7	17.66±2.89	17.09 to 18.22	11.98	133.35	46.06±24.17	41.36 to 50.76
Apr	84	10.5	28.7	16.80±4.67	15.78 to 17.81	10.02	175.60	46.79±40.32	38.04 to 55.54
May	101	11.9	27.0	16.89±2.74	16.34 to 17.43	11.42	144.30	41.26±22.36	36.85 to 45.68
Jun	99	11.5	28.5	19.79±3.78	19.04 to 20.55	14.20	174.60	63.72±33.53	57.03 to 70.41
Jul	103	10.5	29.5	17.64±3.55	16.94 to 18.33	11.20	187.53	45.13±29.14	39.43 to 50.82
Aug	106	13.0	31.4	18.22±3.59	17.53 to 18.91	17.90	203.89	47.48±33.86	40.96 to 54.00
Sep	102	15.0	30.9	19.30±2.36	18.83 to 19.76	24.19	165.15	51.05±19.63	47.19 to 54.91
Oct	104	12.5	27.2	17.86±2.73	17.33 to 18.39	13.89	140.58	43.71±21.48	39.53 to 47.89
Nov	105	13.1	26.4	17.96±2.47	17.48 to 18.43	18.05	120.22	42.16±17.49	38.78 to 45.55
Dec	104	14.7	25.2	18.02±1.97	17.64 to 18.41	24.44	117.38	43.25±15.28	40.28 to 46.22

Notes: *n*, sample size; TL, total length (cm); W, body weight (g); min, minimum; max, maximum; SD, standard deviation; CL, confidence limit.

6.5.4. Recruitment rate

The recruitment pattern of *P. heterolepis* population is more or less continuous throughout the sampling period with a major peak in April-May (Figure 31).

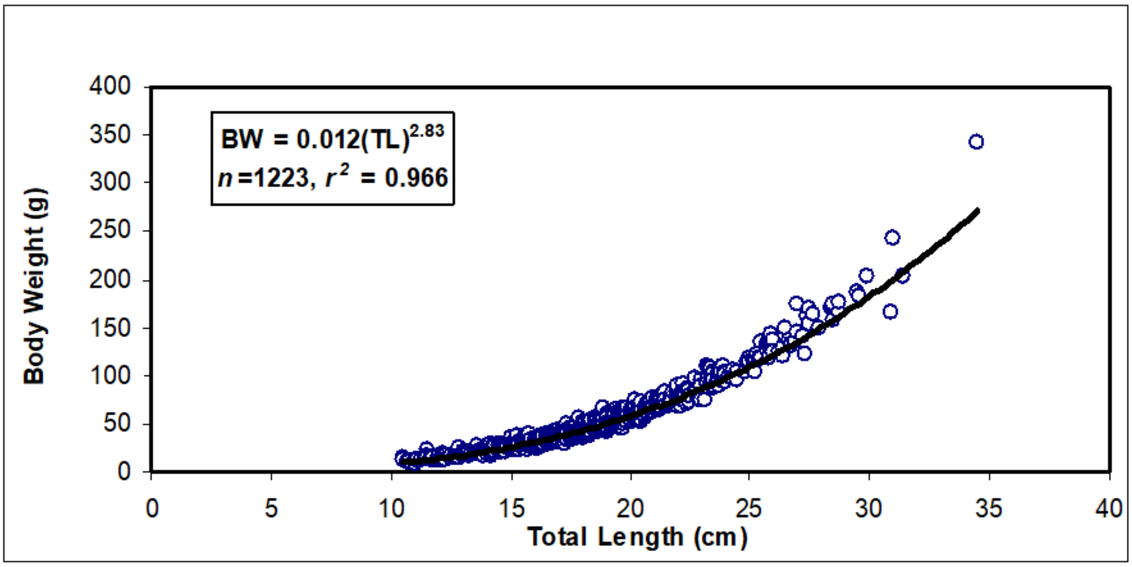


Figure 26. Growth pattern of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

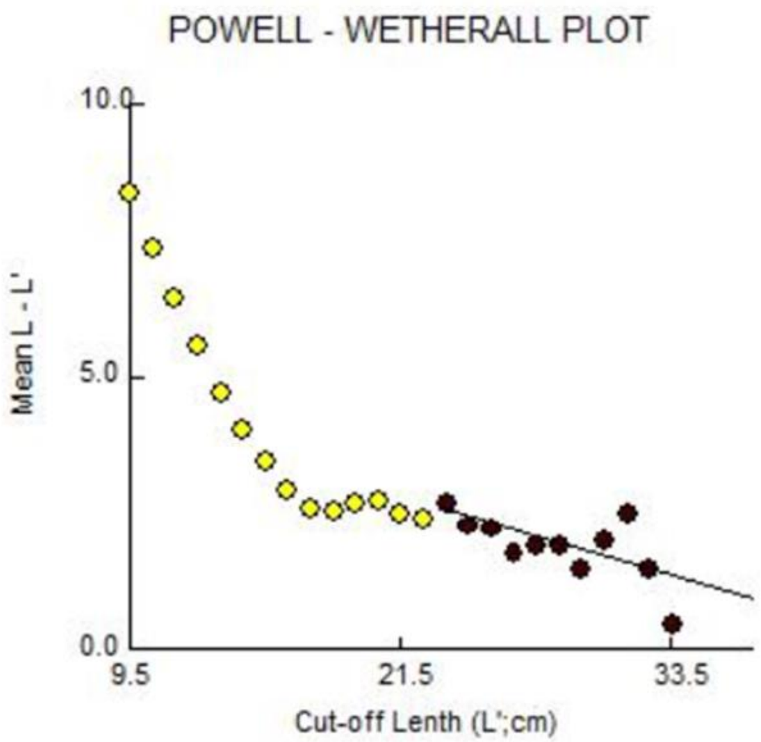


Figure 27. The Powell-Werherall Plot for the length frequency data of *Panna heterolepis* from the Bay of Bengal, Bangladesh. The black dots were used as input in the Powell-Werherall Plot. The regression equation is Y = 1.03–0.255X, r =0.862. Estimated L_∞ = 39.08 cm and Z/K = 5.118.

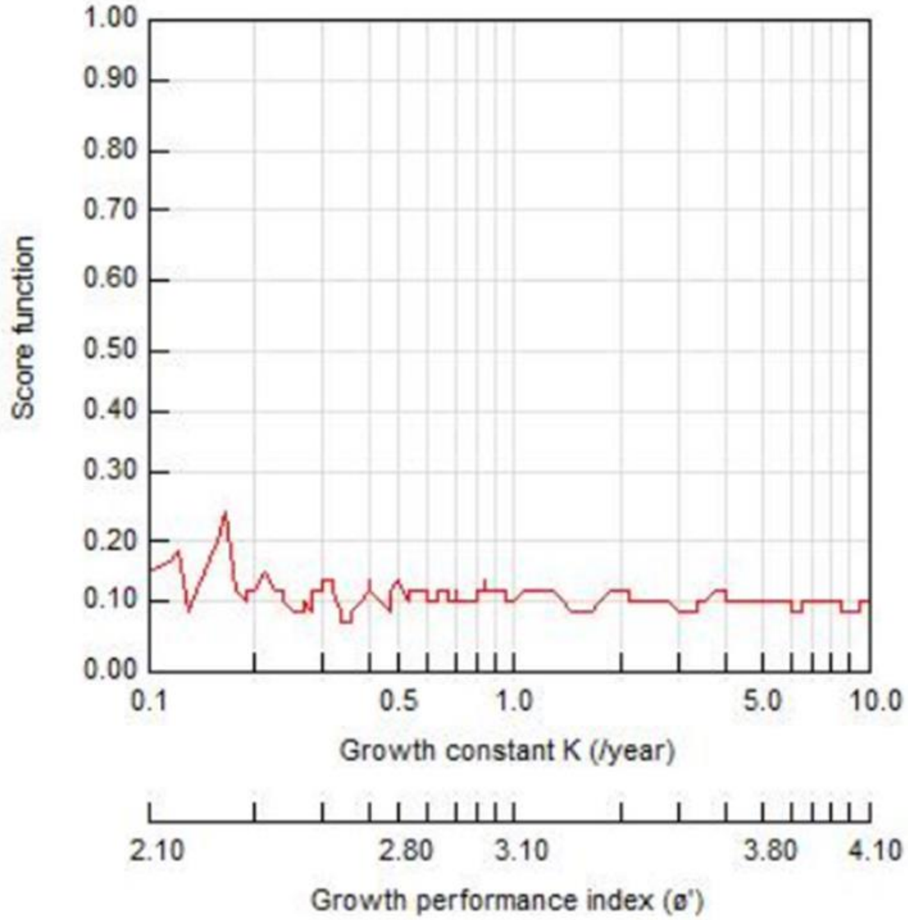


Figure 28. The K-scan routine for determining best growth curvature giving best value of asymptotic length with growth performance indices for *Panna heterolepis* in the Bay of Bengal, Bangladesh.

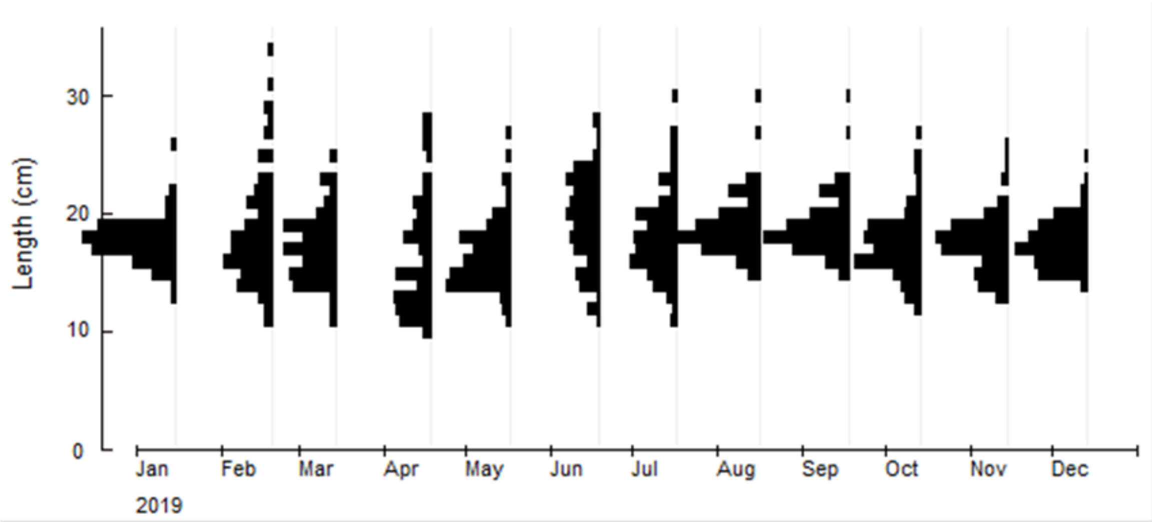
6.5.5. Relative yield-per recruits (Y'/R), Steady state biomass (SSB) and Maximum sustainable yield (MSY)

From Y′/R analysis, the estimated values of E, E_{max}, $E_{0.1}$, and $E_{0.5}$ were 0.490, 0.471, 0.364 and 0.268 respectively (Figure 32; Table 24). Moreover, the calculated TL of *P. heterolepis* at first capture (L_c) was 14.96 cm (Figure 33). The predicted total SSB was 23801.09 metric tons. Consequently, the MSY of *P. heterolepis* was estimated at 10234.47 metric tons.

Table 24. Growth parameters (L_∞ and *K*), mortality (*Z, M, F*) and Fishery parameters (*E*, *Lc* and MSY) of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

Description of Parameters	**Values**
Growth and reproduction	
Asymptotic length (L_∞)	39.08 cm TL
Growth coefficient (*K*)	0.13 $year^{-1}$
Life-span (t_{max})	3.85 year
Growth performance indexes (*Ø'*)	2.30
Age at zero length (t_0)	0.108 year
Age at first sexual maturity (t_m)	0.69 years
Mortality parameters	
Total mortality (*Z*)	0.86 $year^{-1}$
Natural mortality (*M*),	0.44 $year^{-1}$
Fishing mortality (*F*)	0.42 $year^{-1}$
Fishery parameters	
Exploitation ratio (*E*)	0.490
E_{max}	0.471
$E_{0.1}$	0.364
$E_{0.5}$	0.268
Total length at first capture (L_c)	14.96 cm TL
Maximum sustainable yield (MSY)	10234.47 metric ton

(a)



(b)

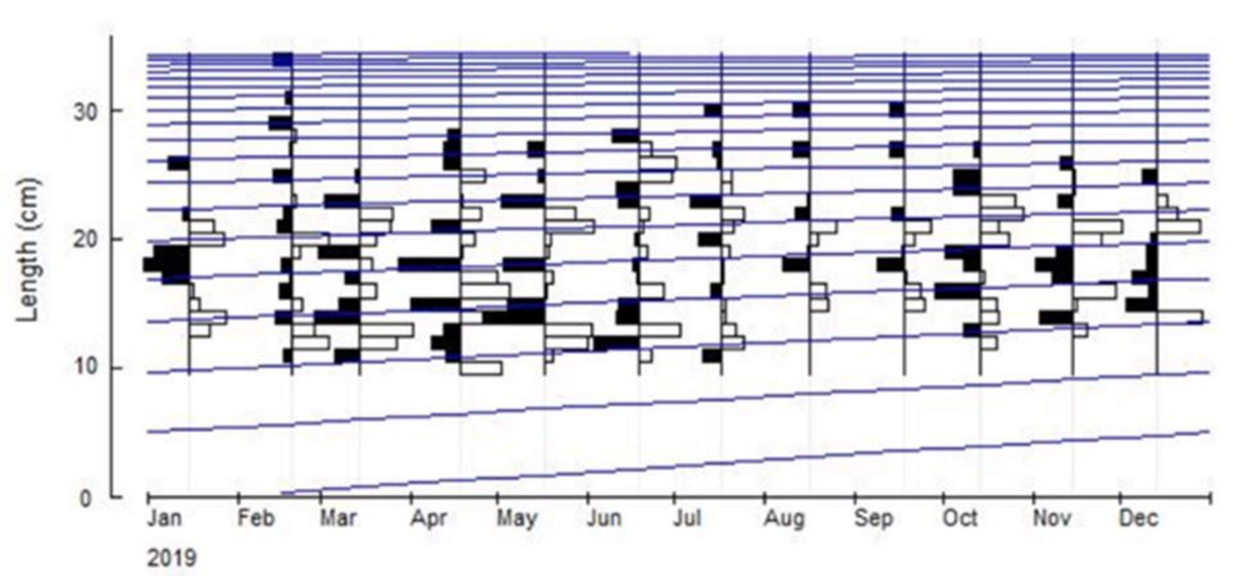


Figure 29. Total length (TL) frequency distribution and growth curve of *Panna heterolepis* in the Bay of Bengal, Bangladesh. (a) Histogram showing distribution of TL frequencydata of collected specimens and (b) von Bertalanffy growth curve (parameters values: L_∞= 39.08 cm and K= 0.13 year^{-1}) superimposed on the restructured length frequency histogram of the *P. heterolepis*.

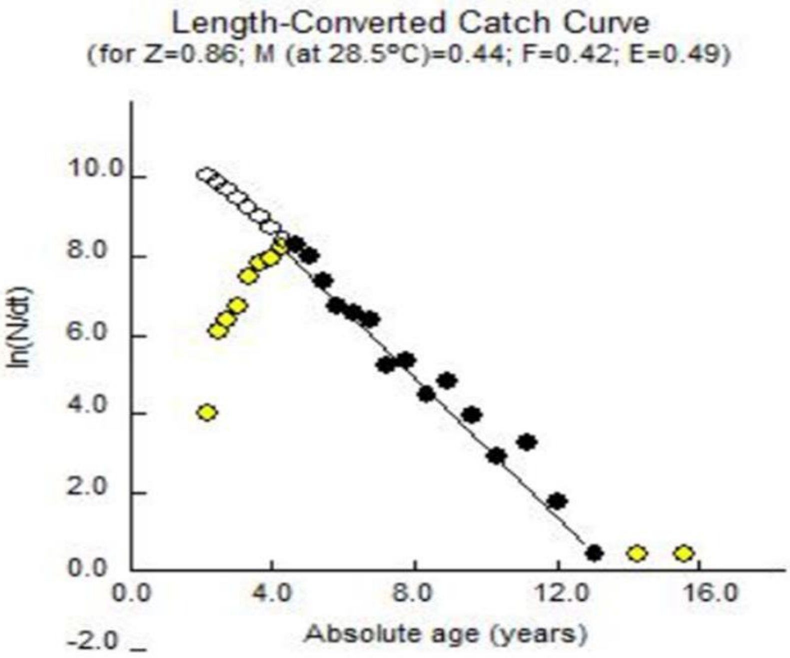


Figure 30. Length-converted catch curve of *Panna heterolepis* in the Bay of Bengal, Bangladesh. Note: only black dots are considered for computation of total mortality.

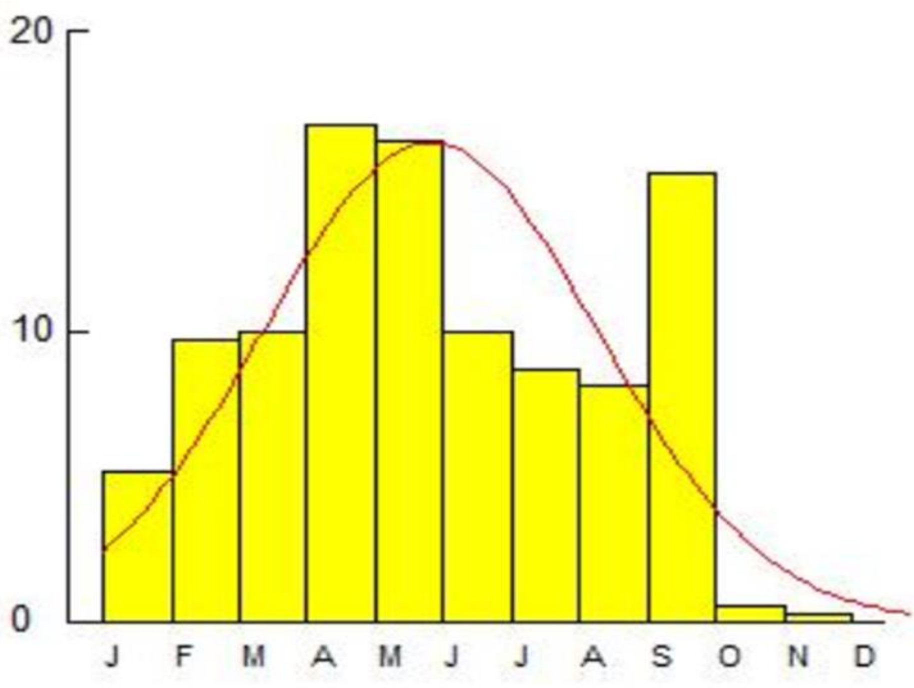


Figure 31. Recruitment pattern of of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

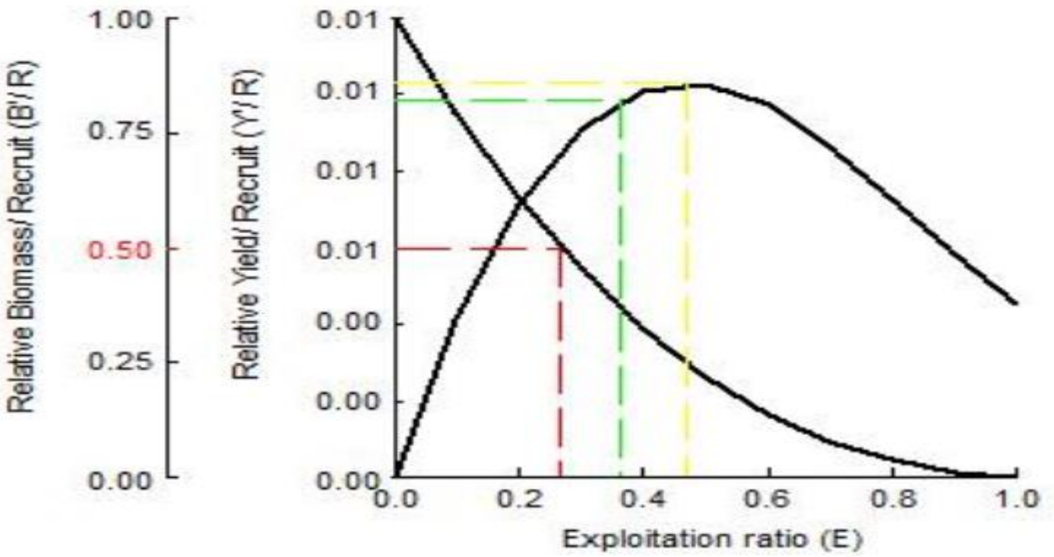


Figure 32. Yield-per-recruit and average biomass per recruit models, showing levels of yield index of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

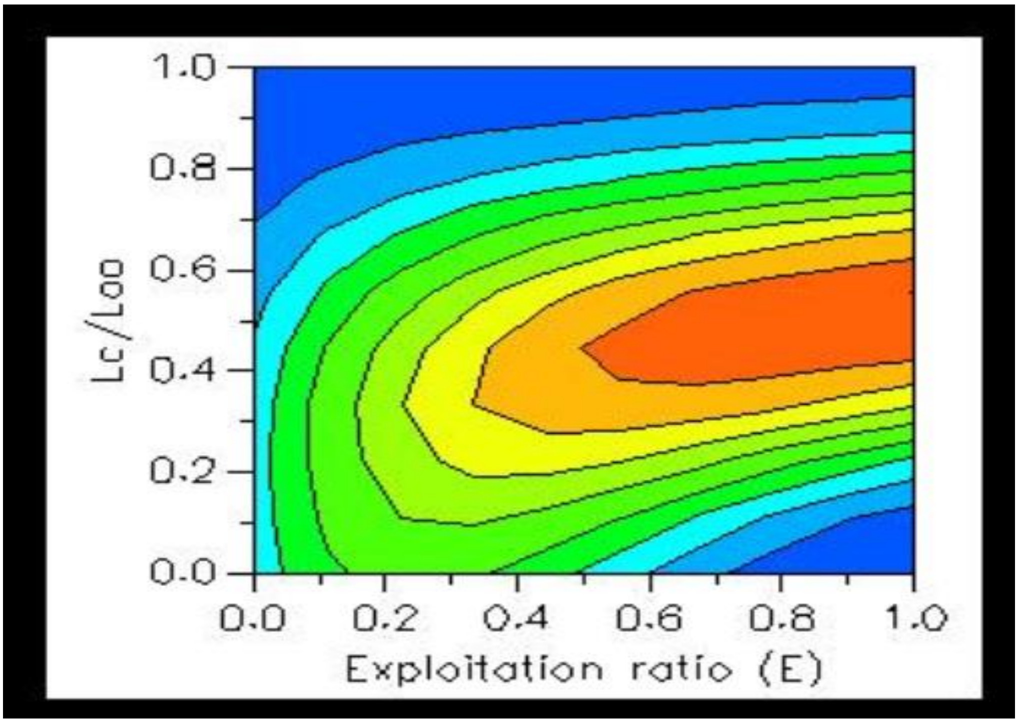


Figure 33. Yield Isopleths, showing optimum fishing activity of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

6.6. Discussion

Stock assessment is essential to obtain highest benefit from a natural stock without hampering the wild population. Information on stock assessment of *P. heterolepis* is absent in literature from Bangladesh and elsewhere. In our study, a large number of specimens (1,223) were sampled using local gears including Seine bag net and Gill net for successive twelve months from Bay of Bengal, Bangladesh. However, absence of individuals smaller than 10.50 cm TL may be attributed to the selectivity of fishing gear (Hossain et al., 2016a, b, c). The highest length of *P. heterolepis* was recorded 34.50 cm from the sampling site. Our study revealed a length of 28.20 cm in standard length (SL) specifically higher than the report (21.40 cm) of Sasaki (1995). Therefore, this study recorded the maximum length (34.50 cm in TL) for *P. heterolepis*.

Carlander (1969) stated that *b* values may range between 2.0 to 4.0 for fishes. On the other hand, Froese (2006**)** reported that the *b* values of LWRs should range between 2.5 to 3.5. In our study, *b* values were found between 2.5 to 3.5 (b = 2.83; negative allometric), which is comparable with the range for teleost fishes (Froese, 2006; Hossain et al. 2015). However, *b* values may differ in the same species because of consolidation of various factors i.e. sex, development of gonad, growth variations in different body parts, physiological condition, food availability and preservation methods (Le Cren, 1951; Hossain et al., 2015).

It is crucial to determine the growth parameters for predicting future yields and stock biomass from a particular aquatic ecosystem (Dadzie et al., 2017). We estimated L_∞ higher than our largest specimen might be attributed that von Bertalanffy model being insufficient for determining the growth of fish species (Vigliola et al., 1998). Consequently, the growth performance index (*Ø'*) was used to compute the least variance compared to other available indices (Pauly and Munro, 1984). However, the calculated *Ø'* for *P. heterolepis* was 2.30. Further, we observed the maximum age or life span (t_{max}) was 3.85 year and age at zero length (t_0) was 0.108 year. There was no previous data on growth parameter of *P. heterolepis* to compare our findings.

Assessment of the mortality rate is crucial for evaluating the abundance of a fish stock which helps to set harvest limits to obtain maximum benefit for the stakeholders of the resource. Total mortality (*Z*) was recorded 0.86 year^{-1}. We found that the natural mortality (M =0.44 year^{-1}) rate is almost similar with fishing mortality (F = 0.42 year^{-1}). Consequently, the standing stock is not quite sustainable with the existing fishing strategy. We found the maximum allowable exploitation rate (E_{max} = 0.471) is lower than the observed exploitation level (E=0.490). Thus the species is facing overexploitation in the Bay of Bengal, Bangladesh. Similarly, we found that the Z/K ratio was 5.118 which denoted that the exploitation level was high (Barry and Tegner, 1989). Pauly and Munro (1984) stated that juveniles of a certain species would be higher in the catch composition if the L_c/L_∞ ratio was lower than 0.5. Our study recorded the (L_c/L_∞) ratio was 0.38. Consequently, the fishing composition of *P. heterolepis* in the Bay of Bengal was dominated by smaller size of fish.

Recruitment typically refers to a new cohort in the catch due to it becoming big or old enough to be vulnerable to the fishery. Our study recorded that there was one major recruitment peak in the population in a year (April-May) and they overlapped in time to provide a continuous pattern throughout the year. Finally, the MSY of *P. heterolepis* was calculated as 10234.47 metric tons, if the recommended length at first capture (L_c = 14.96 cm TL) is maintained.

6.7. Conclusion

Our study describes the growth pattern, growth parameters, mortality, recruitment, exploitation rate and MSY of *P. heterolepis* in the Bay of Bengal, Bangladesh. However, overfishing is the most focal threat for the wild population of *P. heterolepis* in the context of Bay of Bengal, Bangladesh. Therefore, fishing activity must be managed at a level to ensure that the wild stock can remain productive and healthy. Illegal gears should be banned and mesh size should be increased to limit catching mature smaller individuals to provide them opportunity to spawn. The findings might be a potential tool for fishery biologist to initiate alternative management approaches to conserve this prominent fish species from possible future collapse. Moreover, the results will contribute valuable baseline for further studies within the marine ecosystem of Bay of Bengal.

Chapter 7

General Discussion

GENERAL DISCUSSION

Information about *P. heterolepis* is inadequate in literature. Consequently, the present study is the first effort to describe morphometric and meristic characteristics, growth pattern, condition factor, reproductive biology and stock assessment of *P. heterolepis* from the Bay of Bengal, Bangladesh. In total, 1223 specimens of *P. heterolepis* were collected randomly from commercial fisher's catch during January to December 2019.

Morphometric and meristic characters are important for fish species identification and classification as well as the genetic studies (Bagenal and Tesch, 1978; Jayaram 1999; Harrison et al., 2007). Length-frequency distribution provides vital evidence to estimate reproductive potential of a fish population (Khatun et al., 2018). Information on length-weight relationships (LWRs) of a fish species in a given geographic region is helpful in fisheries and environmental monitoring programs (Froese, 2006; Hossain et al, 2012). On the other hand, form factor ($a_{3.0}$) is used widely to identify the body shape of fish in any aquatic habitat (Froese, 2006). In the present study, 8-10 spine fin rays was found in dorsal fin that is similar to Shafi and Quddus (1982); Talwar and Jhingran (1991) ; Rahman (2005), but the branched fin rays were more than their findings. Pectoral fin contains 15-17 fin rays with 1 unbranched ray that is more or less parallel to Rahman (2005). Observed pelvic fin rays (I/5) and anal fin rays (II/5-7) were alike with the study of Shafi and Quddus (1982), Talwar and Jhingran (1991) and Rahman (2005). Caudal fin rays (ii/15-17) were in agreements with Shafi and Quddus (1982). However, meristic counts solely unable to provide the detail information to distinguish among different populations or stocks of the same species. Absence of individuals smaller than 10.5 cm TL during the study may be attributed to the selectivity of fishing gear or low market price or fishers did not go where smaller size of fishes exist (Hossain et al., 2016a,b; Hossen et al., 2019). The maximum TL was found 34.5 cm in favor of female. Our study revealed a length of 28.2 cm in SL specifically higher than the report (21.4 cm) of Sasaki (1995). Therefore, this study was recorded the maximum length (34.5 cm in TL) for *P. heterolepis* in female population. Further, overall *b* value for both male and female showed negative allometric growth. However, *b* values may differ in the same species because of consolidation of various factors i.e. sex, development of gonad, growth variations in different body parts, physiological condition, food availability and preservation methods (Le Cren 1951; Tesch 1968; Hossain et al. 2015), which were excluded during the present study. Moreover, the LLR was extremely correlated, but it was difficult to make any comparisons due to lack of available information on *P. heterolepis*. Additionally, the allometric co-efficient (*b*) was found significantly related with temperature for both male and female. For male population, the *b* value showed isometric growth pattern from December to March when the temperature is comparatively lower. Thereafter, *b* value drops with the increase of temperature but recover steadily from the month of November. For female population, *b* value was found positive allometric in January and Isometric in February and March. Further, *b* value dropped with increasing temperature. The calculated form factor ($a_{3.0}$) was 0.0070 and 0.0071 for male and female *P. heterolepis*, respectively indicated the eel like body shape (Froese, 2006).

Condition factor is an index which is used to understand survival, maturity, health status and reproduction of fish (Le Cren, 1951). Further, it is used as an indicator of water quality and overall health of a population dwelling in a specific ecosystem (Tsoumani et al., 2006). In addition, relative weight (W_R) is the most popular index to assess the status of fish in a particular habitat considering prey-predator status (Froese, 2006; Rypel and Richter, 2008). To assess the overall health and productivity of *P. heterolepis* multiple condition factors including Fulton's (K_F), allometric (K_A), relative (K_R) as well as relative weight (W_R) were used in the present study. According to Spearman rank test, Fulton's condition factor (K_F) and TL were significantly correlated in both sexes denoting that K_F was the best allowing for the well-being of *P. heterolepis* in the Bay of Bengal. In our study, the mean W_R revealed no significant difference from 100 for both male and female populations of *P. heterolepis* indicating the habitat was in balanced condition. Further, the Fulton's condition factor (K_F) was found significantly related with temperature for both male and female. Fish is a poikilothermic animal. Consequently, habitat temperature controls the fish body temperature, food consumption, growth rate and various body functions (Houlihan et al., 1993; Azevedo et al., 1998).

In order to formulate sound fisheries management policy, the knowledge of reproduction is an important concern. Information about reproductive biology of fish is essential for understanding of its population dynamics as well formulating baseline data in the management process (King, 2007). Determining size at first sexual maturity (TL_m) is important simultaneously for differentiating among diverse populations of an identical species and for anticipating a basis that ultimate changes in length at first maturity are due to fisheries pressure or other reasons (Hossain et al., 2010c). Our study revealed that the TL_m of female *P. heterolepis* was 15.0 cm in TL based on GSI, MGSI and DI values. The maturity size may differ according to habitat characteristics accompanied by diverse environmental factors (Sinovcic and Zorica, 2006). However, absence of information on maturity prohibits substantial comparisons with our findings. The government of Bangladesh usually enforces yearly fishing ban for a period of 65 days from 20 May to 23 July to promote the spawning of depleted fish and crustacean stocks in Bay of Bengal since 2019 (DoF, 2019). However, the peak spawning season for the marine fish and crustacean stocks is not yet determined. Alternatively, the coastal fishermen protest against the banning period as marine fishing is the only source of their livelihood. Further, the peak fishing season is extended from the month of June to September in Bay of Bengal. Without supplementary income options, this imposed ban period would drive them into more destitution condition. Spawning season is crucial to assess spawning time and migration of a fish population for spawning purpose (Khatun et al., 2019). According to monthly GSI, MGSI and DI values, female *P. heterolepis* showed a prolonged spawning period from January to July. But peak spawning occurred in February. Consequently, all types of fishing ought to be banned during the peak spawning period to ensure sustainable management of this species in their interminable habitat and allow the coastal fisher folks to continue fishing during the June-September monsoon, which is the ultimate fishing season in the Bay of Bengal. Further, it was noticed that the reproductive behavior of female *P. heterolepis* was influenced by water temperature. Throughout the study, the maximum water temperature was recorded in May-June (34.4^{o}C) and the lowest temperature was noted in January (19.8^{o}C). Besides, the highest GSI (peak spawning period) was detected in the month of February when the water temperature is comparatively lower (24.7^{o}C).

Stock assessment is essential to obtain highest benefit from a natural stock without hampering the wild population. Further, it is crucial to determine the growth parameters for predicting future yields and stock biomass from a particular aquatic ecosystem

(Dadzie et al., 2017). We estimated L_∞ higher than our largest specimen might be attributed that von Bertalanffy model being insufficient for determining the growth of fish species (Vigliola et al., 1998). Consequently, the growth performance index ($Ø'$) was used to compute the least variance compared to other available indices (Pauly and Munro, 1984). However, the calculated $Ø'$ for *P. heterolepis* was 2.30. Further, we observed the maximum age or life span (t_{max}) was 3.85 year and age at zero length (t_0) was 0.108 year. There was no previous data on growth parameter of *P. heterolepis* to compare our findings. In addition, total mortality (Z) was recorded 0.86 $year^{-1}$. We found that the natural mortality (M =0.44 $year^{-1}$) rate is almost similar with fishing mortality (F = 0.42 $year^{-1}$). Consequently, the standing stock is not quite sustainable with the existing fishing strategy. We found the maximum allowable exploitation rate (E_{max} = 0.471) is lower than the observed exploitation level E=0.490. Thus the species is facing overexploitation in the Bay of Bengal, SW Bangladesh. Similarly, we found that the Z/K ratio was 5.118 which denoted that the exploitation level was high (Barry and Tegner, 1989). Pauly and Munro (1984) stated that juveniles of a certain species would be higher in the catch composition if the L_c/L_∞ ratio was lower than 0.5. Our study recorded the (L_c/L_∞) ratio was 0.38. Consequently, the fishing composition of *P. heterolepis* in the Bay of Bengal was dominated by smaller size of fish. The recruitment pattern was almost continuous throughout sampling period with a major peak in April-May. Finally, the MSY of *P. heterolepis* was calculated as 10234.47 metric tons, if the recommended length at first capture (L_c = 14.96 cm TL) is maintained.

Chapter 8

Management Measure

Management Measures

The information was collected from different fishers, eye witness, daily national and international print and electric news media, survey data from different government and non-government organizations and finally from the research findings. The main causes for declining of fishes from the Bay of Bengal, Bangladesh, are

- Over exploitation; and
- Use of illegal gears.

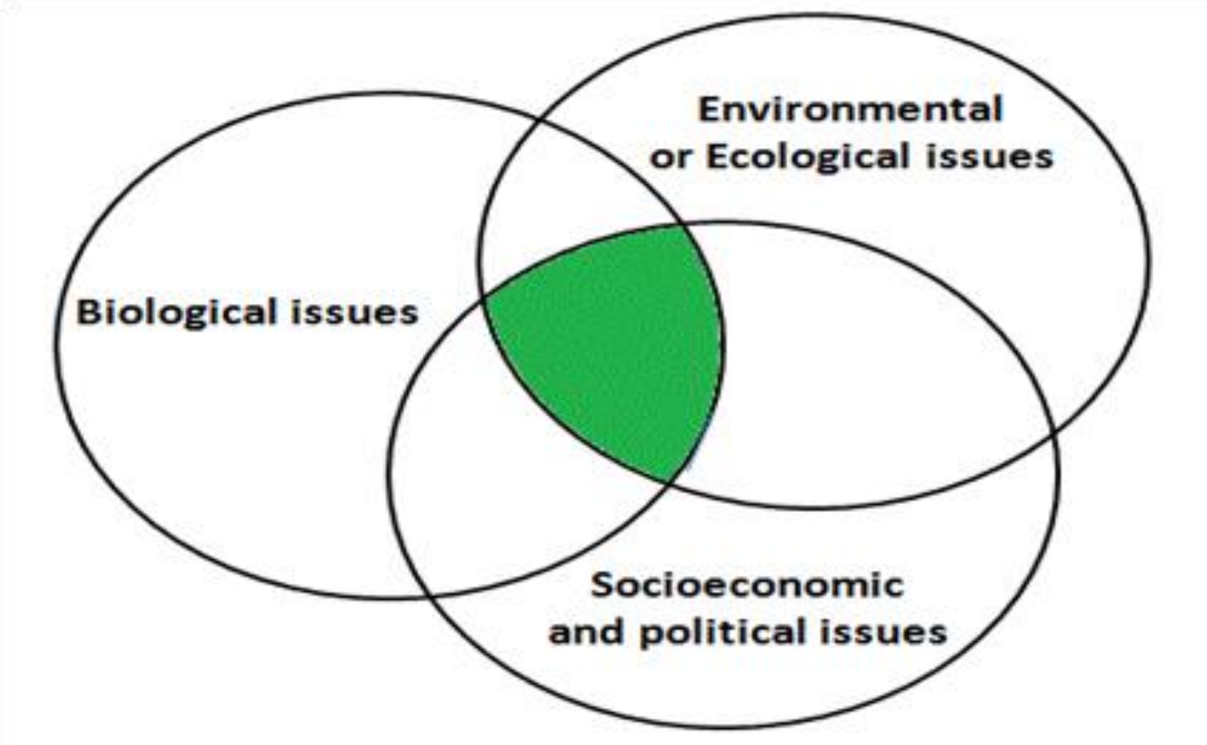


Figure 34. Pie Chart showed the condition of *Panna heterolepis* for suitable environment.

Table 25. A simple guide to fisheries management approach for maintaining sustainable yield of *Panna heterolepis* in the Bay of Bengal.

Goals	Objectives	Management Measures
Biological	✓ To maintain the stock at all times above 50% of its mean exploited level	✓ Fishing in the peak spawning season should be banned. Spawning ground should be protected. ✓ Illegal gear should be banned. ✓ Maximize mesh sizes and escape gap.
Environmental	✓ To ensure the suitability of all the environmental factors (temperature, rainfall, Dissolved Oxygen, Salinity, pH etc)	✓ The temperature of the world environment is being increased every year. ✓ Duration of rainfall has been reducing gradually for different climatic issues. ✓ So, long term management policy should be taken for its sustainable management.
Socio-economic	✓ Maximize employment opportunities. ✓ Maximize the net income of fishers	✓ To be studied

Chapter 9

Conclusion and Recommendation

Conclusion and Recommendation

This study provides complete baseline information on length-weight relationships, length-length relationships, form factor, condition factors in relation to climate parameters, size (minimum) at first sexual maturity, spawning season, peak season, effect of environmental factors on the GSI, growth parameters using VBGF and stock assessment of *P. heterolepis* in the Bay of Bengal, Bangladesh. The study revealed that the growth pattern was negative alometric (b < 3.0) for both male and female population. The allometric co-efficient (b) was found significantly related with temperature for both sexes. The calculated form factor ($a_{3.0}$) was 0.0070 and 0.0071 for male and female *P. heterolepis*, respectively. Based on the values of Spearman rank correlation test, Fulton's condition factor (K_F) was the best-fitted model. Further, K_F was found significantly related with temperature. First sexual maturity was gained at about 15.0 cm in TL. The spawning season was ranged from January to July and the peak season was in February. Further, it was noticed that the reproductive behavior of female *P. heterolepis* was influenced by water temperature. The study revealed that growth coefficient (K = 0.13 year^{-1}), growth performance index ($Ø'$ = 2.30) and life-span (t_{max} = 3.85 year). Further, *P. heterolepis* was found to grow rapidly with an asymptotic length (L_∞) of 39.08 cm. Total mortality (Z) was recorded 0.86 year^{-1}. The recruitment rate of *P. heterolepis* population is more or less continuous throughout the year with a major peak in April-May. We found the maximum allowable exploitation rate (E_{max} = 0.471) is lower than the observed exploitation level E=0.490. Thus the species is facing overexploitation in the Bay of Bengal, Bangladesh. Our study recorded the (L_c/L_∞) ratio was 0.38. Consequently, the fishing composition of *P. heterolepis* in the Bay of Bengal was dominated by smaller size of fish. Finally, the MSY of *P. heterolepis* was estimated at 10234.47 metric tons. The results of the study would be an effective tool for fishery biologists, managers and conservationists to initiate early management strategies and regulations for the sustainable conservation of the remaining stocks of this species in the Bay of Bengal ecosystem. Moreover, this study provides valuable information for the online FishBase database as well as providing an important baseline for future studies within the Bay of Bengal and surrounding ecosystems.

Further studies on the following aspects are recommended:

- Detail studies on the seasonal variations in stomach contents of *P. heterolepis* in the Bay of Bengal and adjacent coastal areas are highly recommended.

- So far, no work has been done on feeding biology of this fish species. Therefore, a complete study on food and feeding habit are recommended.

- It is clear that no attempt has been made to develop aquaculture practice for this fish species. So, captive breeding and culture technique must be tried.

Chapter 10

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PUBLICATIONS

(During the Ph.D research tenure)

Indian Journal of Geo Marine Sciences
Vol. 50 (06), June 2021, pp. 502-506

Short Communication

The Hooghly croaker, *Panna heterolepis* Trewavas, 1977: Identification through morphometric and meristic characteristics

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Received 20 November 2019; revised 18 March 2021

As morphometric information for Hooghly croaker *Panna heterolepis* Trewavas, 1977 is absent in the most extensively accessed and world's largest online database for fishes (FishBase); this study was undertaken to provide the complete informative description on morphometric relationships and meristic counts of various fin rays. A total of 200 individuals were sampled from the Bay of Bengal (Bangladesh) during July 2018 to June 2019, using several traditional fishing gears. Meristic counts were computed using a magnifying glass. Body weight (BW) and several length measurements were taken through an electronic balance and digital slide calipers for each individual. LWRs (Length-weight relationships) were calculated as: $W = a{\times}L^b$. All LWRs and LLRs (length-length relationships) were found significant with $r^2 \geq 0.919$ ($p < 0.0001$) and 0.928 ($p < 0.001$), respectively. BW *vs.* TL and TL *vs.* SL were the best fitted models for LWRs and LLRs, respectively. Fin formula was: dorsal, D. 43–55 (VIII–X+i/34–44); pectoral, P. 15-17 (i/14–16); pelvic, Pv. 6 (I/5); anal, A. 7–10 (II/5–8); and caudal, C. 17–19 (ii/15–17). These results will a) make a vital contribution for species identification in the marine and coastal waters of Bangladesh and adjoining countries, and b) provide information for Fish Base.

[**Keywords**: Bangladesh, Bay of Bengal, Meristic, Morphometric, *Panna heterolepis*]

Introduction

Bangladesh harbour a huge amount of open waterbodies like rivers, freshwater marshes, estuaries, and an extensive coastline of ~710 km. Together with vast water resources, Bangladesh is rich with various fish and other aquatic species. The southern marine and coastal region of Bangladesh is blessed with a high abundance of fishes that can be caught commercially to contribute to the national economy[1-5].

The Hooghly croaker, *Panna heterolepis*, which belongs to the family Sciaenidae, is a tropical demersal fish that inhabits in coastal waters while the juveniles thrive in mangrove swamps. This sciaenid is found abundantly in India and Bangladesh[6-8]. This species is a popular food item and is fairly common in the commercial catch to be marketed fresh or dried/salted.

Morphometric characteristics and meristic counts are important for the identification, classification, and for genetic studies of fish species[9-15] because variation in meristic appearance has been undoubtedly demonstrated in many fish species[16]. Further, morphometric based identification perform a dynamic role in research, being used to compare population structure, and fisheries stock assessments[17-22]. Furthermore, studies based on morphometric and meristic characters are faster and practical than molecular studies, therefore can be applied on field[20].

Morphometric and meristic studies of many aquatic species have been done from Bangladesh in the past[23-34]. However, many studies[5,9,35-38] were conducted region wide on *P. heterolepis*, but none of these studies covered morphometric and meristic traits together. Thus, current study explores the morphometric relationships and meristic counts of *P. heterolepis* collected from marine waters of Bangladesh.

Materials and Methods

Present study was carried out in the Bay of Bengal (21º77′ N; 89º55′ E), Khulna region, Bangladesh. A total of 200 individuals of *P. heterolepis* (Fig. 1) were collected during July 2018 to June 2019 *via* different local gears.

Each fresh sample was immediately chilled with ice in the field and preserved in buffered formalin. Meristic counts were done with the help of a magnifying glass. Wet body weight (BW) was recorded with 0.01 g precision and body lengths were measured to the nearest 0.01 cm accuracy (Fig. S1).

To calculate LWRs, the formula $W = a{\times}L^b$ was used; where, W is the body weight (BW, g), L is one of ten different lengths (cm), and a and b are regression parameters. Furthermore, 95 % confidence limit (CL) of a and b and the coefficient of determination (r^2) were assessed. Extreme outliers were omitted from the regression[39]. To ensure that the *b* values in the regression analyses were substantially diverse from the isometric value, a *t*-test was used[40]. All length-length relationships (LLRs) were assessed by linear regression analysis[29]. The best models were selected from LWRs and LLRs, depending on the highest r^2 values.

Results

The body of *P. heterolepis* is slender. The mouth is large, oblique, and supraterminal and the head bears a rounded snout. The body color is brownish, pertaining lighter on belly with yellowish fins (Fig. 1). Dark margins are present on the dorsal and anal fins. The dorsal fin has a low notch with weak spines and the second anal spine is also weak. The body is covered with small ctenoid scales, but the head is with cycloid scales. The morphometric measurements of *P. heterolepis* are presented in Figure S1. The fin formula of *P. heterolepis* is: dorsal, D. 43 – 55 (VIII – X + i/34 – 44); pectoral, P. 15-17 (i/14 – 16); pelvic, Pv. 6 (I/5); anal, A. 7 – 10 (II/5–8); caudal, C. 17 – 19 (ii/15 – 17) (Fig. 2). All the meristic counts of *P. heterolepis* are presented in Table S1.

In this study, TL ranged from 11.0 to 34.5 cm (mean ± SD = 19.36±3.84 cm) and BW varied from 9.02 to 298.26 g (mean ± SD = 61.25±40.93 g). All morphometric relationships are shown in Table 1. The regression parameters (*a* and *b*) and the significance values are shown in Table 2. Based on r^2 values of LWRs, BW *vs.* TL and BW *vs.* SL were the fittest models among the 10 equations. All LLRs were also highly correlated with r^2 values ≥ 0.928 (Table 3). According to r^2 values of LLRs, TL *vs.* SL and TL *vs.* PcL were the fittest models among 9 equations.

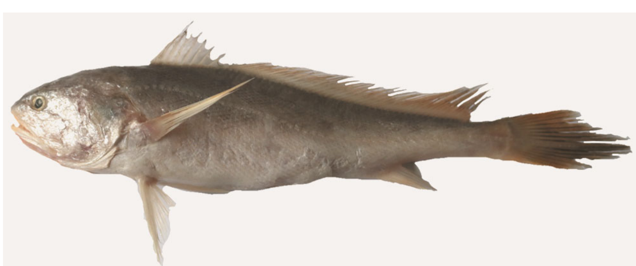

Fig. 1 — Photograph of *Panna heterolepis* collected from the Bay of Bengal, Bangladesh

Discussion

Data on morphometric characters as well as meristic counts for *P. heterolepis* is limited in

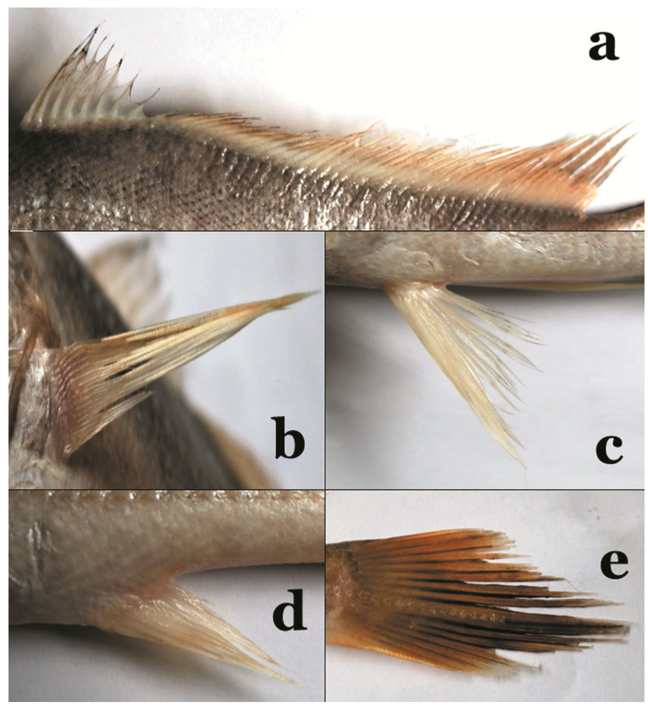

Fig. 2 — Different fins of *Panna heterolepis*: (a) dorsal, (b) pectoral, (c) pelvic, (d) anal, and (e) caudal fin

Table 1 — Morphometric measurements of *Panna heterolepis* Trewavas, 1977 captured from the Bay of Bengal, Bangladesh

Measurements	Min (cm)	Max (cm)	Mean ± SD	95 % CL	% TL
TL (Total length)	11.0	34.5	19.36 ± 3.84	18.82 - 19.90	100.00
SL (Standard length)	8.3	28.2	15.07 ± 3.13	14.64 - 15.51	81.74
HL (Head length)	2.3	6.5	4.04 ± 0.77	3.94 - 4.15	18.84
PrDL (Pre-dorsal length)	2.3	6.9	4.09 ± 0.84	3.97 - 4.21	20.00
PoDL (Post-dorsal length)	7.9	25.4	13.91 ± 3.29	13.46 - 14.37	73.62
PcL (Pectoral length)	2.6	6.8	4.19 ± 0.76	4.08 - 4.29	19.71
PvL (Pelvic length)	2.7	7.5	4.43 ± 0.92	4.30 - 4.56	21.74
AnsL (Anus length)	5.6	14.9	9.42 ± 1.90	9.16 - 9.68	43.19
PrAnL (Pre-anal length)	6.5	15.7	10.47 ± 1.89	10.21 - 1073	45.51
PoAnL (Post-anal length)	7.1	19.7	11.55 ± 2.39	11.21 – 11.88	57.10
BW (Body weight)	9.02*	298.26*	61.25 ± 40.93	55.54 - 66.96	-

Min - minimum; Max - maximum; SD - standard deviation; CL - confidence limit for mean value; and * - weight in g

Table 2 — Descriptive statistics and estimated parameters of the length-weight relationships of *Panna heterolepis* Trewavas, 1977 from 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	0.0075	3.001	0.0062 – 0.0090	2.938 – 3.063	0.978	I
BW = *a* × SL^b	0.0193	2.927	0.0165 – 0.0226	2.868 – 2.986	0.979	A-
BW = *a* × HL^b	0.8867	2.941	0.7606 – 1.0338	2.831 – 3.051	0.933	A-
BW = *a* × PrDL^b	1.1359	2.743	0.9680 – 1.3329	2.629 – 2.857	0.919	A-
BW = *a* × PoDL^b	0.0543	2.630	0.0457 – 0.0645	2.560 – 2.692	0.969	A-
BW = *a* × PcL^b	0.4788	3.298	0.4182 – 0.5482	3.203 – 3.392	0.959	A+
BW = *a* × PvL^b	0.7000	2.922	0.6146 – 0.7972	2.834 – 3.010	0.956	A-
BW = *a* × AnsL^b	0.0969	2.821	0.0801 – 0.1171	2.736 – 2.906	0.956	A-
BW = *a* × PrAnL^b	0.0400	3.069	0.0309 – 0.0517	2.958 – 3.179	0.938	I
BW = *a* × PoAnL^b	0.0465	2.887	0.0388 – 0.0558	2.812 – 2.962	0.967	A-

See Table 1 for abbreviation; *a* and *b* are the regression parameters of LLRs; CL - confidence limits; r^2 - coefficient of determination; GT - growth type; 'A-' – negative allometric; 'A+' – positive allometric; and I - isometric

Table 3 — The estimated parameters of the length-length relationships (y = *a* + *b* × *x*) of *Panna heterolepis* Trewavas, 1977 from the Bay of Bengal, Bangladesh

Equation	Regression parameters		95 % CL of *a*	95 % CL of *b*	r^2
	a	*b*			
TL = *a* + *b* × SL	1.6880	1.177	1.4055 – 1.9706	1.159 – 1.196	0.988
TL = *a* + *b* × HL	-0.2871	4.858	-0.9242 – 0.3500	4.700 – 5.010	0.951
TL = *a* + *b* × PrDL	1.3400	4.400	0.6200 – 2.0599	4.231 – 4.576	0.928
TL = *a* + *b* × PoDL	3.3848	1.148	2.9579 – 3.8118	1.118 – 1.178	0.967
TL = *a* + *b* × PcL	-1.5854	5.001	-2.0521 – -1.1187	4.892 – 5.111	0.988
TL = *a* + *b* × PvL	1.1413	4.111	0.6322 – 1.6504	3.999 – 4.223	0.963
TL = *a* + *b* × AnsL	0.5694	1.995	0.1352 – 1.0037	1.949 – 2.039	0.975
TL = *a* + *b* × PrAnL	-1.3730	1.980	-2.0232 – -2.0229	1.919 – 2.041	0.954
TL = *a* + *b* × PoAnL	0.9744	1.592	0.6580 – 1.2909	1.566 – 1.619	0.986

See Table 1 for abbreviation; *a* and *b* are the regression parameters of LWRs; CL - confidence limits; r^2 - coefficient of determination

literature. This study represents the first thorough morphometric information (LWRs and LLRs) and meristic counts of *P. heterolepis*, which should facilitate the correct identification.

Meristic counts appear to be favorable and easy to assess, and maximum counts can be done from live fish. In this study, 8-10 spine fin rays were found in dorsal fin, which is similar to Shafi & Quddus[41], Talwar & Jhingran[7], and Rahman[6], but the branched fin rays exceeded their findings. In this study, pectoral fins had 15-17 fin rays with 1 unbranched ray, which is also similar to Rahman[6]. Observed pelvic (I/5) and anal fin-ray counts (II/5-7) were identical to those of Shafi & Quddus[41], Talwar & Jhingran[7], and Rahman[6]. Caudal fin rays (ii/15-17) were in agreement with Shafi & Quddus[41]. Hence, meristic counts are inadequate to distinguish among different populations or stocks of the same species.

In general, morphometric and meristic data collection is a tedious process[42]. For this reason, a representative number of samples and individuals (*n* = 200) from small to large body sizes were collected for observation. However, absence of fish smaller than 11.0 cm TL during the study period may reflect selectivity of fishing gear, low market price, or the commercial fishers are not operating where young fish live[29,31,32,35-37]. Present study reported a length of 28.2 cm SL, which is higher than the findings (21.4 cm) of Sasaki[34] but similar to Sabbir *et al.*[37]. The SL (81.74 %) was the highest percentage of TL, opposite of PcL (19.71 %). The mean body weight was found to be 61.25±40.93 g, though the maximum weight was 298.26 g. Low mean weight with a high maximum BW ('skewing') reflected the presence of few large fishes in the sampling site.

According to Carlander[43], the *b* values of LWRs may differ between 2.0 to 4.0, whereas Froese[39] reported the value ranging from 2.5 to 3.5. In this study, the obtained *b* values from relationships between BW and 10 different lengths of *P. heterolepis* were within the range of 2.630 – 3.298. Sabbir *et al.*[37] also reported negative allometric growth for *P. heterolepis* population based on year-round data. However, within the same species, the *b* values can differ due to one or more factors, such as differences in growth across body-parts, gender, physiological condition, gonadal development, food availability, preservation methods, and due to variation in observed lengths of the collected specimens[32], which are not examined in this study. The LWRs, TL and PrAnL showed isometric growth; PcL showed positive allometric growth; and the other body parts showed negative allometric growth.

However, lack of sufficient literature prevents thorough comparisons with current findings. The study also found the fittest model among the equations for several length types based on the coefficient of determination (r^2).

Conclusion

The study describes morphometric information, *i.e.*, LWRs and LLRs, along with meristic counts and the findings should be valuable to fishery biologists to (a) identify *P. heterolepis* and (b) to instigate stock assessment in the Bay of Bengal, Bangladesh.

Supplementary Data

Supplementary data associated with this article is available in the electronic form at http://nopr.niscair.res.in/jinfo/ijms/IJMS_50(06)502-506_SupplData.pdf

Acknowledgements

The authors extend their sincere appreciation to the National Science and Technology (NST) and PIU-BARC NATP-2 PBRG-156 for funding of this work.

Conflict of Interest

The authors declare that they have no conflict of interest for this study.

Author Contributions

WS, MYH & MAR: Conceived the concept. MAR, MAI & MNK: Collected and analyzed the data. AAC, MRH & ZM: Software analysis. WS & MAR: Wrote and edited the manuscript.

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Indian Journal of Geo Marine Sciences
Vol. 50 (06), June 2021, pp. 502-506

Supplementary Data

The Hooghly croaker, *Panna heterolepis* Trewavas, 1977: Identification through morphometric and meristic characteristics

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Sr. No	**Contents**	**Page No.**

Supplementary Tables

Table S1 — Meristic characters of *Panna heterolepis* Trewavas, 1977 captured from the Bay of Bengal, Bangladesh

Meristic data	Numbers	Spine	Unbranched	Branched
Dorsal fin rays	43 - 55	VIII - X	i	34 - 44
Pectoral fin rays	15 - 17	-	i	14 - 16
Pelvic fin rays	6	I	-	5
Anal fin rays	7 – 10	II	-	5 - 8
Caudal fin rays	17 - 19	-	ii	15 - 17

Spine, upper portion of single ray is sharp & pointed; Unbranched, single fin ray; Branched, upper portion of fin is divided into several rays

Supplementary Figures

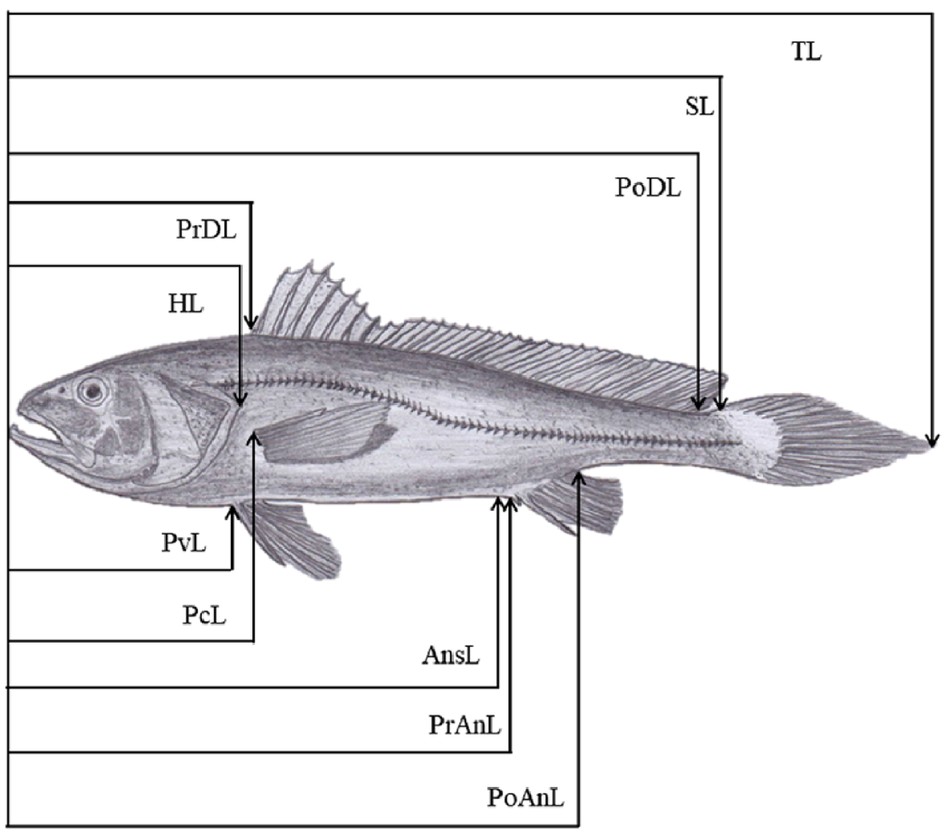

Fig. S1 — Showing the morphometric measurements of *Panna heterolepis* from the Bay of Bengal, Bangladesh

Received: 2 October 2019 | Revised: 24 July 2020 | Accepted: 24 July 2020
DOI: 10.1111/lre.12333

RESEARCH NOTE

Lakes & Reservoirs — Science, Policy and Management for Sustainable Use
WILEY

New maximum size record, length–weight relationships and form factor of Hooghly Croaker *Panna heterolepis* Trewavas, 1977 from the Bay of Bengal (Bangladesh)

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Abstract

The present study analysed the length–weight relationships (LWRs) and form factor ($a_{3.0}$) of *Panna heterolepis* Trewavas, 1977 from the Bay of Bengal, Bangladesh. A total of 316 specimens were sampled during the pre-monsoon ($n = 96$), monsoon ($n = 116$) and post-monsoon ($n = 104$) season (March 2018–February 2019) using a Seine bag net. Individual total length (TL) and body weight (BW) were measured with a measuring board and digital weight balance, respectively. The TL *vs*. BW relationship indicated a negative allometric growth for *P. heterolepis*. The present study also provides LWR, $a_{3.0}$ (0.0070) and a new maximum recorded size (29.50 cm TL and 24.50 cm SL) of *P. heterolepis* for the first time, data currently lacking in the FishBase online database. The results of the present study will be helpful for stock assessment and management of this fish in the Bay of Bengal, Bangladesh and neighbouring countries.

KEYWORDS
Bay of Bengal, form factor, length–weight relationship, *Panna heterolepis*

1 | INTRODUCTION

The Hooghly Croaker (*Panna heterolepis* Trewavas, 1977) under the order Perciformes is a commercially important fish species. This Sciaenid fish is distributed in Bangladesh, Myanmar, India and Sri Lanka (Froese & Pauly, 2020). *P. heterolepis* dwells in shallow coastal and estuarine waters, and juveniles are also found in mangrove swamps and rivers (Sasaki, 1995; Sasaki, 2001; Sanphui, Gupta & Dasgupta, 2018). According to the IUCN (2019), *P. heterolepis* has not been globally evaluated.

Length–weight relationships (LWRs) are essential for studying fish stock assessment and population dynamics (Hossain, Hossen, Ahmed et al., 2017; Parvin et al. 2018; Hossen, Rahman, Hossain et al., 2019), allowing calculation of weights consistent with a given body length. It is widely used in analyses of fishery data, mainly because of the difficulty and time required to record weights in the field (Andrade & Camos, 2002). This relationship is often used to convert growth-in-length equations for predicting weight-at-age and use in stock assessment models (Pauly, 1993). It is also useful for comparison of morphological traits among species, or among population, of certain species from various habitats and/or areas (Hossain, Rahman, Abdallah et al., 2013; Hossen, Rahman, Hossain et al., 2019). At the same time, form factor ($a_{3.0}$) is widely used to compare fish body shapes between geographic locations (Froese, 2006).

There appears to be no sound analysis of the length–weight relationships (except Sanphui, Gupta & Dasgupta, 2018) and form factor of *P. heterolepis* in the worldwide literature. Thus, the objective of the present study is to describe the LWRs and form factor for *P. heterolepis*, using recorded size from the Bay of Bengal (BoB), Bangladesh.

2 | MATERIALS AND METHODS

Fish sampling was conducted during the pre-monsoon ($n = 96$), monsoon ($n = 116$) and post-monsoon ($n = 104$) season (March 2018 to February 2019) from different parts of the Bay of Bengal around the Khulna region (21.7728°N; 89.5592°E) of Bangladesh through traditional fishing gears including seine bag net, gill nets etc. The collected samples were chilled and immediately taken to the laboratory. The fish samples were identified (Rahman, 2005; Sanphui, Gupta & Dasgupta, 2018; Sasaki, 1995; Talwar, 1995), with the scientific names checked according to the procedure of Froese & Pauly (2020). The total body weight (BW) was measured with an electronic balance to the nearest 0.01 g and the total length (TL) using a measuring board with 0.01 cm precision, respectively. The LWRs were estimated using the following equation:

$$W = a * L^b, \tag{1}$$

where W = BW (g); L = TL (cm); and *a* and *b* are the regression parameters. The 95% confidence level (CL) was calculated for the *a* and *b* parameters (Froese, 2006).

The form factor was assessed according to the procedure of Froese (2006), as follows:

$$a_{3.0} = 10^{\log a - s(b-3)}, \tag{2}$$

where *a* and *b* = regression parameters of LWRs; and *S* = regression slope of *ln a vs. b*. The mean slope, $S = -1.358$, was used to calculate the form factor because of lack of information regarding the LWR for *P. heterolepis*.

Statistical analyses were conducted with GraphPad prism 6.5 software. All statistical analyses were considered significant at the 5% ($p < .05$) significance level.

3 | RESULTS

A total of 316 *P. heterolepis* samples were analysed during the present study. Descriptive statistics on the species length and weight measurements are summarized in Table 1, while the regression parameters *a* and *b* of the LWR and their 95% confidence limits and coefficients of determination (r^2) are presented in Table 2 and Figure 1. The minimum and maximum TL was found to be 10.50 cm and 29.50 cm, respectively, for *P. heterolepis*. The LWRs indicated a negative allometric growth ($b = 2.81$) for *P. heterolepis*. All LWRs were highly significant ($p < 0.001$) with coefficient of determination values ≥ 0.962 (Table 2). The estimated form factor ($a_{3.0}$) for *P. heterolepis* was 0.0070.

4 | DISCUSSION

This is the first study on the length–weight relationships of *P. heterolepis*. Nevertheless, one previous study was conducted by Sanphui et al. (2018) with the title of morphometry and length–weight relationship in the Hooghly River of India, although it did not provide any values of the regression parameters *a* & *b*. Based on the present study, the maximum sizes were 29.50 cm (TL) and 24.50 cm (SL), which is higher than the 21.4 cm (SL) value reported by Sasaki (1995), with this difference possibly attributable to the selectivity of the fishing gear (Hossen, Paul, Hossain et al., 2019) or because fishermen did not go to locations with larger sized fish exist (Khatun et al. 2019; Ahamed et al. 2017).

The calculated allometric coefficient (*b*) of this fish species obtained in the present study was within the range of 2.5–3.5 observed by Froese (2006). The overall *b* value of LWR indicated negative allometric ($b = 2.81$) growth. As there was no LWR regression parameter reported for *P. heterolepis*, the results of the

TABLE 1 Descriptive statistics on the length (cm) and weight (g) measurements of *Panna heterolepis* Trewavas, 1977 from the Bay of Bengal, Bangladesh

Measurement	Sampling season	*n*	Minimum	Maximum	Mean ± SD	95% CL
TL	Pre-monsoon	96	11.90	27.00	19.89 ± 2.74	16.34–17.43
	Monsoon	116	10.50	29.50	17.64 ± 3.55	16.94–18.33
	Post-monsoon	104	13.10	26.40	17.96 ± 2.47	17.48–18.43
	Overall	316	10.50	29.50	17.14 ± 3.05	16.80–17.48
SL	Pre-monsoon	96	9.30	21.30	13.30 ± 2.15	12.88–13.72
	Monsoon	116	8.00	24.00	13.78 ± 2.86	13.22–14.34
	Post-monsoon	104	10.40	20.70	14.00 ± 1.94	13.63–14.37
	Overall	316	8.00	24.50	13.46 ± 2.41	13.19–13.73
BW	Pre-monsoon	96	11.42	144.30	41.26 ± 22.36	36.85–45.68
	Monsoon	116	11.20	187.53	45.13 ± 29.14	39.43–50.82
	Post-monsoon	104	18.05	120.22	42.16 ± 17.49	38.78–45.55
	Overall	316	11.20	187.53	42.57 ± 24.85	39.79–45.37

Abbreviations: BW, body weight; CL, confidence limit for mean values; *n*, sample size; SD, standard deviation; SL, standard length; TL, total length.

TABLE 2 Descriptive statistics and estimated parameters of the length–weight relationships of *Panna heterolepis* Trewavas, 1977 from the Bay of Bengal, Bangladesh

		Regression parameters				
Sampling season	Equation	*a*	*b*	95% CL of *a*	95% CI of *b*	r^2
Pre-monsoon	$BW = a \times TL^b$	0.0120	2.86	0.0087–0.0164	2.84–2.97	0.962
	$BW = a \times SL^b$	0.0230	2.87	0.0174–0.0303	2.76–2.97	0.965
Monsoon	$BW = a \times TL^b$	0.0132	2.80	0.0104–0.0168	2.71–2.88	0.977
	$BW = a \times SL^b$	0.0317	2.73	0.0250–0.0403	2.64–2.82	0.972
Post-monsoon	$BW = a \times TL^b$	0.0148	2.74	0.0116–0.0189	2.65–2.82	0.976
	$BW = a \times SL^b$	0.0281	2.75	0.0227–0.0347	2.67–2.83	0.978
Overall	$BW = a \times TL^b$	0.0133	2.81	0.0112–0.0158	2.75–2.87	0.964
	$BW = a \times SL^b$	0.0273	2.79	0.0235–0.0318	2.74–2.85	0.966

Abbreviations: *a* and *b*, LWR parameters; BW, body weight (g); CI, confidence intervals; *n*, sample size; r^2, coefficient of determination; SL, standard length (cm); TL, total length (cm).

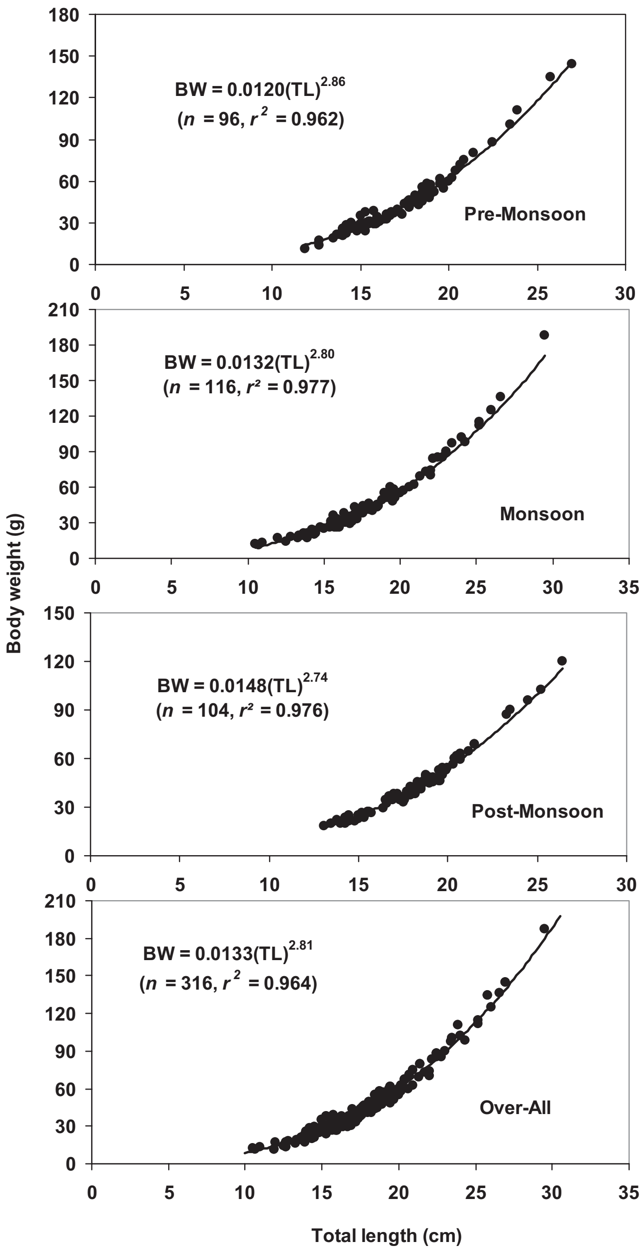

FIG. 1 Length–weight relationships of *Panna heterolepis* Trewavas, 1977 in the Bay of Bengal, Bangladesh

present study cannot be compared with other studies. The growth pattern might attributable to several factors, including sex, health condition, gonadal maturity, habitat accessibility, periodic effects, degree of stomach fullness, preservation schemes and variations in the studied length class (Hossain et al., 2012, Hossain et al. 2019; Rahman, Hasan, Hossain et al., 2019) all of which were not considered in the present study.

The calculated form factor for *P. heterolepis* was 0.0070. It was not possible to find any references to the form factor of *P. heterolepis*, making it difficult to compare the findings of the present study to other studies.

In conclusion, the results of determining the LWR, $a_{3.0}$ and new recorded size should be useful for stock assessment and management of *P. heterolepis* in the Bay of Bengal and other oceans. Further, these findings can be used as baseline data for *P. heterolepis* in the largest global fish database (FishBase).

ACKNOWLEDGEMENTS

This work was supported by (i) the National Science and Technology (NST) of the Government of Bangladesh with a research grant, and (ii) PIU-BARC, NATP-2, PBRG-156 for technical supports.

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How to cite this article: Sabbir W, Hossain MY, Mawa Z, et al. New maximum size record, length–weight relationships and form factor of Hooghly Croaker *Panna heterolepis* Trewavas, 1977 from the Bay of Bengal (Bangladesh). *Lakes & Reserv*. 2020;25:346–349. https://doi.org/10.1111/lre.12333

Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 24(7): 847 – 862 (2020)
www.ejabf.journals.ekb.eg

Growth pattern of the Hooghly Croaker *Panna heterolepis* Trewavas, 1977 in the Bay of Bengal (Bangladesh) in relation to eco-climatic factors

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ARTICLE INFO

Article History:
Received: Sept. 28, 2020
Accepted: Nov. 29, 2020
Online: Dec. 24, 2020

Keywords:
Panna heterolepis,
growth pattern,
Bay of Bengal,
eco-climatic factors,
Bangladesh.

ABSTRACT

The present study investigated the length-frequency (LFDs) distributions, length-length (LLRs) relationships and growth pattern based on length-weight (LWRs) relationships related to eco-climatic factors of *Panna heterolepis* captured from the Bay of Bengal, Bangladesh. In total, 1223 specimens (male = 654, female = 569) were collected from January to December 2019. Total length (TL), as well as body weight (BW), was measured by measuring board and digital balance with 0.01 cm and 0.01 g accuracy, respectively. TL varied between 10.70-31.40 cm for males and 10.50-34.50 cm for females. The overall allometric co-efficient (*b*) value for both sexes indicated negative allometric growth (< 3.00) for most of the months. In addition, the LLR (TL *vs.* SL) were extremely correlated ($p < 0.001$), with all $r^2 \geq 0.982$. The *b* of LWR was found significantly related to temperature for both sexes. However, rainfall, DO and pH did not reveal any significant correlation with the growth pattern for both sexes. This study recorded the maximum size of females as 34.5 cm TL. The outcomes of the study will be helpful for stock assessment as well as management of this fish in the Bay of Bengal, considering their response to climatic change.

INTRODUCTION

The Hooghly Croaker, *Panna heterolepis* Trewavas, 1977 is a tropical marine fish species **(Talwar and Jhingran, 1991)** under the family Sciaenidae. This Sciaenid fish is distributed in Bangladesh, India, Myanmar and Sri Lanka **(Sasaki, 1995)**. This species is commercially important as a fish food item for the coastal people of Bangladesh. However, total demand of this species is met through the capture from wild stock due to absence of culture practice. Consequently, overfishing is considered the notable threat for the natural stock of *P. heterolepis* in Bay of Bengal **(Hossain, 2014; Hossen *et al*., 2019; Sabbir *et al*., 2020a)**.

Length-frequency (LFDs) distribution is an important biometric index to detect the dynamic rates of recruitment, growth and mortality **(Neuman and Allen, 2001)**. Also, LFD is an important indicator of stock status, spawning period as well as river health **(Ranjan *et al*., 2005)**. In addition, LFD is useful for the comparison of morphological traits among species or among populations of the certain species from various habitats **(Hossain *et al*., 2013a; Hossen *et al*., 2019; Rahman *et al*., 2019a)**. Besides, length-weight (LWRs) relationships are essential for relating the life histories of fishes between various geographic areas **(Hossain *et al*., 2013a, Rahman *et al*., 2019b)** as well as helpful for stock assessment **(Ahmed *et al*., 2012)**. Likewise, the length-length (LLRs) relationships are very important because several eco-physiological features are dependent on length **(Hossain *et al*., 2006)**.

At present, climatic issues are considered as vibrant warning to aquatic living resources accompanied by other risks like overfishing, contamination in addition to habitat deterioration **(Rose, 2005)**. Temperature is thought to be the most imperative climatic factor influencing the distribution of larval accumulations of marine and freshwater fish species **(Jakobsen *et al*., 2009; Houde and Zastrow, 1993)**. Likewise, rainfall is another important climatic factor prompting the hydrological events through runoff and river inflow **(Patrick, 2016)**. In order to maintain inclusive fish growth, an optimum level of DO (dissolved oxygen) is necessary for their metabolic activities **(Abdel-Tawwab *et al*., 2015)**. Besides, pH denotes the acidic and alkaline condition of an aquatic ecosystem. Upper pH level (9-14) affects fish physiology not only by denaturing cell membranes but also altering different parameters of an aquatic ecosystem **(Brown and Sadler, 1989)**.

Nevertheless, only a few studies with the morphology **(Sasaki, 1995)**, morphometry **(Sanphui *et al*., 2018)**, condition factor **(Sabbir *et al*., 2020a)** along with length-weight relationships and form factor **(Sabbir *et al*., 2020b)** have been completed on *P. heterolepis*. Consequently, the objective of the study is to illustrate the length-frequency distributions (LFDs), length-length (LLRs) relationships and growth pattern based on length-weight relationships (LWRs) in relation to eco-climatic factors of *P. heterolepis* for consecutive twelve months from the Bay of Bengal, Bangladesh.

MATERIALS AND METHODS

Study site and sampling

The study was conducted in the Bay of Bengal, Khulna region, Bangladesh. In total, 1223 specimens (male = 654, female = 569) of *P. heterolepis* were collected randomly from commercial fisher's catch during January to December 2019. The samples were preserved in 10% formalin solution to avoid decomposition.

Fish measurement

Male and female individuals were identified by gonadal observation under microscope. Total length (TL) and standard length (SL) along with body weight (BW) were measured by measuring board and digital balance with 0.01 cm and 0.01 g accuracy, respectively.

Population structure and growth pattern

Population structure through LFDs for *P. heterolepis* was assembled using 1 cm intervals of TL. Growth pattern was calculated by LWRs involving the equation: $W = a \times L^b$, where W stands for body weight (g) and L represents the total length (cm). The parameters a and b were assessed using linear regression analysis based on natural logarithms: $ln (W) = ln (a) + b\ ln (L)$. A t-test was executed to approve whether the b values of the linear regression were significantly different from the isometric value of b = 3 **(Sokal and Rohlf, 1987)**. Further, LLR i.e. TL *vs.* SL was assessed with linear regression analysis **(Hossain *et al*., 2006)**.

Eco-climatic parameters

In order to assess the relationship between allometric co-efficient (b) with habitat condition, monthly eco-climatic factors were also recorded from the sampling site following **APHA (2005)** procedures. The collected parameters were temperature, pH and dissolved oxygen (DO). Further, the data of scheduled rainfall was collected from meteorological station of Khulna, Bangladesh.

Statistical analysis

Statistical analyses were conducted by GraphPad Prism 6.5 and Microsoft® Excel-add-in-DDXL software with 5% significance level. Homogeneity as well as normality of data was checked by pictorial assessment of histograms and box plots and confirmed with Shapiro-Wilk test. Further, non-parametric Mann-Whitney U-test was applied to relate the mean values between sexes. ANCOVA was executed to confirm the difference of growth type between male and female. Spearman rank test was done to relate allometric co-efficient (b) with different eco-climatic factors.

RESULTS

Population structure

LFDs of *P. heterolepis* revealed that the size range was 10.5 to 34.5 cm TL for combined sex. Besides, LFD indicated that 18.00–18.99 cm and 17-17.99 cm TL size group was precisely dominant for male and female population, respectively. The LFD for both male and female failed to pass the normality. In addition, Mann-Whitney U-test revealed no significant differences between males and females (P = 0.5125). The TL varied between 10.7-31.4 cm and 10.5-34.5 cm for males and females, respectively (Figure 1). The study further indicated that the BW varied from 10.02 to 203.89 g for male and 9.02 to 342.26 g for female population (Table 1). Besides, Mann-Whitney U-test indicated that BW of both sexes were not significantly different (P = 0.5355).

Growth pattern

The study further stated that overall *b* value for both males and females indicated negative allometric growth ($b < 3.00$) (Figure 2). However, males exhibited isometric growth ($b = 3$) during January to March and December. Furthermore, females showed positive allometric growth ($b > 3$) in January while isometric growth in February and March. All LWRs were extremely significant ($p < 0.001$), with r^2 values ≥ 0.957. The monthly sample size (*n*), regression parameters with 95% confidence limit of the LWRs and r^2 values of *P. heterolepis* were presented in Table 2. Moreover, ANCOVA revealed no statistical difference in LWRs between male and female population ($P < 0.067$). The LLR (TL *vs*. SL) was extremely related ($P < 0.001$), with r^2 values ≥ 0.982 (Table 3 and Figure 3).

Eco-climatic factors

We observed four eco-climatic factors namely temperature (^{o}C), rainfall (mm), DO (mg/l) and pH. The maximum and minimum water temperature was documented 34.4^{o}C in May-June and 19.8^{o}C in January, respectively. The peak rainfall was occurred in August (370 mm) but no precipitation was recorded in January. Further, the highest DO was found in July (6.15 mg/l) and the lowest DO was recorded in December (5.42 mg/l). However, minimum pH was found in May and September (6.76) and the maximum pH was recorded in the month of July (7.32). The allometric co-efficient (*b*) of LWRs was found significantly related with temperature for both sexes. However, rainfall, DO and pH did not show statistical correlation with *b* value between sexes (Table 4). The relationship between growth pattern (*b*) and eco-climatic factors are presented in Figure 4 and 5.

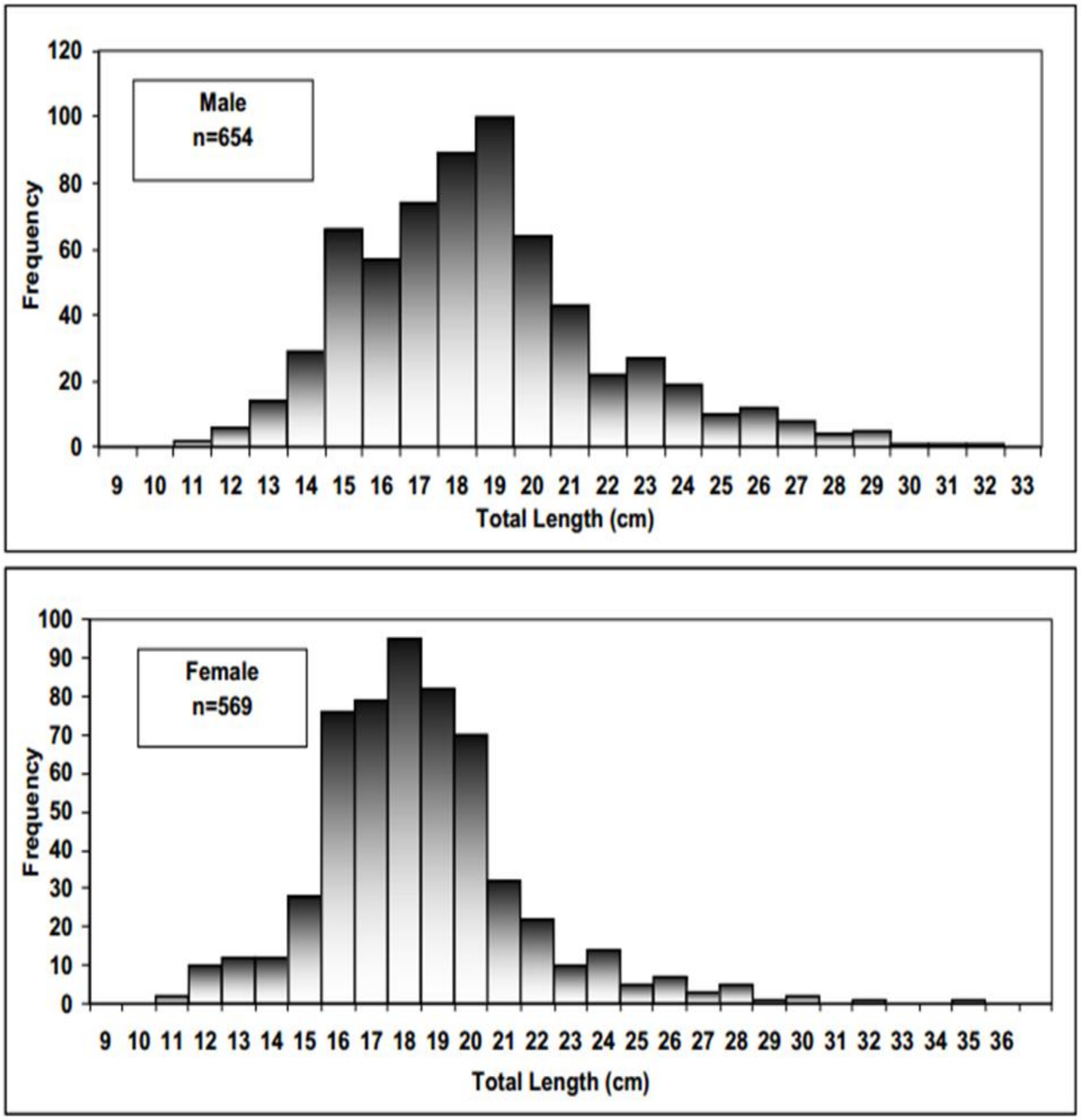

Figure 1. Length-frequency distribution of *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Table 1. Descriptive statistics on the total length (cm) and body weight (g) measurements of *Panna heterolepis* Trewavas, 1977 in the Bay of Bengal, Bangladesh.

Month	Sex		TL (cm)				BW (g)			
			Min	Max	Mean ± SD	95% CL	Min	Max	Mean ± SD	95% CI
January	M	35	14.3	19.5	16.75±1.44	16.26-17.25	20.09	52.34	34.00±8.38	31.12-36.88
	F	72	12.0	25.9	17.46±1.90	17.01-17.91	12.39	134.28	42.50±16.35	38.66-46.34
February	M	37	11.3	29.6	19.23±4.07	17.87-20.59	12.52	182.56	59.81±39.20	46.74-72.88
	F	67	11.0	34.5	18.41±4.55	17.30-19.52	9.02	342.26	59.18±58.50	44.91-73.45
March	M	47	11.9	21.2	16.93±2.30	16.25-17.61	12.60	73.45	38.34±16.30	33.55-43.12
	F	57	11.1	25.7	18.25±3.19	17.41-19.10	11.98	133.35	52.43±27.66	45.10-59.77
April	M	50	10.8	28.7	17.15±4.83	15.78-18.52	10.02	175.60	48.54±42.24	36.54-60.55
	F	34	10.5	27.5	16.27±4.48	14.42-17.83	12.31	170.30	44.21±37.80	31.02-57.40
May	M	76	11.9	25.8	16.68±2.64	16.08-17.29	11.42	134.43	39.10±20.74	34.36-43.84
	F	25	12.7	27.0	17.50±3.00	16.26-18.73	17.40	144.30	47.82±26.08	37.06-58.59
June	M	77	12.5	28.5	20.73±3.30	19.99-21.48	14.20	174.60	69.63±31.30	62.53-76.74
	F	22	11.5	27.0	16.46±3.42	14.95-17.98	15.34	173.19	43.02±33.50	28.16-57.87
July	M	66	10.7	26.0	17.58±3.34	16.76-18.40	11.20	124.74	43.40±25.39	37.16-49.64
	F	37	10.5	29.5	17.73±3.94	16.42-19.05	12.44	187.53	48.21±35.03	36.53-59.90
August	M	63	13.0	31.4	18.53±4.15	17.48-19.58	17.90	203.89	51.32±41.03	40.98-61.65
	F	43	13.6	24.8	17.76±2.54	16.98-18.55	21.37	103.21	41.86±18.08	36.30-47.43
Septemb.	M	60	15.0	30.9	19.74±2.53	19.09-20.39	24.19	165.15	53.47±21.45	47.93-59.01
	F	42	15.0	23.8	18.66±1.94	18.06-19.26	24.54	104.44	47.60±16.31	42.51-52.68
October	M	45	12.5	24.2	16.74±2.48	16.00-17.48	13.89	96.92	35.58±15.22	31.00-40.15
	F	59	13.6	27.2	18.71±2.62	18.03-19.39	18.29	140.58	49.92±23.53	43.78-56.05
November	M	42	13.1	25.2	17.44±2.50	16.66-18.21	18.05	102.65	39.00±16.27	33.93-44.07
	F	63	13.5	26.4	18.30±2.41	17.69-18.91	19.58	120.22	44.27±18.08	39.72-48.43
December	M	56	15.2	25.2	18.37±1.93	17.85-18.89	25.06	117.38	44.96±16.31	40.59-49.33
	F	48	14.7	23.5	17.62±1.95	17.05-18.19	24.44	96.29	41.25±13.87	37.22-45.28

Notes: *n*, sample size; M, male; F, female; TL, total length; W, body weight; min, minimum; max, maximum; SD, standard deviation; CL, confidence limit.

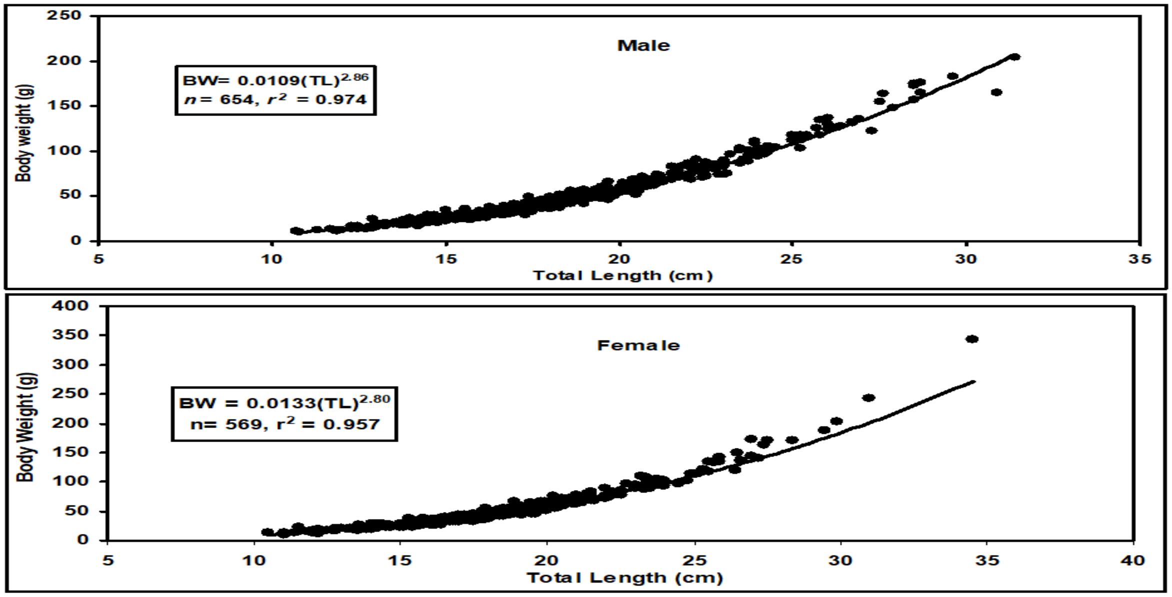

Figure 2. Growth pattern through length-weight relationships (TL *vs.* BW) of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

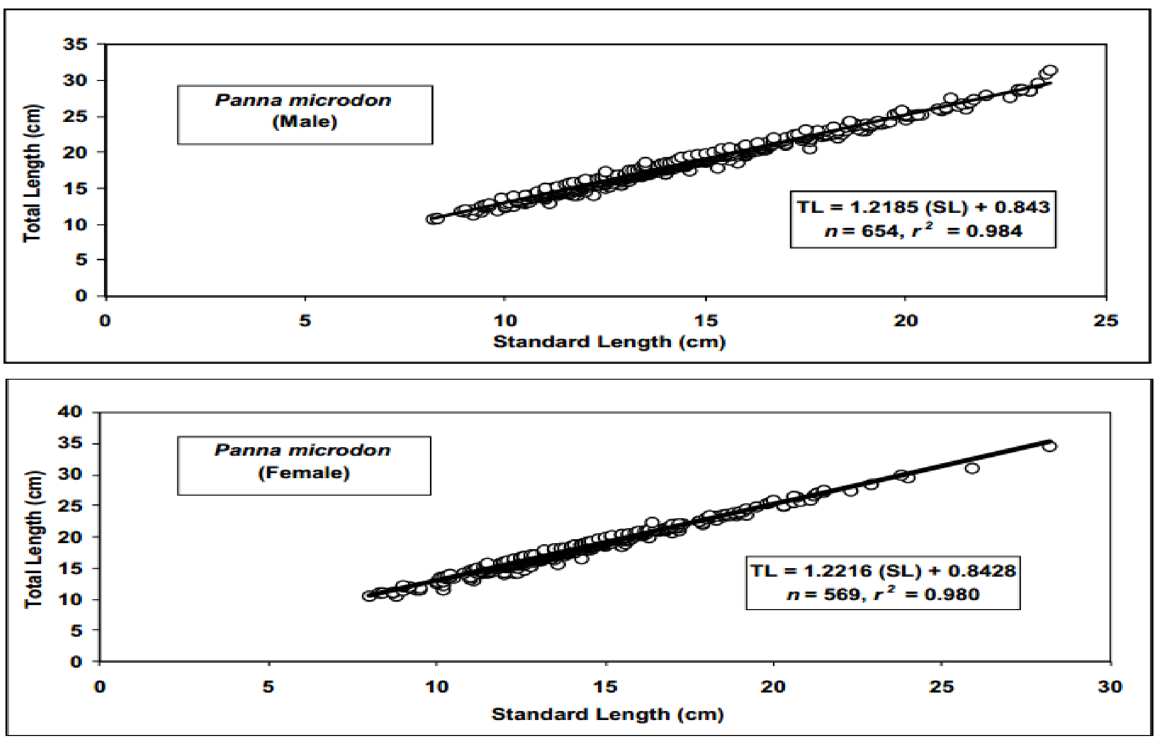

Figure 3. Total length-Standard length (TL vs. SL) relationships of *Panna heterolepis* from the Bay of Bengal, Bangladesh.

Table 2. Descriptive statistics and estimated parameters of the length-weight relationships ($BW = a \times TL^b$) of the *Panna heterolepis* Trewavas, 1977 in the Bay of Bengal, Bangladesh.

Month	**Sex**	***n***	**Regression parameters**		**95% CL of *a***	**95% CL of *b***	**r^2**	**GT**
			a	*b*				
January	M	35	0.0086	2.93	0.0055-0.0135	2.77-3.09	0.977	I
	F	72	0.0056	3.11	0.0040-0.0079	2.99-3.23	0.974	+A
	C	107	0.0052	3.13	0.0037-0.0072	3.01-3.25	0.965	+A
February	M	37	0.0057	3.08	0.0037-0.0088	2.94-3.23	0.982	I
	F	67	0.0069	3.04	0.0045-0.0104	2.90-3.19	0.964	I
	C	104	0.0067	3.04	0.0049-0.0091	2.94-3.15	0.969	I
March	M	47	0.0058	3.09	0.0037-0.0093	2.92-3.25	0.969	I
	F	57	0.0077	3.01	0.0052-0.0113	2.88-3.14	0.974	I
	C	104	0.0063	3.07	0.0047-0.0085	2.97-3.17	0.971	I
April	M	50	0.0107	2.89	0.0081-0.0140	2.79-2.99	0.987	-A
	F	34	0.0173	2.75	0.0104-0.0286	2.56-2.93	0.967	-A
	C	84	0.0134	2.82	0.0102-0.0176	2.72-2.92	0.976	-A
May	M	76	0.0122	2.84	0.0085-0.0174	2.72-2.97	0.964	-A
	F	25	0.0145	2.80	0.0077-0.0273	2.58-3.03	0.967	-A
	C	101	0.0120	2.86	0.0087-0.0164	2.74-2.97	0.962	-A
June	M	77	0.0088	2.94	0.0067-0.0114	2.85-3.03	0.984	-A
	F	22	0.0120	2.88	0.0063-0.0226	2.65-3.11	0.972	-A
	C	99	0.0149	2.77	0.0116-0.0192	2.69-2.86	0.977	-A
July	M	66	0.0110	2.85	0.0083-0.0147	2.75-2.95	0.980	-A
	F	37	0.0169	2.72	0.0114-0.0252	2.58-2.86	0.978	-A
	C	103	0.0132	2.80	0.0104-0.0168	2.71-2.88	0.977	-A
August	M	63	0.0099	2.88	0.0073-0.0135	2.77-2.98	0.980	-A
	F	43	0.0182	2.67	0.0122-0.0271	2.54-2.81	0.974	-A
	C	106	0.0117	2.83	0.0092-0.0148	2.74-2.91	0.978	-A
September	M	60	0.0193	2.65	0.0135-0.0275	2.53-2.76	0.972	-A
	F	42	0.0081	2.95	0.0052-0.0126	2.80-3.10	0.975	-A
	C	102	0.0162	2.71	0.0121-0.0218	2.61-2.81	0.967	-A
October	M	45	0.0129	2.79	0.0088-0.0190	2.65-2.93	0.975	-A
	F	59	0.0106	2.87	0.0075-0.0150	2.75-2.99	0.976	-A
	C	104	0.0108	2.86	0.0086-0.0137	2.78-2.94	0.979	-A
November	M	42	0.0142	2.75	0.0095-0.0212	2.61-2.89	0.975	-A
	F	63	0.0153	2.73	0.0111-0.0212	2.61-2.84	0.975	-A
	C	105	0.0148	2.74	0.0116-0.0189	2.65-2.82	0.976	-A
December	M	56	0.0063	3.03	0.0044-0.0092	2.90-3.16	0.976	I
	F	48	0.0166	2.71	0.0111-0.0248	2.57-2.85	0.971	-A
	C	104	0.0114	2.84	0.0084-0.0153	2.74-2.94	0.962	-A

Note: M, male; F, female; C, combined; *n*, sample size; *a*, intercept; *b*, slope ; CL, confidence limit; GT, growth type; +A, positive allometric growth; -A, negative allometric growth; I, isometric growth.

Table 3. Descriptive statistics and estimated parameters of the TL vs. SL relationships (TL = *a* +*b* × SL) of the *Panna heterolepis* Trewavas, 1977 in the Bay of Bengal, Bangladesh.

Month	**Sex**	***n***	**Regression parameters**		**95% CL of *a***	**95% CL of *b***	***r*²**
			a	*b*			
January	M	35	0.2992	1.2810	-0.5817 to 1.1801	1.2127-1.3494	0.978
	F	72	0.7890	1.2392	0.2057 to 1.3722	1.1961-1.2823	0.979
	C	107	0.7377	1.2442	0.2706 to 1.2048	1.2092-1.2793	0.979
February	M	37	0.2323	1.2432	-0.6037 to 1.0684	1.1896-1.2967	0.984
	F	67	0.7990	1.2036	0.2111 to 1.3869	1.1647-1.2426	0.983
	C	104	0.6366	1.2155	0.1644 to 1.1089	1.1846-1.2463	0.984
March	M	47	0.2651	1.2606	-0.4623 to 0.9926	1.2061-1.3152	0.980
	F	57	0.7521	1.2270	0.2461 to 1.2580	1.1921-1.2619	0.989
	C	104	0.6764	1.2304	0.2899 to 1.0628	1.2028-1.2580	0.987
April	M	50	0.7148	1.2250	0.2766 to 1.1530	1.1936-1.2564	0.992
	F	34	0.2478	1.2578	-0.4602 to 0.9559	1.2042-1.3114	0.986
	C	84	0.5376	1.2370	0.1638 to 0.9115	1.2096-1.2643	0.990
May	M	76	0.0075	1.2697	-0.6295 to 0.6445	1.2218-1.3176	0.974
	F	25	0.3258	1.2442	-0.7272 to 1.3787	1.1690-1.3194	0.981
	C	101	0.1118	1.2612	-0.4155 to 0.6391	1.2221-1.3004	0.976
June	M	77	1.0579	1.1867	0.4414 to 1.6744	1.1500-1.2234	0.982
	F	22	-0.6985	1.3038	-2.1156 to 0.7185	1.1980-1.4095	0.971
	C	99	0.5904	1.2127	0.0761 to 1.1046	1.1808-1.2446	0.983
July	M	66	0.4278	1.2503	-0.0307 to 0.8862	1.2175-1.2831	0.989
	F	37	0.8624	1.2149	0.3511 to 1.3738	1.1790-1.2507	0.993
	C	103	0.6309	1.2341	0.2930 to 0.9688	1.2100-1.2581	0.990
August	M	63	1.1193	1.2059	0.6226 to 1.6161	1.1724-1.2394	0.988
	F	43	0.7673	1.2282	0.1008 to 1.4338	1.1806-1.2759	0.985
	C	106	1.0302	1.2109	0.6503 to 1.4102	1.1847- 1.2372	0.988
September	M	60	0.8640	1.2389	0.1721 to 1.5559	1.1938-1.2839	0.981
	F	42	1.7704	1.1742	1.0624 to 2.4785	1.1253-1.2231	0.983
	C	102	1.1208	1.2210	0.6305 to 1.6110	1.1883-1.2536	0.982
October	M	45	-0.3632	1.3215	-1.0809 to 0.3544	1.2666-1.3764	0.982
	F	59	1.7926	1.1662	1.1408 to 2.4444	1.1218-1.2106	0.980
	C	104	0.9175	1.2249	0.4359 to 1.3991	1.1905-1.2593	0.980
November	M	42	0.2787	1.2558	-0.4490 to 1.0064	1.2031-1.3086	0.983
	F	63	0.4172	1.2572	-0.3255 to 1.1600	1.2054-1.3090	0.975
	C	105	0.2818	1.2624	-0.2424 to 0.8061	1.2253-1.2995	0.978
December	M	56	1.5931	1.1760	0.9367 to 2.2495	1.1303-1.2217	0.980
	F	48	1.5143	1.1818	0.8736 to 2.1550	1.1351-1.2248	0.983
	C	104	1.5571	1.1786	1.1155 to 1.9988	1.1472-1.2099	0.982

Note: M, male; F, female; C, combined; n, sample size; *a*, intercept; *b*, slope ; CL, confidence limit; r^2, co-efficient of determination.

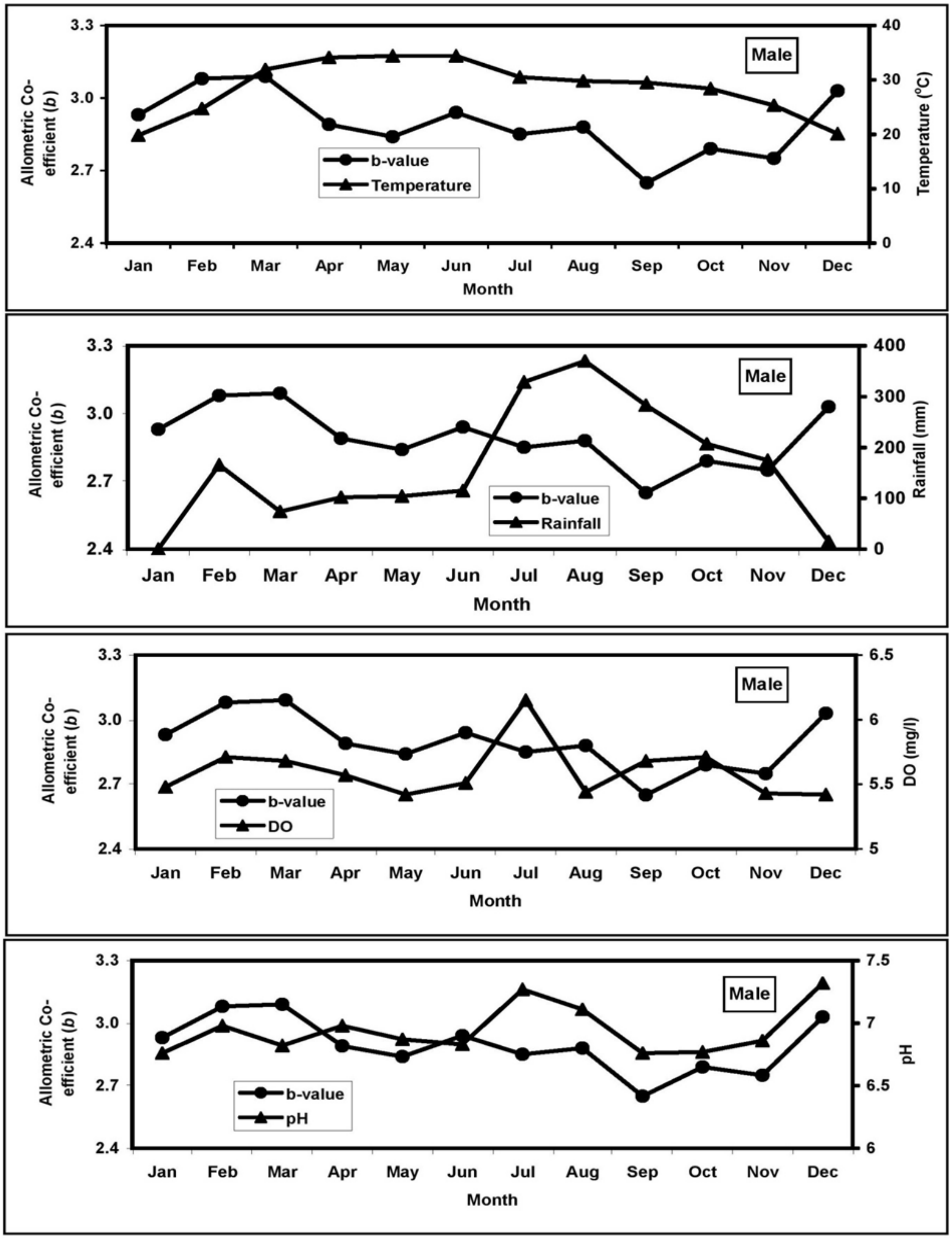

Figure 4. Relationship between allometric co-efficient (*b*) with eco-climatic factors of male *Panna heterolepis* Trewavas, 1977 from the Bay of Bengal, Bangladesh.

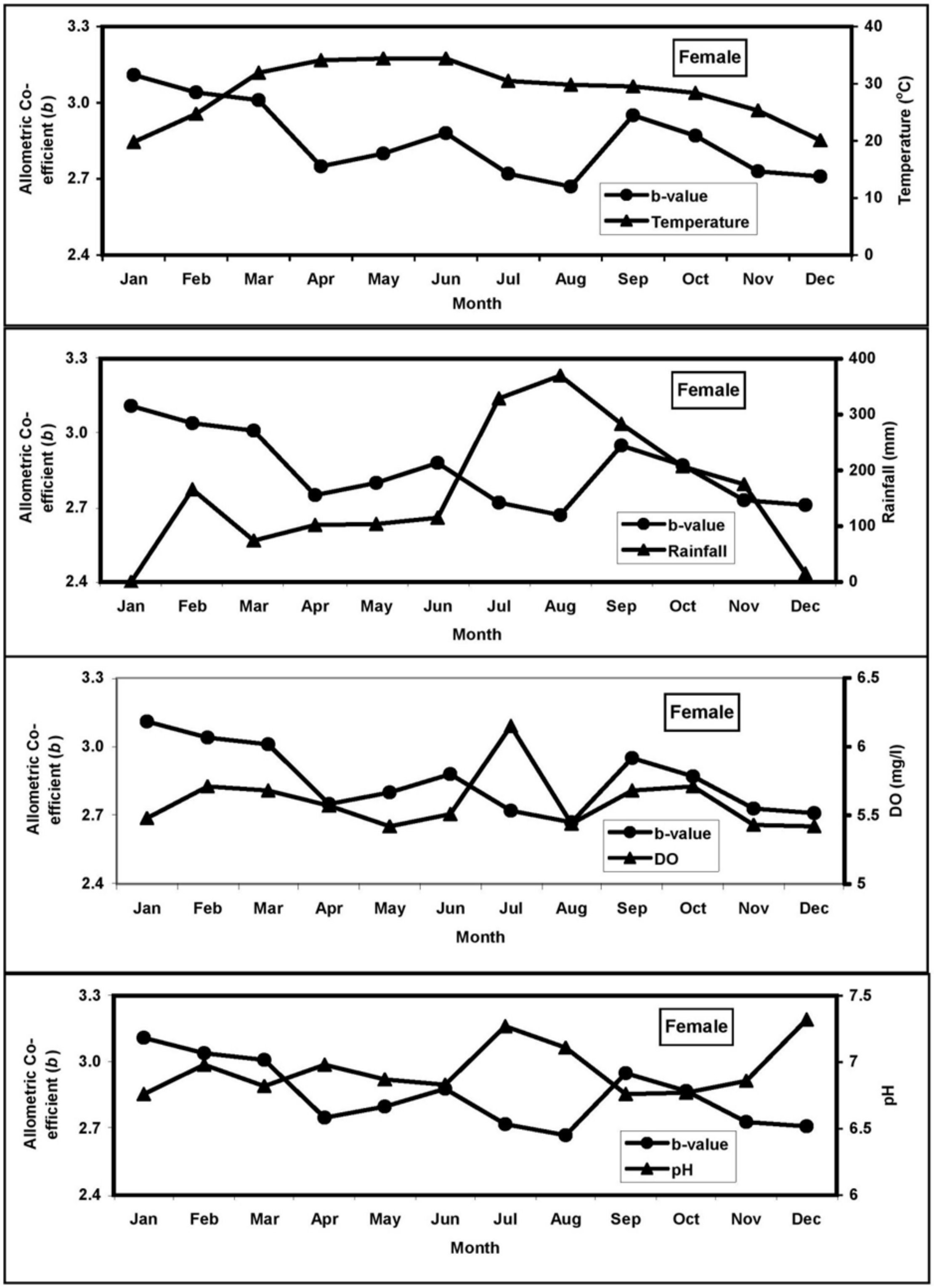

Figure 5. Relationship between allometric co-efficient (*b*) with eco-climatic factors of female *Panna heterolepis* Trewavas, 1977 from the Bay of Bengal, Bangladesh.

Table 4. Relationship between allometric co-efficient (*b*) with eco-climatic factors of *Panna heterolepis* Trewavas, 1977 in the Bay of Bengal, Bangladesh.

Relationships	Sex	r_s values	95% CL of r_s	*P* values	Significance
Temp. *vs. b*	M	-0.5534	-0.8607 to 0.04947	*P* = 0.0335	*
Rain *vs. b*		-0.5874	-0.8732 to -0.0009	*P* = 0.0789	*ns*
DO vs. b		0.03163	-0.5657 to 0.6072	*P* = 0.9251	*ns*
pH *vs. b*		0.2`561	-0.3892 to 0.7328	*P* = 0.4182	*ns*
Temp. *vs. b*	F	-0.6725	-0.9030 to -0.1415	*P* = 0.0189	*
Rain *vs. b*		-0.3916	-0.7965 to 0.2535	*P* = 0.2097	*ns*
DO *vs. b*		0.3550	-0.2928 to 0.7795	*P* = 0.2558	*ns*
pH *vs. b*		-0.7404	-0.9252 to -0.2715	*P* = 0.6273	*ns*

Note: M, male; F, female; Temp, temperature (^{o}C); Rain; rainfall (mm); DO, dissolved oxygen (mg/l); r_s, Spearman rank correlation values; CL, confidence limit; *P*, level of significance; *significant; *ns*, not significant.

DISCUSSION

Information on LFDs and growth pattern of *P. heterolepis* are inadequate in literature. Although a study has been done with a title of morphometry and length-weight relationship in the Hoogly River of Inida by **Sanphui *et al.* (2018)** but did not show any values of regression parameters (*a* and *b*). Further, **Sabbir *et al.* (2020b)** studied the length-weight relationships and form factor of *P. heterolepis* with occasional data from the Bay of Bengal. Consequently, the present study is the first effort to describe LFDs and growth pattern of *P. heterolepis* from the Bay of Bengal, Bangladesh in relation to eco-climatic factors with a year round data. In our study, all together 1223 specimens of different body sizes were sampled using local gears for successive twelve months. However, absence of individuals smaller than 10.5 cm TL may be attributed to the selectivity of fishing gear or fishers did not go where smaller size of fishes exist **(Hossain *et al*., 2016; Islam *et al.*, 2020)**. The maximum TL was found 34.5 cm in favor of female. Our study revealed a length of 28.2 cm in SL specifically higher than the report (24.5 cm) of **Sabbir *et al.* (2020b)**. Therefore, this study was recorded the maximum length (34.5 cm in TL) for *P. heterolepis* in female population. However, information about maximum length is important to assess the asymptotic length as well as growth co-efficient of fishes for formulating appropriate fisheries management policy **(Ahmed *et al*., 2012; Khatun *et al*., 2018; 2019)**. **Carlander (1969)** stated that *b* values may range between 2.0 to 4.0 for fishes. On the other hand, **Froese (2006)** reported that the *b* values of LWRs should range from 2.5 to 3.5. In our study, *b* values were found between 2.5 to 3.5 (*b* = 2.65 to 3.09 for males and *b* = 2.67 to 3.11 for females), which is comparable with the range for teleost fishes **(Froese, 2006; Hossain *et al*., 2013b; 2015)**. Further, overall *b* value for both male and female showed negative allometric growth. **Sabbir *et al.* (2020b)** also reported that the overall *b* value for combined sex was negative allometric (*b* = 2.81) for *P. heterolepis* in the Bay of Bengal. However, *b* values may differ in the same species because of consolidation of various factors i.e. sex, development of gonad, growth variations in different body parts, physiological condition, food availability and preservation methods **(Le Cren, 1951; Tesch, 1968; Hossain *et al*., 2015)**, which were excluded during the present study. Moreover, the LLR was extremely correlated, but it was difficult to make any comparisons due to lack of available information on *P. heterolepis*.

Further, the allometric co-efficient (*b*) was found significantly related with temperature for both male and female. For male population, the *b* value showed isometric growth pattern from December to March when the temperature is comparatively lower. Thereafter, *b* value drops with the increase of temperature but recover steadily from the month of November. For female population, *b* value was found positive allometric in the month of January and Isometric in February and March. Further, *b* value dropped with increasing temperature. However, rainfall, DO and pH did not show statistically significant correlation with growth pattern between sexes. DO is a vital ecological factor for aerobic metabolism of fish **(Timmons *et al*., 2001)**. The minimum DO level must be above 3.5 mg/l for marine fish stocks for their survival **(EPA, 2000)**. Likewise, pH is considered as an essential factor for any aquatic habitat. If an aquatic ecosystem is more acidic (pH < 4.5) or more alkaline (pH > 9.5) for extended time, growth and reproduction will be reduced **(Ndubuisi *et al*., 2015)**. In the present study, monthly DO level fluctuated from 5.42 to 6.15 mg/l and pH varied from 6.76 to 7.32 indicating a suitable habitat for *P. heterolepis* in the Bay of Bengal, Bangladesh **(Sabbir *et al*., 2020a)**.

CONCLUSION

Our study described the length-frequency distribution, growth pattern in relation to eco-climatic factors of *P. heterolepis* from the Bay of Bengal, Bangladesh. Growth pattern was significantly correlated with temperature for both sexes. Also, this study recorded the maximum size of *P. heterolepis* from the Bay of Bengal. These findings might be a potential tool for fishery biologist to initiate stock assessment of the standing stock of *P. heterolepis* in the marine waters of Bangladesh. Moreover, the results will contribute valuable baseline for further studies within the marine and coastal ecosystems.

ACKNOWLEDGEMENTS

This work was supported by (i) the National Science and Technology (NST), Government of Bangladesh for a research grant and (ii) PIU-BARC, NATP-2, PBRG-156 for technical supports.

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Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 24(2): 591 – 608 (2020)
www.ejabf.journals.ekb.eg

First Report on Condition Factor of *Panna heterolepis* (Trewavas, 1977) in the Bay of Bengal (Southwestern Bangladesh) in Relation to Eco-Climatic Factors

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ARTICLE INFO

Article History:
Received: April 17, 2020
Accepted: April 30, 2020
Online: May, 2020

Keywords:
Panna heterolepis;
condition factor;
eco-climatic factors;
Bay of Bengal.

ABSTRACT

The current study describes the first report on condition factors (Fulton's, K_F; allometric, K_A; relative, K_R and relative weight, W_R) of *Panna heterolepis* in relation to eco-climatic factors (temperature, rainfall, dissolved oxygen and pH) in the Bay of Bengal, SW Bangladesh. All together 1224 specimens (male = 654, female = 570) were caught through January to December 2019. Bodyweight (BW), as well as total length (TL), was assessed by digital balance and measuring board with 0.01 g and 0.01 cm accuracy. TL was varied between 10.70-31.40 cm for males and 10.50-34.50 cm for females. Further, BW was ranged from 10.02-203.89 g for males and 9.02- 342.26 g for the female population. The K_F values ranged from 0.56 to 1.12 for males and 0.60 to 1.45 for females. On the other hand, K_A varied between 0.0047 to 0.0212 for males and 0.0050 to 0.0267 for females. Besides, K_R varied between 0.79 to 1.39 for males and 0.73 to 1.55 for females. However, W_R ranged from 78.55 to 139.24 for males and 73.24 to 154.47 for females. Fulton's condition factor (K_F)was found the best for evaluating the well-being of this species in the Bay of Bengal. Further, K_F was found significantly related to temperature for both males (P = 0.04) and females (P = 0.04) but not with other factors. The mean W_R indicated that the habitat was in a balanced condition considering prey-predator status. The outcomes of the study will be helpful for future management of this fish in the Bay of Bengal considering the emerging climate change.

INTRODUCTION

If we accept that the fishery is an important branch for food production worldwide, it is urgent to discover fish biology as well as their health condition. Condition factor is the index which is used to understand survival, maturity, health status and reproduction of fish **(Le Cren, 1951; Hossain, 2010; Ahmed *et al*., 2012)**. Further, it indicates the quality of a water body and overall fitness of a population dwelling in a specific ecosystem **(Tsoumani *et al*., 2006)**. The condition of fish could be influenced by sex, water quality parameters, stress, availability of feeds and season **(Khallaf *et al*., 2003; Hossain *et al*., 2006; Rahman *et al*., 2012)**. Consequently, the knowledge of condition factor is vital for evaluating the life cycle of a particular fish population for proper management and to upkeep the stability of the ecosystem **(Hossain *et al*., 2013a)**. In addition, relative weight (W_R) is the most popular index to assess the status of fish in a particular habitat considering prey-predator status **(Froese, 2006; Rypel and Richter, 2008; Hossain *et al*., 2013b)**.

Likewise, climate change is considered as an important hazard to fisheries along with other different risk such as overfishing, pollution and habitat deterioration **(Rose, 2005)**. Climatic factors mainly temperature and rainfall has constant effect on fish growth and survival **(Shoji *et al*., 2011)**. Temperature is the most significant climatic factor regulating the progresses of larval accumulations of freshwater as well as marine species **(Houde and Zastrow, 1993; Jakobsen *et al*., 2009)**. Similarly, rainfall is a basic climatic factor influencing the entire chain of hydrological events through runoff and river inflow **(Patrick, 2016)**. To ensure comprehensive fish health, it is urgent to maintain an optimum DO (dissolved oxygen) level for physiological and metabolic activities. The DO requirement increases with increasing fish size during grow out period **(Abdel-Tawwab *et al*., 2015)**. Alternatively, pH indicates whether the habitat is acidic or alkaline condition. Higher level of pH (9-14) not only affects fish by denaturing cell membranes but also alter other water quality parameters **(Brown and Sadler, 1989)**. A number of studies on eco-climatic effect on distributional changes in worldwide marine fish stocks have been well documented **(Beare *et al*., 2004; Alheit *et al*., 2005; Perry *et al*., 2005)**. However, in the Bay of Bengal, to our knowledge, such studies are absent.

The Hooghly Croaker, *Panna heterolepis* (Trewavas, 1977) belonging to the family Sciaenidae is a tropical demersal fish inhabit estuaries and marine-water **(Talwar and Jhingran, 1991)**. This Sciaenid fish is distributed in Bangladesh, Myanmar, India and Sri Lanka **(Sasaki, 1995)**. This species is locally known as *Poa* and commercially very important as a table food item in Bangladesh. Due to lack of culture practice, the overall demand of this species is met through the capture from wild stock. As a result, overfishing is the foremost threat for the abundance of wild stock **(Hossain *et al*., 2012a; Hossen *et al*., 2019)**.

According to the author's knowledge, only a few works including the morphology **(Sasaki, 1995)** and morphometry as well as length-weight relationship **(Sanphui *et al*., 2018)** have been done on *P. heterolepis*. Consequently, the objective of this study is to illustrate the condition factors (Fulton's, K_F; allometric, K_A and relative, K_R) and relative weight (W_R) considering the eco-climatic factors of *P. heterolepis* for successive twelve months from the Bay of Bengal, (SW) Bangladesh.

MATERIALS AND METHODS

Study site and sampling. The study was done in Bay of Bengal (in Khulna region, SW Bangladesh). Altogether, 1224 individuals (male = 654, female = 570) of *P. heterolepis* were collected randomly from fisher's catch during January to December, 2019. The collected samples were immediately preserved with ice and then fixed with 10% formalin solution to prevent decomposition of fish.

Fish measurement. Male and female individuals were identified by microscopic observation of gonads. The overall sex ratio (male: female = 1.00:0.87) varied statistically from the predictable ratio of 1:1 (df =1, $\chi 2$ = 5.91, $p > 0.05$). Body weight (BW) as well as total length (TL) was assessed by digital balance and measuring board with 0.01 g and 0.01 cm accuracy.

Calculation of condition factors. Fulton's condition factor (K_F) was determined using the equation: $K_F = 100\times(W/L^3)$ **(Fulton, 1904)**, where W stands for BW in g and L is the TL in cm. The scaling factor 100 was used to bring the K_F close to unit. The allometric condition factor (K_A) was estimated by the equation: $K_A = W/L^b$ **(Tesch, 1968)**, where W is the BW in g, L represents the TL in cm and b is the LWRs parameter. Further, relative condition factor (K_R) was assessed with the equation: $K_R = W/(a\times L^b)$ **(Le Cren, 1951)**, where W is the BW in g, L is the TL in cm and a and b are LWRs parameters. The relative weight (W_R) was calculated by the equation: $W_R = (W/Ws)\times 100$ **(Froese, 2006)**, where W is the BW of a specific individual and W_S is the anticipated standard weight for the identical individual as calculated by $W_S = a\times L^b$, where a and b values were acquired from the relationships between TL and BW.

Eco-climatic parameters. To evaluate the relationship between the most suitable condition factor of *P. heterolepis* with habitat status, monthly ecological parameters were also recorded from the sampling site following **APHA (2005)** procedures. The collected parameters were temperature (^{o}C), pH and dissolved oxygen (DO; mg/L). Further, the data of monthly rainfall (mm) was collected from meteorological station of Khulna, Bangladesh.

Statistical Analyses. For statistical analyses GraphPad Prism 6.5 Software was used. Homogeneity as well as normality of data was checked and confirmed with the Kolmogorov-Smirnov test and Shapiro-Wilk normality test. Where test for normality assumption was not met, the nonparametric Mann-Whitney U test was applied to compare the condition factors between sexes. The Wilcoxon signed rank test was conducted to compare the average relative weight (W_R) and 100 **(Anderson and Neumann, 1996)**. The Spearman's rank test was used to correlate body measurements (TL and BW) with condition factors (K_F, K_A, K_R and W_R) as well as to relate the best condition factor with different eco-climatic factors. Additionally, a chi-square test was executed to observe the sex ratio departure from the predictable value of 1:1 (male:

female). Furthermore, data analyses were done through Microsoft® Excel-add-in-Solver. All statistical analyses were conducted with 5% significance level.

RESULTS

Total 1224 specimens (male = 654, female = 570) were caught through January to December 2019, where TL was varied between 10.70-31.40 cm for males and 10.50-34.50 cm for females and BW was ranged from 10.02-203.89 g for males and 9.02-342.26 g for females. The overall sex ratio (male: female = 1.00:0.87) varied statistically from the predictable ratio of 1:1 (*df* =1, $\chi 2$ = 5.91, p > 0.05).

Table 1. Descriptive statistics on Fulton's condition factor (K_F) measurements and their 95% confidence limits of the *Panna heterolepis* in the Bay of Bengal, SW Bangladesh.

Month	**Sex**	***n***	**Fulton′s condition factor (K_F)**			
			Min	**Max**	**Mean±SD**	**95% CL**
January	M	35	0.656	0.757	0.709±0.028	0.700-0.719
	F	72	0.691	0.855	0.768±0.043	0.758-0.778
February	M	37	0.580	0.868	0.736±0.067	0.713-0.758
	F	67	0.594	1.040	0.777±0.104	0.752-0.803
March	M	47	0.599	0.858	0.745±0.057	0.728-0.761
	F	57	0.656	0.993	0.789±0.070	0.771-0.808
April	M	50	0.610	1.125	0.789±0.077	0.767-0.811
	F	34	0.678	1.451	0.870±0.147	0.819-0.922
May	M	76	0.658	1.045	0.789±0.070	0.773-0.805
	F	25	0.723	1.046	0.835±0.077	0.803-0.867
June	M	77	0.633	0.946	0.731±0.048	0.720-0.742
	F	22	0.723	1.046	0.857±0.085	0.819-0.894
July	M	66	0.620	0.957	0.729±0.061	0.714-0.744
	F	37	0.642	1.075	0.772±0.089	0.743-0.802
August	M	63	0.565	0.905	0.702±0.062	0.687-0.718
	F	43	0.644	0.880	0.716±0.056	0.698-0.733
September	M	60	0.560	0.769	0.673±0.046	0.661-0.685
	F	42	0.628	0.775	0.710±0.034	0.699-0.720
October	M	45	0.636	0.822	0.722±0.053	0.706-0.738
	F	59	0.639	0.854	0.723±0.046	0.711-0.735
November	M	42	0.632	0.825	0.703±0.052	0.687-0.719
	F	63	0.616	0.812	0.694±0.047	0.682-0.706
December	M	56	0.634	0.779	0.700±0.034	0.691-0.709
	F	48	0.659	0.824	0.734±0.044	0.721-0.747

Note: M, Male; F, Female; *n*, Sample size; Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, Confidence limit of mean.

Fulton's condition factor (K_F). The lowest and highest K_F values for male were 0.56 and 1.12 in September and April, respectively. Besides, lowest and highest K_F values for females were 0.60 and 1.45 in February and April, respectively (Table 1; Figure 1). K_F revealed significant variations between sexes ($P < 0.0001$) during the study. According to Spearman rank test, Fulton's condition factor (K_F) and TL were significantly correlated in both sexes indicating that K_F was the best allowing for the well-being of *P. heterolepis* in the Bay of Bengal (Table 2).

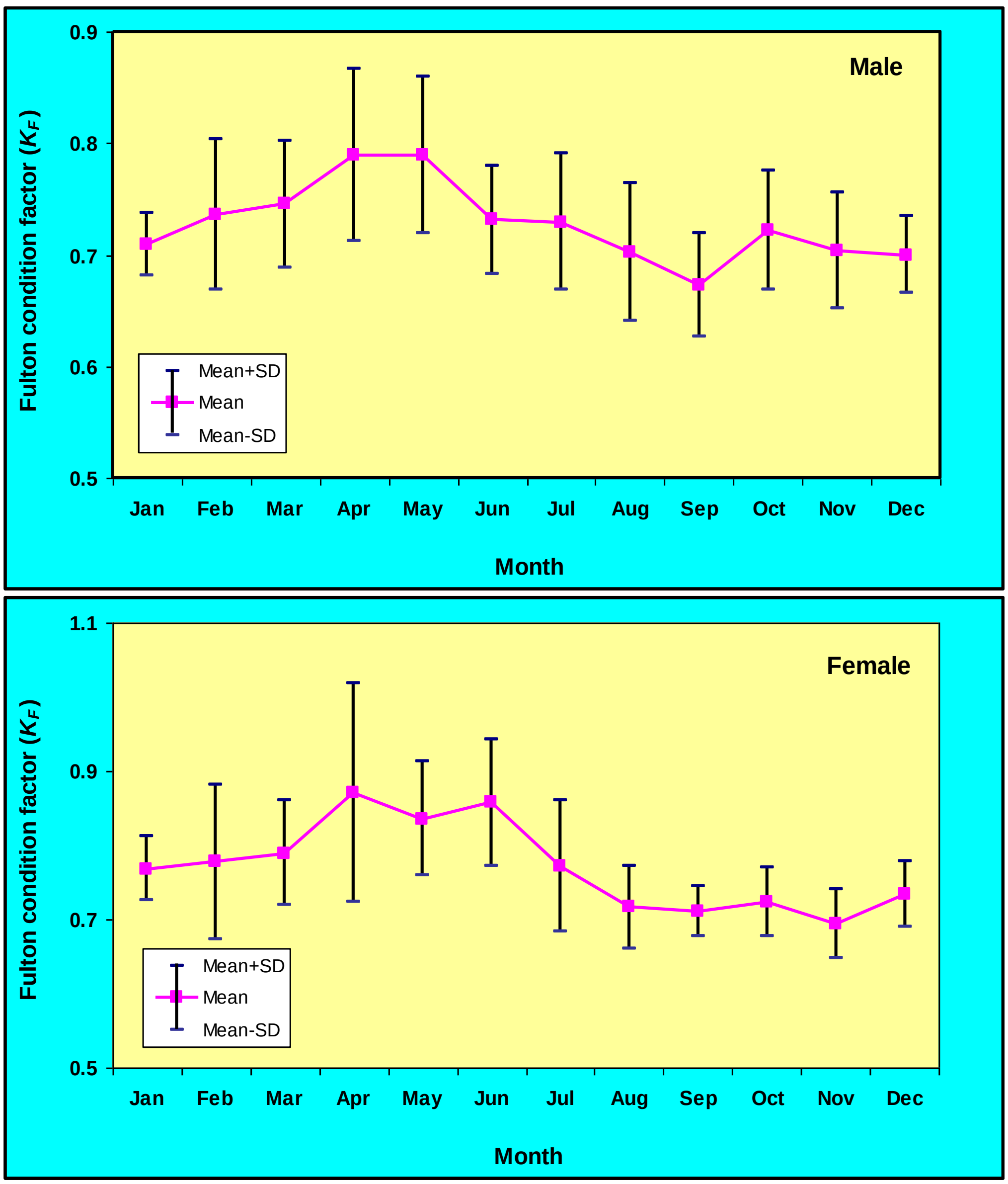

Figure 1. Monthly variations of Fulton's condition factor of *Panna heterolepis* in the Bay of Bengal, SW Bangladesh.

Table 2. Relationships of condition factor with total length and body weight of *Panna heterolepis* in the Bay of Bengal, (SW) Bangladesh.

Relationships	Sex	r_s values	95% CL of r_s	*P* values	Significance
TL *vs.* K_F	M	-0.2500	-0.3226 to -0.1746	< 0.001	*
TL *vs.* K_A		0.0324	-0.0466 to 0.1111	0.2038	*ns*
TL *vs.* K_R		0.0324	-0.0467 to 0.1111	0.2041	*ns*
TL *vs.* W_R		0.0324	0.0467 to 0.1111	0.2041	*ns*
BW *vs.* K_F		-0.1001	-0.1777 to -0.0214	0.0104	*
BW *vs.* K_A		0.1827	0.1053 to 0.2579	< 0.0001	***
BW *vs.* K_R		0.1827	0.1053 to 0.2579	< 0.0001	***
BW *vs.* W_R		0.1827	0.1053 to 0.2579	< 0.0001	***
TL *vs.* K_F	F	-0.2466	-0.3245 to -0.1654	< 0.0001	***
TL *vs.* K_A		0.0401	-0.0447 to 0.1243	0.3396	*ns*
TL *vs.* K_R		0.0401	-0.0447 to 0.1243	0.3393	*ns*
TL *vs.* W_R		0.0402	-0.0446 to 0.1244	0.3391	*ns*
BW *vs.* K_F		-0.0566	-0.1406 to 0.0282	0.1776	*ns*
BW *vs.* K_A		0.2280	0.1462 to 0.3067	< 0.0001	***
BW *vs.* K_R		0.2280	0.1462 to 0.3067	< 0.0001	***
BW *vs.* W_R		0.2280	0.1462 to 0.3068	< 0.0001	***

Note: M, Male; F, Female; *ns*, not significant; * significant; ***highly significant

Allometric condition factor (K_A). This study indicated the minimum and maximum allometric condition factor (K_A) were 0.0047 in February and 0.0212 in September for males. On the other hand, the lowest and highest K_A values for female population were 0.0050 in January and 0.0267 in April (Figure 2). Further, K_A revealed significant variations between sexes ($P < 0.0001$) during the study.

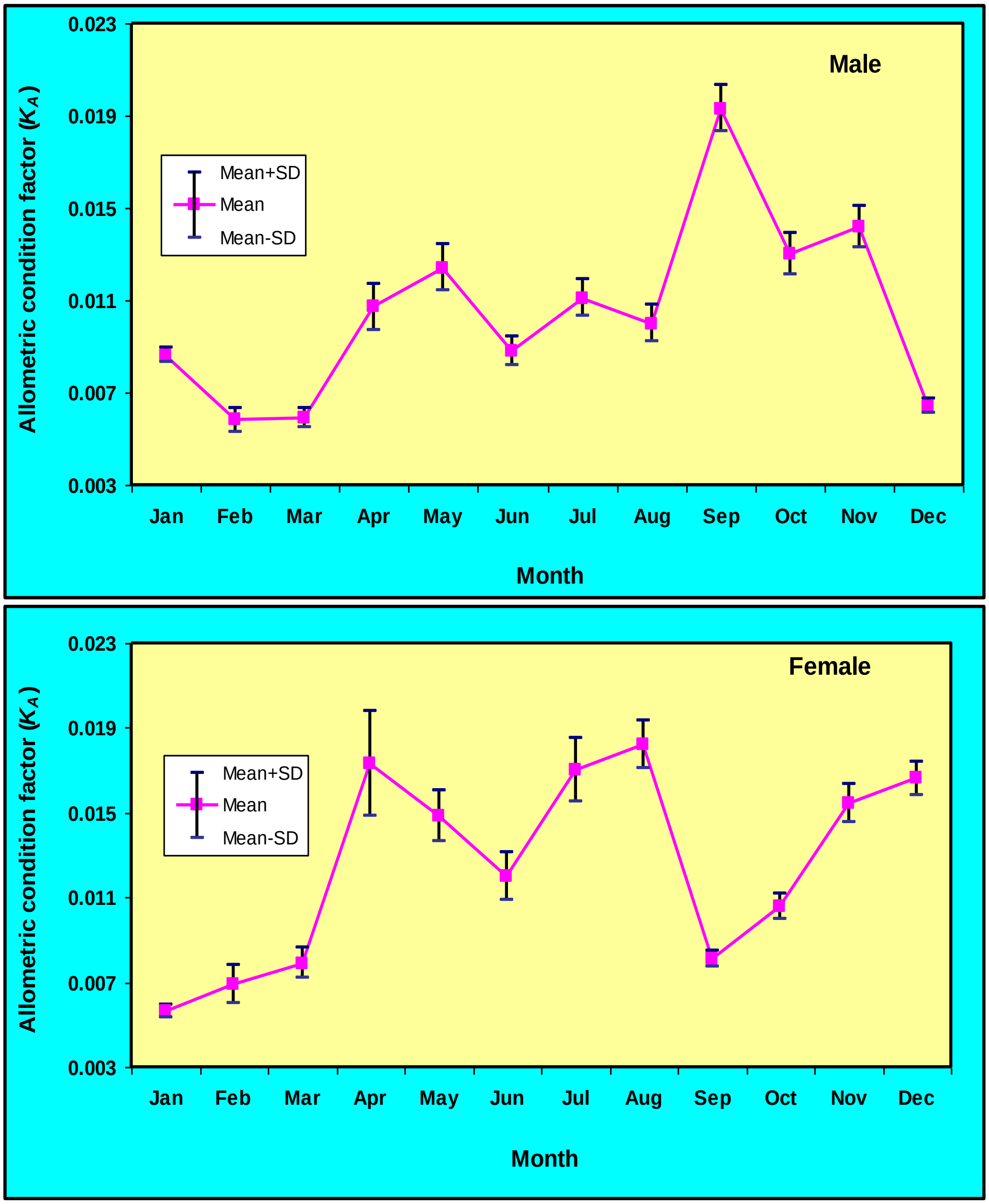

Figure 2. Monthly variations of allometric condition factor of *Panna heterolepis* in the Bay of Bengal, SW Bangladesh.

Relative condition factor (K_R). The study revealed the lowest and highest relative condition factor (K_R) was 0.79 and 1.39 for males. On the other hand, the lowest and highest K_R values for female population were 0.73 and 1.55. Minimum and maximum values for both males and females were recorded in April (Figure 3). However, K_R revealed no significant variations between sexes (P = 0.1641) during the study.

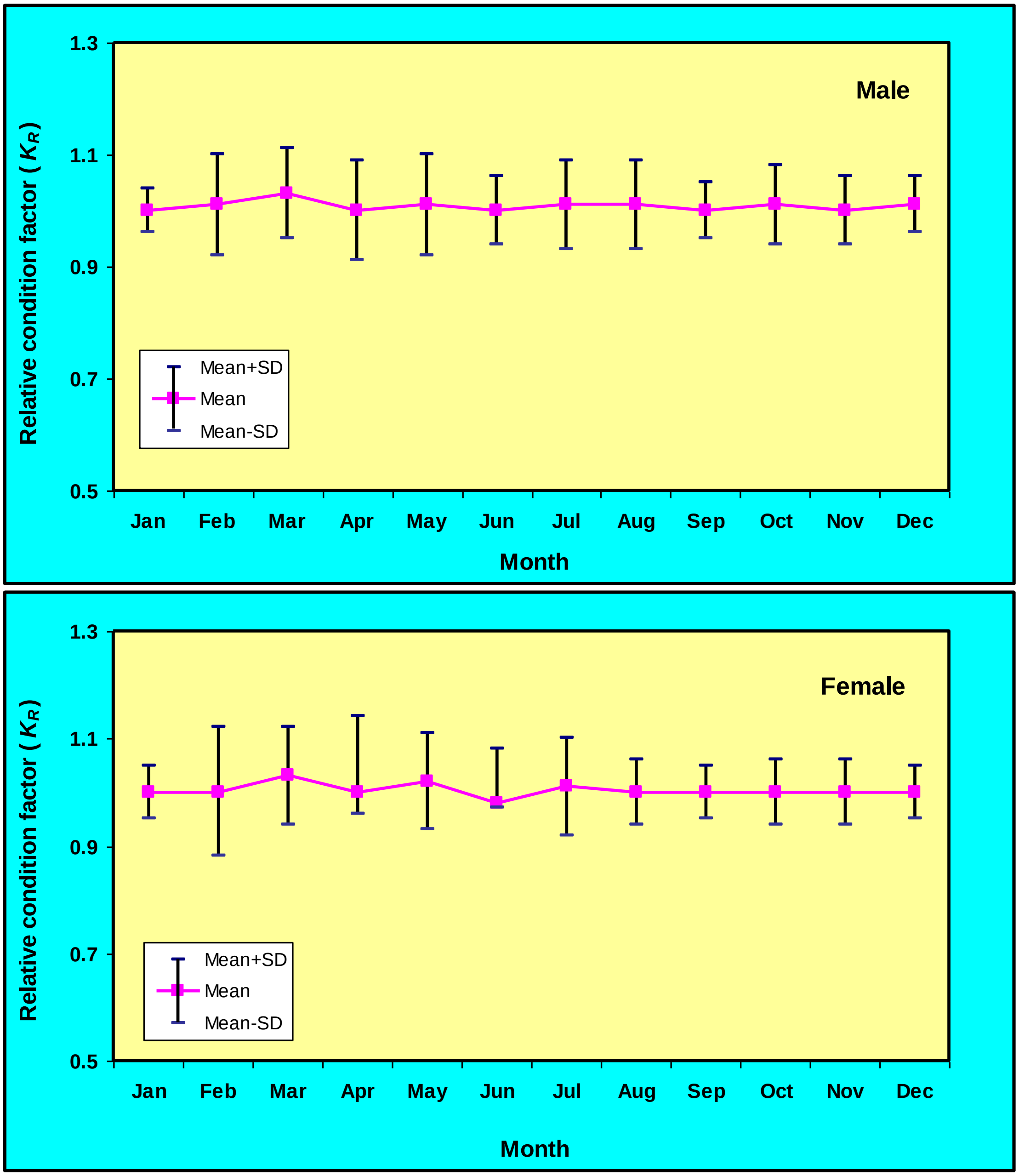

Figure 3. Monthly variations of relative condition factor of *Panna heterolepis* in the Bay of Bengal, SW Bangladesh.

Relative weight (W_R). The lowest and highest W_R values for male were 78.55 and 139.24, respectively. Besides, minimum and maximum W_R values for females were 73.24 and 154.47, respectively. Further, minimum and maximum values for both males and females were recorded in April (Table 3, Figure 4). According to Wilcoxon sign rank test, W_R showed no significant difference from 100 for both males (P = 0.33) and females (P = 0.48).

Table 3. Descriptive statistics on relative Weight (W_R) measurements and their 95% confidence limits of the *Panna heterolepis* in the Bay of Bengal, SW Bangladesh.

Month	Sex	*n*	Relative Weight (W_R)			
			Min	Max	Mean±SD	95% CL
January	M	35	92.25	107.20	100.28±8.36	98.95-101.61
	F	72	90.14	111.69	100.04±5.44	98.76-101.32
February	M	37	81.71	124.48	101.15±9.16	98.10-104.21
	F	67	76.24	134.77	100.17±13.46	96.88-103.45
March	M	47	82.85	119.75	102.75±7.73	100.19-104.75
	F	57	85.17	128.98	102.53±9.12	100.11-104.95
April	M	50	78.55	139.24	100.40±9.22	97.78-103.02
	F	34	73.24	154.47	99.92±14.20	94.96-104.88
May	M	76	81.97	132.11	101.29±8.47	99.35-103.23
	F	25	86.77	124.50	101.74±8.62	98.18-105.29
June	M	77	86.17	127.56	99.54±6.42	98.08-100.99
	F	22	83.99	120.95	99.66±9.49	95.45-103.87
July	M	66	85.30	130.25	100.67±7.71	98.77-102.57
	F	37	81.93	122.05	100.58±8.89	97.61-103.54
August	M	63	80.47	126.54	100.64±8.38	98.52-102.75
	F	43	89.37	115.52	99.99±6.08	98.11-101.86
September	M	60	89.85	109.84	100.06±5.36	98.68-101.45
	F	42	88.98	110.87	100.42±4.80	98.92-101.91
October	M	45	88.70	113.82	100.60±6.63	98.61-102.59
	F	59	87.41	116.42	100.11±5.96	98.56-101.67
November	M	42	90.16	111.35	100.28±6.24	98.34-102.23
	F	63	88.54	111.70	100.38±5.61	98.96-101.79
December	M	56	91.27	112.57	100.88±4.85	99.59-102.18
	F	48	90.00	110.12	100.10±5.07	98.62-101.57

Note: M, Male; F, Female; *n*, Sample size; Min, Minimum; Max, Maximum; SD, Standard Deviation; CL, Confidence limit of mean.

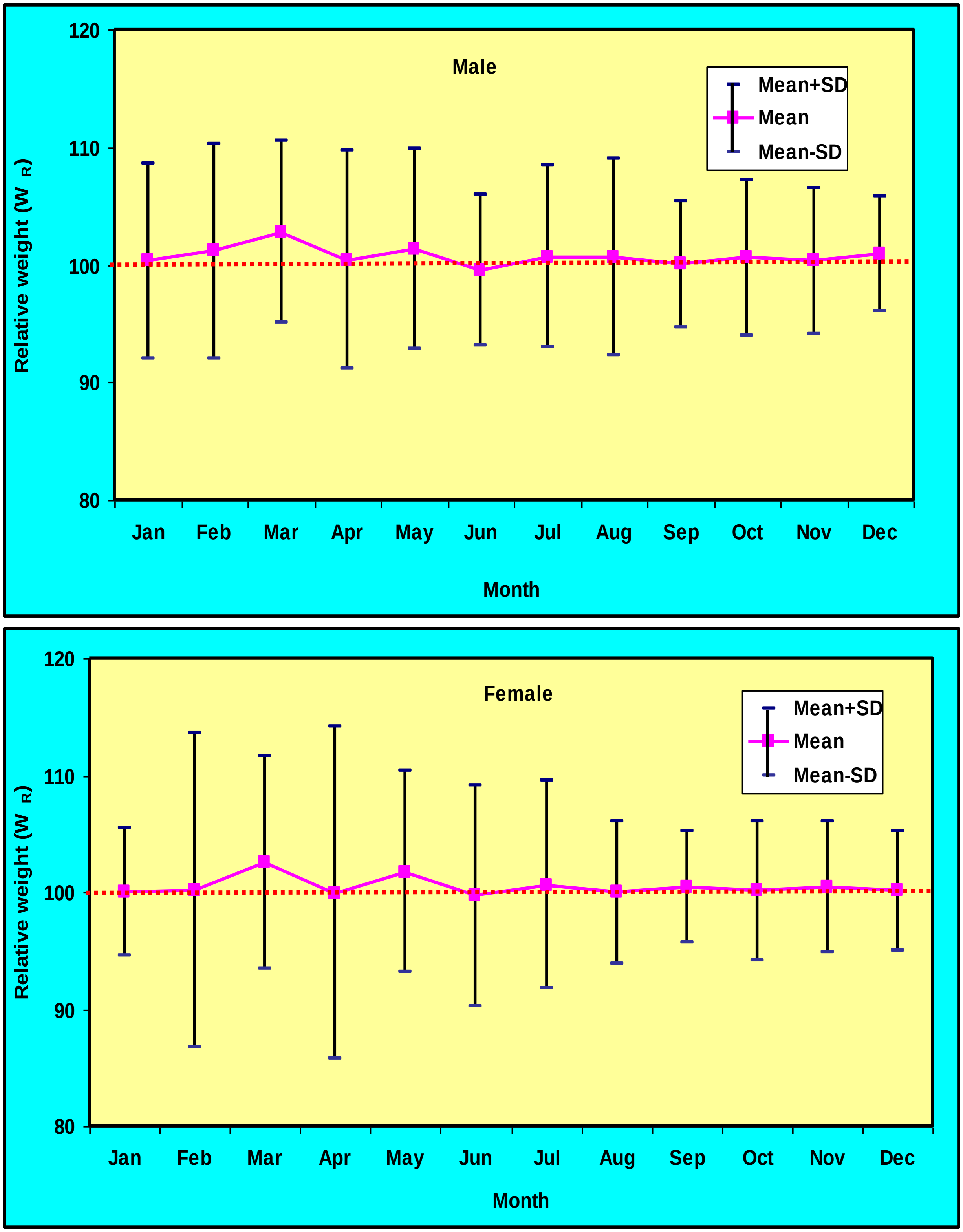

Figure 4. Monthly variations of relative weight of *Panna heterolepis* in the Bay of Bengal, SW Bangladesh.

Eco-climatic parameters. In our study, four eco-climatic parameters were recorded namely temperature, rainfall, DO and pH. The Fulton's condition factor (K_F) was found statistically related with temperature for both male (P = 0.04) and female (P = 0.04). However, Rainfall, DO and pH did not reveal any significant correlation with K_F (Table 4). The relationship between K_F and eco-climatic factors are presented in Figure 5 and 6.

Table 4. Relationship between eco-climatic factors with Fulton's condition factor of *Panna heterolepis* in the Bay of Bengal, SW Bangladesh.

Relationships	Sex	r_s values	95% CL of r_s	*P* values	Significance
Temp. *vs.* K_F	M	0.6123	0.0397 to 0.8821	0.0378	*
Rain *vs.* K_F		-0.3117	-0.7596 to 0.3367	0.3154	*ns*
DO vs. K_F		0.1813	-0.4538 to 0.6943	0.5679	*ns*
pH vs. K_F		0.0685	-0.5400 to 0.6300	0.8310	*ns*
Temp. *vs.* K_F	F	0.6200	0.0521 to 0.8849	0.0352	*
Rain *vs.* K_F		-0.4685	-0.8278 to 0.1631	0.1275	*ns*
DO *vs.* K_F		0.0984	-0.5183 to 0.6478	0.7606	*ns*
pH *vs.* K_F		0.1474	-0.4811 to 0.6758	0.6459	*ns*

Note: M, male; F, female; Temp, temperature (^oC); Rain; rainfall (mm); DO, dissolved oxygen (mg/l), r_s, Spearman rank correlation values; CL, confidence limit; P, level of significance; *ns*, not significant; *significant.

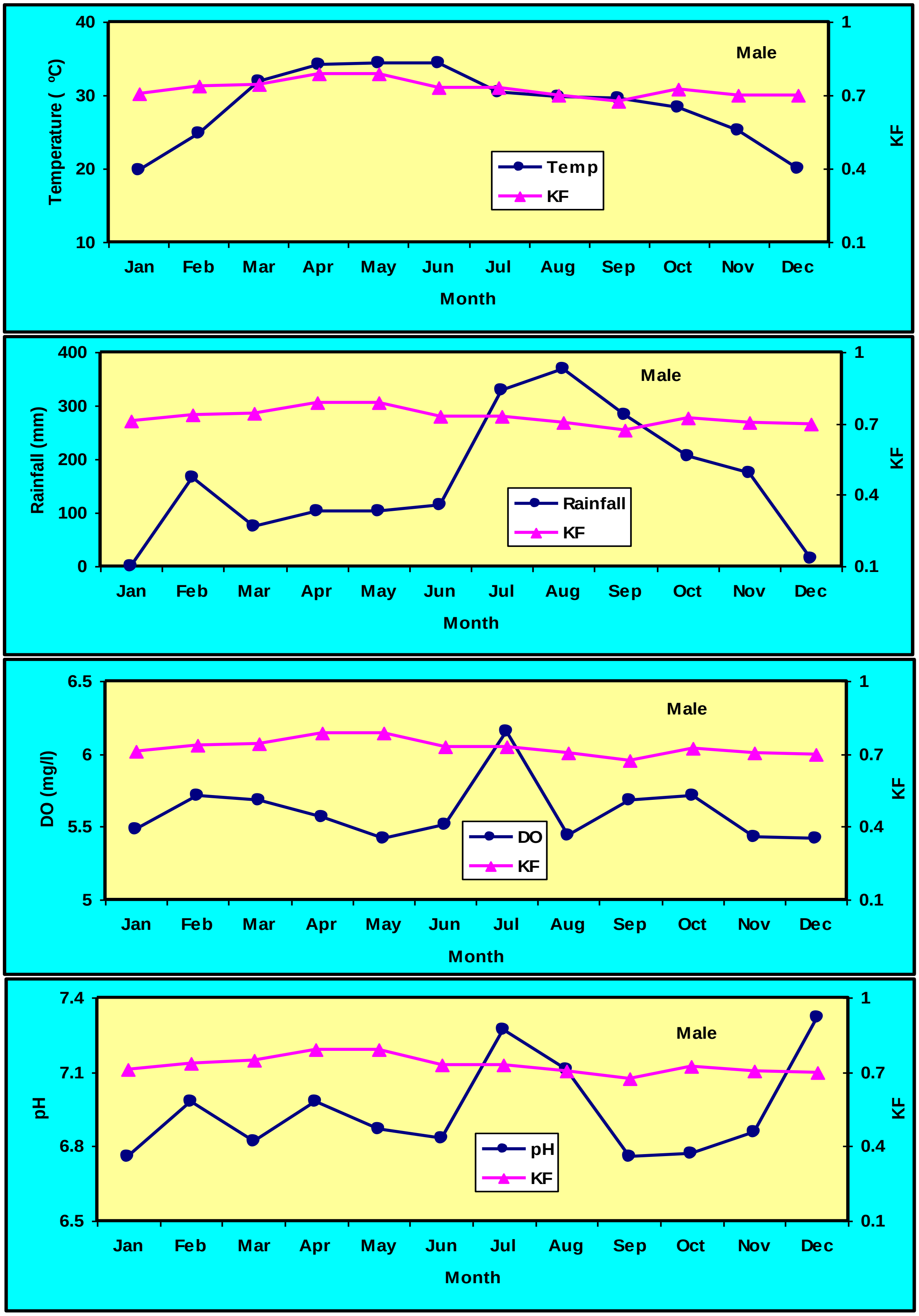

Figure 5. Relationship between Fulton's condition factor with eco-climatic factors of male *Panna heterolepis* in the Bay of Bengal, SW Bangladesh.

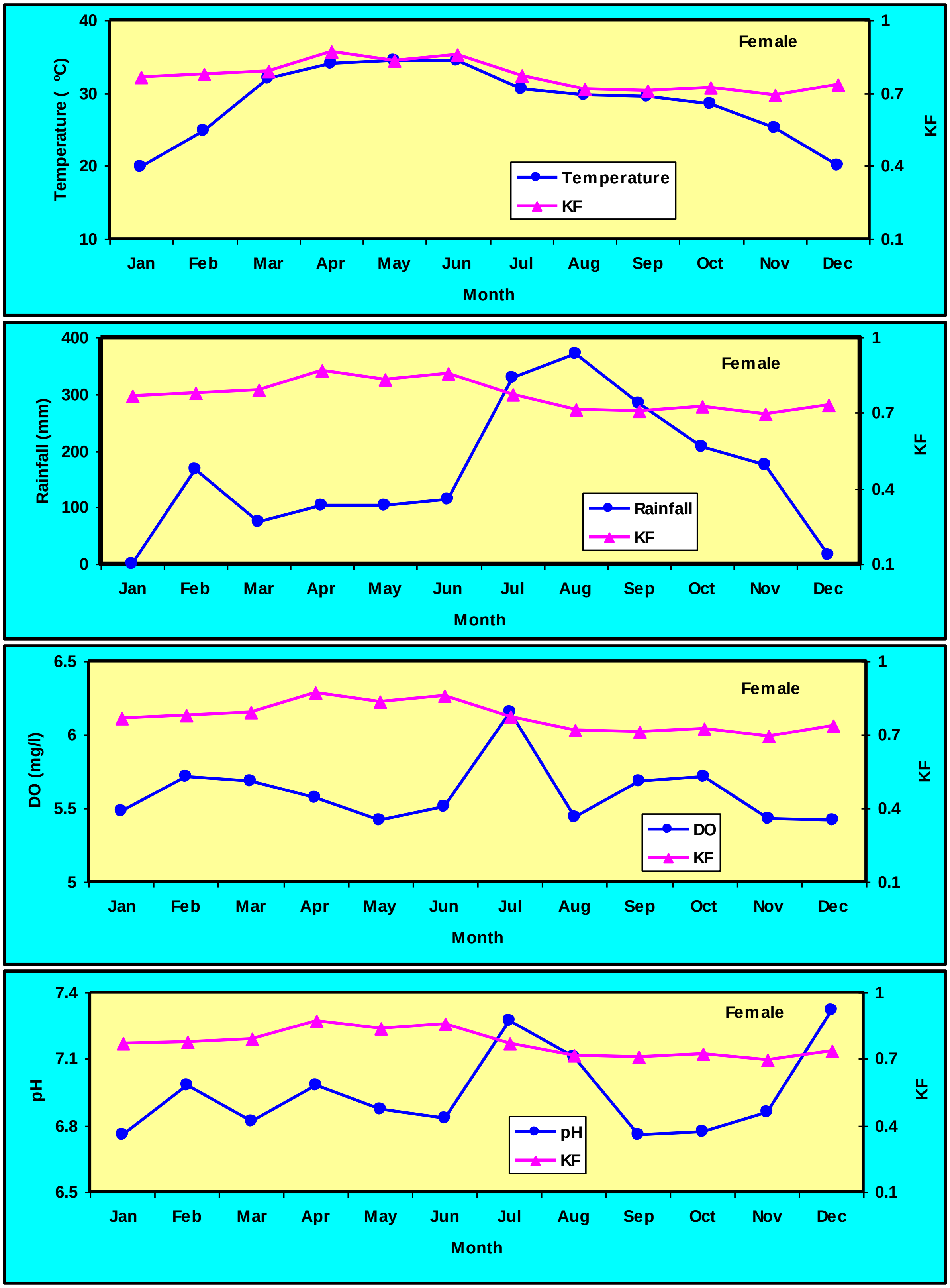

Figure 6. Relationship between Fulton's condition factor with eco-climatic factors of female *Panna heterolepis* in the Bay of Bengal, SW Bangladesh.

DISCUSSION

Information on condition factor of *P. heterolepis* is inadequate in literature elsewhere. Consequently, the present study is the first effort to describe condition factor as well as relative weight of *P. heterolepis* from the Bay of Bengal (SW) Bangladesh in relation to eco-climatic factors. In our study, altogether 1224 specimens of different body sizes were sampled using local gears for successive twelve months. To assess the overall health and proficiency of *P. heterolepis* a number of condition factors i.e. Fulton's (K_F), allometric (K_A), relative (K_R) as well as relative weight (W_R) were used in the present study. Multiple condition factors were used to determine the best suited condition factor assessing the health as well as habitat condition of *P. haterolepis* in the Bay of Bengal, SW Bangladesh.

Condition factor indicates the status of well-being of a fish population in their natural ecosystem **(Hossain *et al*., 2012b)**. Besides, it reveals several bio-ecological interactions i.e. level of fitness, maturity status and impassableness of a habitat with respect to feeding behavior **(Hossen *et al*., 2019)**. Moreover, the condition value is a widespread biological index for fish which specifies the overall health of a stock **(Richter, 2007)**. The higher value of condition factor indicates that the fish are in better condition **(Hossain *et al*., 2017; Maurya *et al*., 2018)**. According to Spearman rank test, Fulton's condition factor (K_F) and TL were significantly correlated for both sexes denoting that K_F was the best allowing for the well-being of *P. heterolepis* in the Bay of Bengal. During the study, the Fulton's condition factor was higher in the month of March to June with some fluctuations. But maximum favorable condition was estimated during the month of April for both male and female.

Relative weight (W_R) of an aquatic ecosystem influences the recruitment pattern of a fisheries community **(Shulman and Ogden, 1987)**. The W_R declining below 100 for a population indicates lower prey or high predator density; whereas values above 100 indicate a prey surplus or lower predator **(Froese, 2006)**. In our study, the mean W_R revealed no significant difference from 100 for both sexes of *P. heterolepis* indicating the habitat was in balanced condition. We found no reference about the condition factor and relative weight of *P. heterolepis* elsewhere. Therefore, it is difficult to compare the finding with other studies.

Further, the Fulton's condition factor (K_F) was found significantly related with temperature for both male and female. Fish is a poikilothermic animal. Consequently, habitat temperature controls the fish body temperature, food consumption, growth rate and various body functions **(Houlihan *et al*., 1993; Azevedo *et al*., 1998)**. Throughout the study, the maximum water temperature was recorded in June-July (34.4^{o}C) and the minimum was in January (19.8^{o}C). The K_F value showed a positive correlation with temperature. However, rainfall, DO and pH did not reveal any significant correlation with K_F between sexes. The highest rainfall was observed in August and no precipitation was occurred in the month of January. DO is considered the most vital parameter due to its necessity for aerobic metabolism **(Timmons *et al*., 2001)**. The level of DO should be above 3.5 mg/l for coastal fisheries resources **(EPA, 2000)**. Similarly, pH is also considered crucial for any aquatic ecosystem. If the pH value of any aquatic ecosystem is more acidic (pH < 4.5) or more alkaline (pH > 9.5) for long time, growth and reproduction will be diminished **(Ndubuisi *et al*., 2015)**. In our study, the monthly DO level ranged from 5.42 to 6.15 mg/l and pH ranged from 6.76 to 7.32 indicating a suitable habitat for marine fisheries resources in the Bay of Bengal, (SW) Bangladesh.

CONCLUSION

In fine, K_F was found the best for assessing the wellbeing of the above-mentioned species. Further, K_F value showed a positive correlation with temperature for both sexes. The findings of our study might be a potential tool for future management of the standing stock of *P. heterolepis* in the marine and coastal waters of Bangladesh.

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Environmental Science and Pollution Research (2021) 28:23152–23159
https://doi.org/10.1007/s11356-020-12310-w

RESEARCH ARTICLE

First report on reproductive features of the Hooghly croaker *Panna heterolepis* Trewavas, 1977 from the Bay of Bengal in relation to environmental factors

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Received: 10 June 2020 / Accepted: 29 December 2020 / Published online: 13 January 2021

Abstract
This study highlights the reproductive biology of Hooghly Croaker, *Panna heterolepis* Trewavas, 1977 which is one of the dominant fish in the Bay of Bengal (Bangladesh) based on monthly sampling of 569 female individuals from January to December 2019. We observed the effect of different environmental factors (temperature, rainfall, dissolved oxygen, and pH) on the reproduction of *P. heterolepis*. Measurements of each individual like total length (TL) and body weight (BW) were taken by using of measuring board and digital balance. Gonads were carefully removed through ventral dissection from females and weighed to 0.01 g accuracy. To assess the size at sexual maturity (L_m), spawning season, and its peak, the GSI (gonadosomatic index in %), MGSI (modified gonadosomatic index in %), and DI (Dobriyal index) were considered. Based on these indices, the L_m was documented 15.0 cm in TL. Moreover, L_{50} was predicted by logistic calculation as 15.0 cm TL. Furthermore, greater values of GSI, MGSI, and DI values denoted the spawning season as of January to July, with a peak in February. Additionally, Fulton's condition factor (K_F) was significantly correlated with GSI values. In addition, GSI was statistically correlated with temperature. However, other environmental factors (rainfall, dissolved oxygen, and pH) did not show any significant relation with GSI. Finally, the outcomes of our study might be useful to carry out specific management programs for *P. heterolepis* in the Bay of Bengal and nearby aquatic ecosystem.

Keywords Hooghly croaker · Size at sexual maturity · Environmental factors · Spawning season · *Panna heterolepis* · Bay of Bengal

Introduction

The Hooghly croaker, *Panna heterolepis* Trewavas 1977 is abundant in Bangladesh, India, Myanmar, and Sri Lanka (Sasaki 1995). This sciaenid species is a representative of the family Sciaenidae inhabiting coastal and marine waters (Talwar and Jhingran 1991). *Panna heterolepis* coexist in the Indian Ocean with *P. microdon* and *P. perarmatus* (Froese and Pauly 2020). This species is locally called Poa and commercially significant as a popular food fish for the coastal people of Bangladesh and India. Consequently, overfishing is considered the major threat to the wild population of *P. heterolepis* in Bangladesh (Hossen et al. 2019; Sabbir et al. 2020a). Besides, this species is a profitable source of large-scale and subsistence fishers who use several of traditional gears like gill net (Hossain et al. 2012a). Further, this species is considered least concern worldwide (IUCN 2020).

The government of Bangladesh usually enforces a yearly fishing ban for a period of 65 days from 20 May to 23 July to promote the spawning of depleted fish and crustacean stocks in the Bay of Bengal since 2019 (DoF 2019). However, the peak spawning seasons for the marine fish and crustacean stocks are not yet known. But the coastal fishermen protest against the banning period, as marine fishing is the only

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source of their livelihood; their peak fishing season extends from June to September in the Bay of Bengal. Without supplementary income options, this imposed ban period would drive them into more destitute condition.

To formulate a sound fisheries management policy, knowledge of reproduction is an important concern. Information about fish reproductive biology is essential for understanding of population dynamics and formulating baseline data in the management process (King 2007). Effective management for conserving commercially important fish species depends on understanding the regenerative capacity of populations including their reproductive behavior (Tracey et al. 2007) whose spawning aggregations are extremely harmed by commercial fishers (Hardie et al. 2007). Besides, evaluation of reproductive behavior suggests that dynamic causes may influence survival and recruitment of different fish species (Khatun et al. 2019). Fish population replenishment is dependent on fruitful reproduction (Hossain et al. 2017), and stock assessment models largely depend on reproductive understanding of fish stocks for sustainable management (Nitschke et al. 2001; Tracey et al. 2007). Consequently, knowledge of GSI, size at first maturation, and spawning season are considered useful methods in fish reproductive research (Hossain et al. 2013).

At present, changes in environmental factors are vital threats to fisheries resources together with risks like contamination and overfishing (Rose 2005). Moreover, assessment of environmental and biological onsets of fish reproduction is of foremost importance to recognize population environment relationships and denote vulnerability of a fish population to climate change (Khatun et al. 2019). Environmental issues like temperature and rainfall affect fish growth and reproduction (Pankhurst and Porter 2003; Shoji et al. 2011). Thermal fluctuations represent a vital arena for understanding the reproductive success of fish populations in any ecosystem by directly affecting gametogenesis and spawning timing (Pankhurst and Munday 2011). Besides, temperature is the basic abiotic factor controlling the movements of larval assemblages (Houde and Zastrow 1993) of freshwater and marine species (Jakobsen et al. 2009). Rainfall is another important factor affecting river inflow and runoff (Patrick 2016). Rainfall supports fish spawning by decreasing the water temperature and enhancing dissolved oxygen (Ahamed et al. 2018). Further, the reproductive biology of fish in a particular aquatic habitat is greatly influenced by various ecological factors like pH, salinity, dissolved oxygen, and photoperiod. On the other hand, pH specifies the acidic or alkaline condition of a particular ecosystem. Higher pH (9–14) affects fish physiology by denaturing cell membranes as well as changing different parameters of an aquatic ecosystem (Brown and Sadler 1989).

Nevertheless, only a few studies of the morphology (Sasaki 1995), morphometry (Sanphui et al. 2018), length-weight relationships (Sabbir et al. 2020b), and condition factor (Sabbir et al. 2020a) have been completed on *P. heterolepis*. Consequently, our objective is to discover the reproductive biology (size at first sexual maturity along with spawning and peak-spawning season) of *P. heterolepis* relative to environmental changes from the Bay of Bengal, Bangladesh.

Materials and methods

Sampling site and sampling

The study was performed in the Bay of Bengal, Khulna region, Bangladesh (21.67° N; 89.55° E). Monthly specimens of *P. heterolepis* were collected from commercial fishers' catch from January to December 2019 through multiple traditional fishing gears like gill net (mesh size: 3.0 cm) and seine bag nets (mesh size: 4.0 cm). The collected specimens were immediately preserved with 10% formalin solution to avoid decomposition.

Fish measurement

Male and female individuals were identified by gonadal observation under a microscope but only females were studied. Further, each female was washed with water and kept open to air for drying before weighing. Individual body weight (BW) for each sample was weighed with 0.01 g accuracy by electric balance, and a measuring board assessed total length (TL) with 0.01 cm precision. Then, gonads were carefully removed through ventral dissection of females and weighed (GW) to 0.01 g accuracy. Furthermore, gonads were examined microscopically to distinguish their maturity status.

Size at first sexual maturity (TL_m)

TL_m was determined with three indices (i) gonadosomatic index (GSI) vs. TL; (ii) modified gonadosomatic index (MGSI) vs. TL; and (iii) Dobriyal index (DI) vs. TL. The gonadosomatic index was measured using the equation: GSI (%) = (GW/BW) × 100 (Nikolsky 1963). Modified gonadosomatic index was determined by the equation: MGSI (%) = (GW/BW − GW) × 100 (Nikolsky 1963). Additionally, Dobriyal index was calculated by the equation: $DI = \sqrt[3]{GW}$ (Dobriyal et al. 1999). Individuals having GSI ≥ the critical GSI value (GSI at the smallest size of sexual maturity) were recognized as mature for *P. heterolepis* (Fontoura et al. 2009; Hossain et al. 2012b; Rahman et al. 2018).

Moreover, TL_{50} denoted the minimum length break wherein 50% of the individual specimens were mature. To estimate TL_{50}, a logistic curve following King (2007) was applied by plotting the percentage of mature individuals (PMI) against TL class as $PMI = 100/[1+ \exp.\{-f\,(TL_m - TL_{50})\}]$, where f is the growth coefficient and TL_m is the midpoint of each TL class. However, not all mature individuals in a population spawn simultaneously. Consequently, PMI never exceeded

100% even in the largest TL class. Therefore, following the established method of King (2007), the data were adjusted to overcome an unreasonably high estimate of TL_{50}.

Spawning period

To determine the spawning period monthly gonadal changes of females were observed. Consequently, spawning and peak spawning periods were estimated using three indices: GSI, MGSI, and DI.

Condition factor

Fulton's condition factor (K_F) helped assess the relationship between GSI and K_F. Fulton's condition factor (K_F) was estimated by: $K_F = 100 \times (W/L^3)$ (Fulton 1904), where W was the BW in g and L was TL in cm.

Environmental parameters

Monthly water quality parameters were collected from the sampling site through APHA (2005) procedures to assess the impact of environmental parameters on GSI of female *P. heterolepis*. The parameters were water temperature (°C), dissolved oxygen (DO; mg/L), and pH. A fixed sampling hour was maintained strictly (between 9.00 and 10.00 am) throughout the sampling months to confirm the comparability of the collected parameters with time and space. Furthermore, monthly rainfall (mm) data was documented from the meteorological station of Khulna, Bangladesh.

Statistical analyses

Statistical analyses were done by GraphPad Prism 6.5 and Microsoft ® Excel-add-in-DDXL software with 5% significance level. Normality of the data was confirmed by Kolmogorov-Smirnov test. Besides, Spearman rank correlation was performed to assess the relationship between GSI and K_F. The impact of environmental factors on GSI and spawning season was performed by Spearman rank correlation and canonical correspondence analysis (CCA).

Results

A total of 569 female specimens were collected from January to December 2019, with TL ranging from 10.50 to 34.50 cm, BW 9.02 to 342.26 g, and GW 0.03 to 20.63 g (Table 1).

Table 1 Descriptive statistics on the total length (cm), body weight (g), and gonad weight (g) measurements of *Panna heterolepis* Trewavas, 1977 in the Bay of Bengal (Bangladesh)

Characters	*n*	Min	Max	Mean ± SD	95% CL
Total length (cm)	569	10.5	34.5	17.91 ± 3.11	17.65–18.17
Standard length (cm)		8.0	28.2	13.97 ± 2.52	13.76–14.18
Body weight (g)		9.02	342.26	47.25 ± 29.91	44.79–49.72
Gonad weight (g)		0.03	20.63	2.29 ± 2.79	2.06–2.52

n, sample size; *Min*, minimum; *Max*, maximum; *SD*, standard deviation; *CL*, confidence limit

Size at first sexual maturity (TL_m)

The relationship between TL vs. GSI, MGSI, and DI of female *P. heterolepis* is specified in Fig. 1. GSI, MGSI, and DI values were lower (< 5.4%, < 5.6%, and < 1.0, respectively) for females smaller than 15.0 cm TL. Furthermore, GSI, MGSI, and DI rose rapidly at 15.0 cm TL. Consequently, TL_m may be considered 15.0 cm for female *P. heterolepis*. Furthermore, the relationship between TL and the percentage of mature individuals was expressed by the logistic calculation of mature *P. heterolepis* females for each length class (TL) group (Fig. 2). The smallest mature female was 10.5 cm. Hence, the projected size at sexual maturity (TL_{50}) was 15.0 cm TL in the Bay of Bengal, Bangladesh.

Spawning season

Monthly variations of GSI, MGSI, and DI for female *P. heterolepis* are shown in Fig. 3. The lowest values of GSI, MGSI, and DI were recorded from August to December. In contrast, the highest GSI, MGSI, and DI values were recorded from January to July to denote the spawning season. In addition, peak values of GSI, MGSI, and DI were found in February, the peak spawning season for *P. heterolepis* in the Bay of Bengal, Bangladesh.

Condition factors

Monthly deviations of Fulton's condition factor (K_F) and GSI values were measured. The lowermost and uppermost K_F values for females were recorded in February (0.60) to April (1.45), respectively, with an average 0.76 ± 0.09. Based Spearman rank test, K_F and TL were significantly correlated for female *P. heterolepis* ($r_s = -0.2466$; $P < 0.0001$). Furthermore, K_F was significantly correlated with GSI (r_s = 0.6022; $P = 0.0383$) (Fig. 4).

Environmental factors

In our study, four environmental factors, i.e., temperature, rainfall, DO, and pH, were examined for potential impact on gonadal maturation of *P. heterolepis*. However, only temperature was significantly related to GSI (Table 2; Figs. 5 and 6).

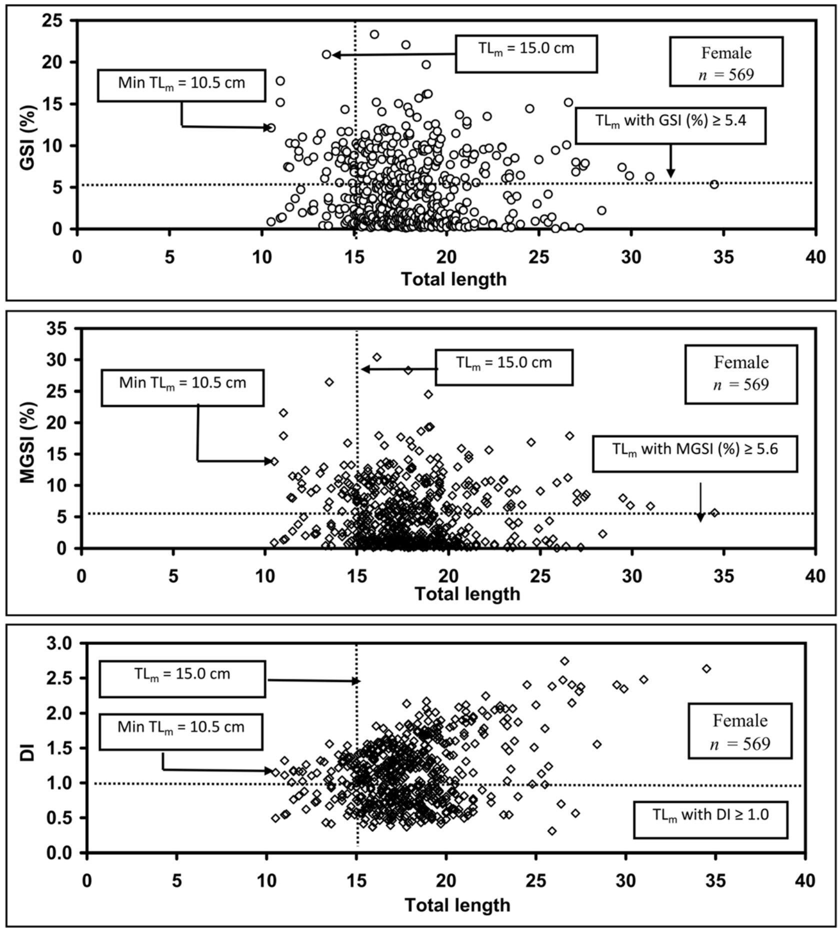

Fig. 1 Relationship between gonadosomatic index (GSI), modified gonadosomatic index (MGSI), and Dobriyal index (DI) with total length of female *Panna heterolepis* in the Bay of Bengal

Discussion

Appropriate management of exploited stocks is dependent on a careful assessment of fish maturity (Rahman et al. 2018). Where histological observation facilities are scarce, macroscopic and biological indices are normally used as rather easy and cost-effective techniques for describing fish ripeness

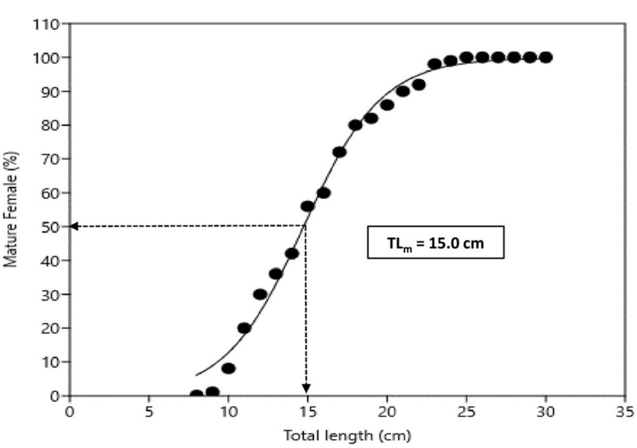

Fig. 2 Adjusted percentage of mature females of *Panna heterolepis* versus total length showing the logistic curve fitted to the data

status (West 1990; Khatun et al. 2019). Furthermore, GSI has been used effectively by several researchers to assess fish maturity (Fontoura et al. 2009; Hossain et al. 2012b, 2017; Rahman et al. 2018). Knowledge of reproductive biology is vital to assess the life cycle and stocks of an individual fish species (Hossain et al. 2017). Information on the reproductive biology of *P. heterolepis* is insufficient elsewhere. Therefore, we describe sexual maturity and spawning season of *P. heterolepis*, together with the consideration of environmental factors from Bay of Bengal, Bangladesh.

Determining size at first sexual maturity (TL_m) is critical for (a) differentiating among diverse stocks of an identical species and (b) assessment whether changes in length at first maturity are due to fisheries pressure or other reasons (Hossain et al. 2010). This is essential for fisheries biologists to manage and conserve a particular fish population (Lucifora et al. 1999). Our study revealed that TL_m of female *P. heterolepis* was 15.0 cm based on GSI, MGSI, and DI values. Moreover, precise estimations of TL_m benefit management of particular fish stock (Rahman et al. 2018). The maturity size may differ according to habitat and other environmental factors (Sinovcic and Zorica 2006). However, absence of literature data on *P. heterolepis* maturity prohibits comparisons. Our study

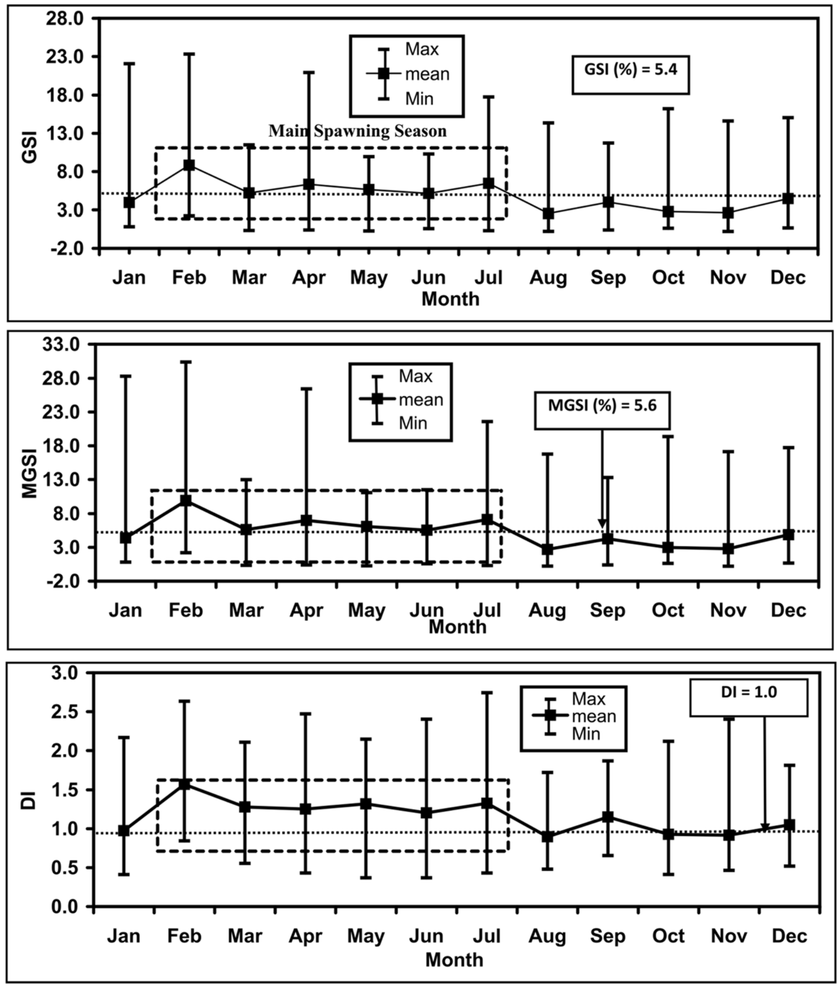

Fig. 3 Spawning season through gonadosomatic index (GSI), modified gonadosomatic index (MGSI), and Dobriyal index (DI) of *Panna heterolepis* in the Bay of Bengal (Bangladesh)

denotes the first widespread information on sexually mature size of *P. heterolepis* which could help determine the mesh size for limiting catch of mature smaller individuals to allow their spawning (Rahman et al. 2018).

We mentioned earlier that a yearly fishing ban is imposed by the Bangladeshi Government from 20 May to 23 July in the Bay of Bengal, to conserve the depleted marine fish stocks and allow adequate spawning (DoF 2019). However, the spawning and peak spawning seasons for most of the marine fish stocks are unknown. On the other hand, the prolonged fishing ban has a negligible impact on the income and livelihoods of the poor subsistence coastal fishers. Therefore, it is necessary to quantify the spawning and peak-spawning period in spite of different fishes dwelling in the Bay of Bengal. Analyses of spawning season are crucial to assess spawning time and migration of a fish population for spawning purposes (Vadas 2000; Khatun et al. 2019). According to monthly GSI, MGSI, and DI values, female *P. heterolepis* showed a prolonged spawning period from January to July, but peak spawning occurred in February. Consequently, all types of

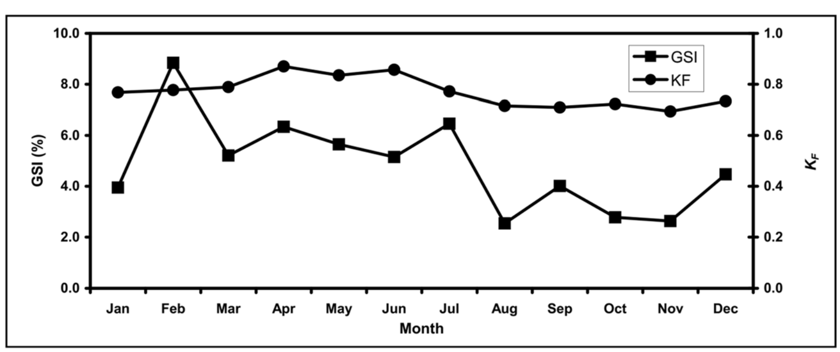

Fig. 4 Monthly variations of gonadosomatic index (GSI) and Fulton's condition factor (K_F) of female *Panna heterolepis* in the Bay of Bengal (Bangladesh)

Table 2 Relationship between environmental factors with GSI of *Panna heterolepis* Trewavas, 1977 in the Bay of Bengal (Bangladesh)

Relationship	r_s value	95% CL of r_s	p values	Significance
Temperature vs. GSI	−0.5433	−0.8067 to 0.7741	0.0421	*
Rainfall vs. GSI	−0.2098	−0.7093 to 0.4300	0.5137	*ns*
DO vs. GSI	0.4042	−0.2394 to 0.8010	0.1922	*ns*
pH vs. GSI	0.3333	−0.3151 to 0.7696	0.2874	*ns*

GSI, gonadosomatic index; *DO*, dissolved oxygen; r_s, Spearman rank correlation values; *CL*, confidence limit; *p*, level of significance; *ns*, not significant. *Significant

fishing ought to be banned during the peak spawning period to ensure sustainable management of this species depending on when peak spawning occurs for other fish species and allow the coastal fisher folks to continue fishing during the June–September monsoon in the Bay of Bengal.

In general, condition factor denotes the status of well-being of a particular population in the natural habitat (Hossen et al. 2019). Furthermore, it helps assess maturity status and fitness (Sabbir et al. 2020a). In our study, Fulton's condition factor (K_F) was significantly correlated with monthly GSI values. We found that the spawning period of *P. heterolepis* began in January, peaked in February, and ended in July. The condition factor of *P. heterolepis* was almost constant during pre-spawning period, decreased during spawning, and was lowest during peak-spawning period (Hossain et al. 2016).

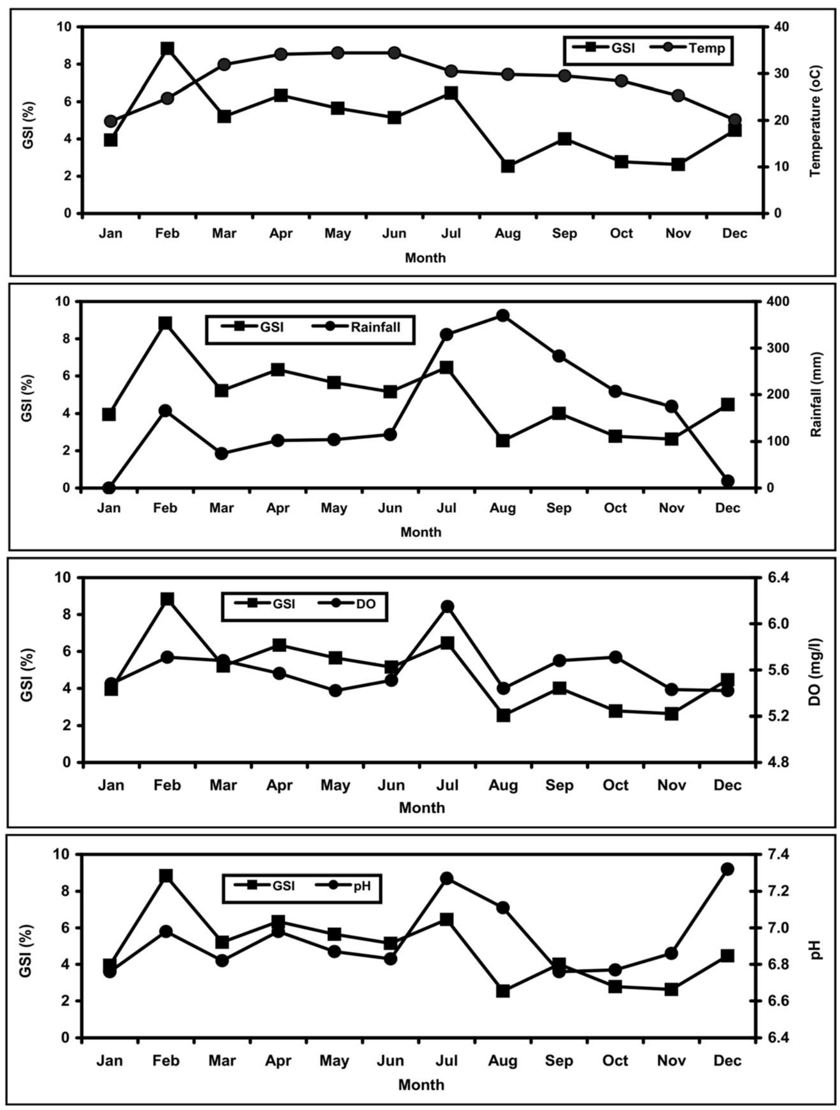

Fig. 5 Relationship between gonadosomatic index (GSI) with environmental factors of female *Panna heterolepis* in the Bay of Bengal (Bangladesh)

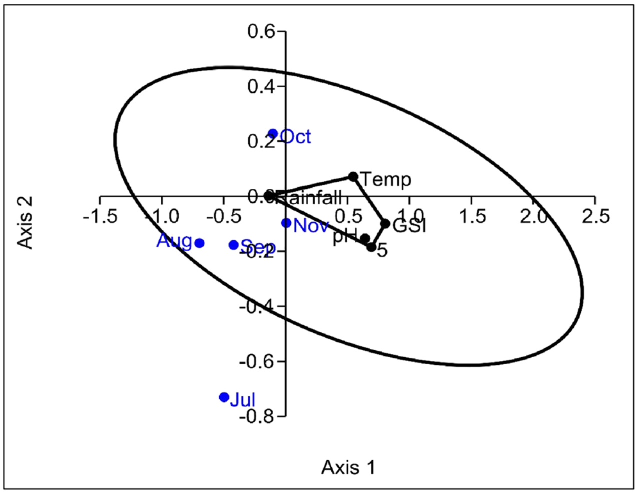

Fig. 6 Relationship between gonadosomatic index (GSI) with environmental factors of female *Panna heterolepis* in the Bay of Bengal (Bangladesh) through CCA (canonical correspondence analysis) plot

Further, the reproductive behavior of female *P. heterolepis* may be influenced by water temperature. Throughout the study, the maximum water temperature was recorded in May–June (34.4 °C) and minimum temperature was seen in January (19.8 °C). The highest GSI (peak spawning period) was detected in February when water temperature was relatively low (24.7 °C). Alternatively, reproductive behavior was not significantly influenced by rainfall, DO, or pH in the Bay of Bengal (SW Bangladesh). Maximum rainfall recorded in August (370 mm) and no rainfall occurred in January. But DO is important for the aerobic metabolism of fish (Timmons et al. 2001) and optimum DO level exceeds 3.5 mg/l for marine fisheries resources (EPA 2000). Similarly, pH is considered an important ecological factor for any aquatic ecosystem. If an aquatic ecosystem is more acidic (pH < 4.5) or alkaline (pH > 9.5) for an extended time, growth and reproduction will be reduced (Ndubuisi et al. 2015). In our study, the monthly DO level ranged from 5.42 to 6.15 mg/l and pH was 6.76–7.32 indicating an appropriate habitat for marine fisheries resources in the Bay of Bengal, Bangladesh. These factors were not closely related with reproduction of *P. heterolepis* in the study site. However, further incentive studies are recommended for its sound clarification.

Conclusion

The length at sexual maturity of *P. heterolepis* helps to set a suitable capture size. Furthermore, the spawning season of this species extended from January to July with a peak in February. The adults should conserve during the peak for sustainable exploitation of this species. GSI displayed a statistically significant correlation with temperature, and it should be considered in future management policy especially in the face of climate change. The outcomes of our study might be advantageous to biologists or ecologists for the suitable management of *P. heterolepis* in the Bay of Bengal (Bangladesh) and nearby aquatic ecosystems. For the avoidance of over-exploitation and the introduction of aquaculture to increase yield, a thorough stock assessment of this species is strongly recommended.

Funding We are grateful to the (i) PIU-BARC, NATP-2, PBRG-156 for research grants and (ii) MoST-GoB for NST-Ph.D Fellowships (For Senior author-Wasim Sabbir).

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Heliyon 7 (2021) e07711

Contents lists available at ScienceDirect

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Research article

Stock assessment of Hooghly Croaker *Panna heterolepis* in the Bay of Bengal (Southern Bangladesh): implications for sustainable management

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ARTICLE INFO

Keywords:
Bay of bengal
Stock assessment
Panna heterolepis
Bangladesh

ABSTRACT

The study describes growth pattern, growth parameter, mortality, recruitment pattern, exploitation rate (E) and maximum sustainable yield (MSY) to *Panna heterolepis* from the Bay of Bengal (Bangladesh). About 1223 specimens were collected from commercial fishermen for 12 consecutive months from January to December, 2019. Length–frequency data were analyzed with FAO-ICLARM Stock Assessment Tool. Moreover, our study recorded different water quality and environmental parameters including pH, rainfall, temperature and DO (dissolved oxygen) from the Bay of Bengal. The findings of the study revealed that the allometric co-efficient (b) value indicated negative allometric growth (<3.00) for *P. heterolepis* population. Whereas, the population dynamic parameters showed growth coefficient (K) 0.13 year^{-1}, life-span (t_{max}) 3.85 year and growth performance index ($Ø'$) 2.30. Along with this, *P. heterolepis* was found to grow rapidly with an asymptotic length (L_∞) of 39.08 cm. We found that the natural mortality (M =0.44 year^{-1}) rate was almost similar with fishing mortality (F = 0.42 year^{-1}). Consequently, the standing stock was not quite sustainable with the existing fishing strategy. Furthermore, the maximum allowable exploitation rate (E_{max} = 0.471) was lower than the recorded exploitation rate (E = 0.490). Subsequently, overfishing is the most focal threat to the wild stock. The recruitment pattern was almost continuous throughout sampling period. Finally, the MSY was assessed at 10234.47 metric tons. Additionally, the environmental parameters denoted that the ecosystem was in a balanced condition for the wild population. The findings would be very useful to introduce appropriate fishing regulations in the Bay of Bengal and nearby ecosystem.

1. Introduction

Fish and their products are the most significant protein source for global population (Roy et al., 2020). The increasing demand for products creates massive fishing pressure on natural stock, especially in the open-water ecosystem (Panhwar et al., 2013). Fish are now considered as limited renewable resources (Gulland, 1982). Therefore, it is essential to assess the life-history traits i.e. growth, reproductive characteristics, recruitment pattern and mortality to ensure sustainable management for conserving the wild stock (Foster and Vincent, 2004). Besides, the lack of information about such traits on marine fisheries resources is a barrier to implementing suitable fishing strategies in the marine ecosystem (Dinh et al., 2018) and this demands quick investigation.

Length-frequency distribution (LFD) is an important biometric index to assess the dynamic rates of recruitment, growth, mortality, yields and stock biomass in a particular ecosystem (Neuman and Allen, 2001) through dynamic mathematical models (Beverton and Holt, 1979). Likewise, growth pattern is essential to detect the temporal variation of fish growth (Hossain and Ohtomi, 2010). Growth of fish and other aquatic organisms largely depend on sex, maturity status and environmental factors (Dall et al., 1990). Fast growth rate of fish is advantageous in many ways. Rapid growth rate of fish not only gives the fish immunity from predators but also allows carrying large numbers of eggs with higher chances of larval survival (Hossain et al., 2017). In addition, growth and recruitment have remarkable effects on the maintenance of maximum sustainable yield of a wild stock (Ahmed et al., 2012).

Presently environmental issues are vibrant threats to marine fish populations accompanied by other hazards like overfishing, pollution in addition to habitat deterioration (Rose, 2005). Environmental changes are considered the latest warning that causes rapid declining of marine

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https://doi.org/10.1016/j.heliyon.2021.e07711
Received 29 March 2021; Received in revised form 11 July 2021; Accepted 30 July 2021

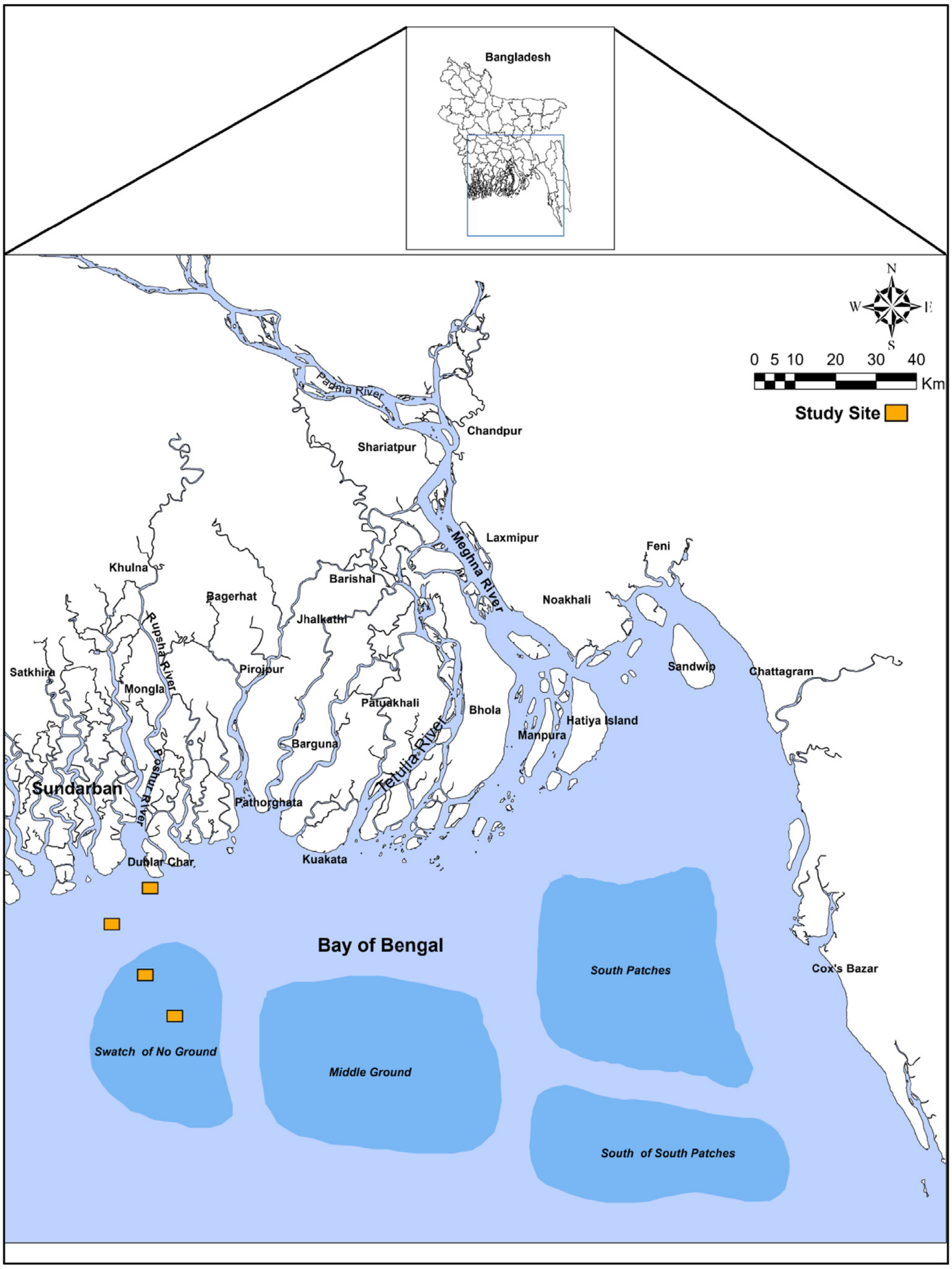

Figure 1. The study site in the Bay of Bengal, Bangladesh (Rectangle shapes indicate the sampling sites).

fish stocks worldwide (Cochrane et al., 2009). Consequently, this has a catastrophic impact on the livelihoods of many poor fishers, especially in developing countries like Bangladesh (Allison et al., 2009). Already marine fisher folks are facing deviations in the diversity and abundance of target fish species in the marine and coastal ecosystem (Johnson and Welch, 2009). Therefore, evaluating fisheries vulnerability in relation to environmental factors is obligatory for safeguarding the sustainability of the marine fisheries resources.

Hooghly Croaker *Panna heterolepis* is found profusely in the Bay of Bengal ecosystem (Sasaki, 1995). Talwar and Jhingran (1991) stated that *P. heterolepis* belongs to the family Sciaenidae inhibits marine and brackish-water ecosystems. According to Froese and Pauly (2020), *P. heterolepis* is very famous among the three representative species under the genus *Panna* in the Bay of Bengal existing with *P. perarmatus* and *P. microdon*. In Bangladesh, *P. heterolepis* is locally called Poa. Besides, it is commercially very important as a widespread food fish item because of outstanding flesh quality. However, total demand of this species is met through the capture from wild stock due to absence of culture practice (Hossen et al., 2019; Sabbir et al., 2020a). Besides, the species is considered as the least concern worldwide (IUCN, 2020).

A good number of studies with morphology (Sasaki, 1995), condition factor (Sabbir et al., 2020a) and reproductive biology (Sabbir et al., 2021) were done on *P. heterolepis*. Therefore, our aim is to describe the growth pattern, growth parameters, recruitment pattern, mortality, exploitation rate and maximum sustainable yield of *P. heterolepis* through evaluating the monthly length data collected from the commercial fishers' catch for consecutive 12 months as well as to suggest sustainable management approach considering the effects of environmental factors.

Table 1. Descriptive statistics on the total length (cm) and body weight (g) measurements of *Panna heterolepis* Trewavas, 1977 in the Bay of Bengal, Bangladesh.

Month	*n*	Total length (cm)				Body weight (g)			
		Min	Max	Mean ± SD	95 % CL	Min	Max	Mean ± SD	95 % CL
Jan	107	12.0	25.9	17.23 ± 1.79	16.88 to 17.57	12.39	134.28	39.72 ± 14.75	36.89 to 42.55
Feb	104	11.0	34.5	18.70 ± 4.39	17.85 to 19.56	9.02	342.26	58.74 ± 51.08	48.80 to 68.67
Mar	104	11.1	25.7	17.66 ± 2.89	17.09 to 18.22	11.98	133.35	46.06 ± 24.17	41.36 to 50.76
Apr	84	10.5	28.7	16.80 ± 4.67	15.78 to 17.81	10.02	175.60	46.79 ± 40.32	38.04 to 55.54
May	101	11.9	27.0	16.89 ± 2.74	16.34 to 17.43	11.42	144.30	41.26 ± 22.36	36.85 to 45.68
Jun	99	11.5	28.5	19.79 ± 3.78	19.04 to 20.55	14.20	174.60	63.72 ± 33.53	57.03 to 70.41
Jul	103	10.5	29.5	17.64 ± 3.55	16.94 to 18.33	11.20	187.53	45.13 ± 29.14	39.43 to 50.82
Aug	106	13.0	31.4	18.22 ± 3.59	17.53 to 18.91	17.90	203.89	47.48 ± 33.86	40.96 to 54.00
Sep	102	15.0	30.9	19.30 ± 2.36	18.83 to 19.76	24.19	165.15	51.05 ± 19.63	47.19 to 54.91
Oct	104	12.5	27.2	17.86 ± 2.73	17.33 to 18.39	13.89	140.58	43.71 ± 21.48	39.53 to 47.89
Nov	105	13.1	26.4	17.96 ± 2.47	17.48 to 18.43	18.05	120.22	42.16 ± 17.49	38.78 to 45.55
Dec	104	14.7	25.2	18.02 ± 1.97	17.64 to 18.41	24.44	117.38	43.25 ± 15.28	40.28 to 46.22

Notes: *n*, sample size; TL, total length; W, body weight; min, minimum; max, maximum; SD, standard deviation; CL, confidence limit.

2. Materials and methods

2.1. Sampling site and sampling

In total, 1223 individuals of *P. heterolepis* were harvested during January to December 2019 by using different local gears from the Bay of Bengal (21.7728°N; 89.5592°E), southern Bangladesh (Figure 1) on a monthly basis.

2.2. Fish measurement

Total length (TL) and body weight (BW) of each specimen were assessed with 0.1 cm and 0.01 g accuracy.

2.3. Growth pattern

Growth pattern was calculated by LWRs involving the calculation: $W = a \times L^b$. The regression coefficient a and b were assessed using the formula: $\ln(W) = \ln(a) + b \ln(L)$. A t-test was executed to approve whether the b value was statistically dissimilar from isometric value ($b = 3$).

2.4. Estimation of growth parameters

Length-frequency data were analyzed with FiSAT software version 1.1 (Gayanilo and Pauly, 1997). The von Bertalanffy Growth Function (VBGF) was employed to obtain the asymptotic length (L_∞) and growth constant (K) (Gayanilo et al., 2002). The life-span (t_{max}) was determined using the formula of $\log(t_{max}) = 0.5496 + 0.957 * \log(t_m)$ (Froese and Binohlan, 2005), where t_m indicates the age of first sexual maturity. Age at zero length (t_0) was determined with the calculation of $\log(-t_0) = -0.3922 - 0.2752 \log L_\infty - 1.038 \log K$ (Pauly, 1980) and growth performance index was calculated as $Ø' = \log_{10}K + 2\log_{10}L_\infty$ (Pauly and Munro, 1984).

2.5. Estimation of mortality and exploitation

Total mortality (Z) was calculated by the length-converted catch curve method (Gayanilio et al., 2002). Natural mortality (M) was assessed as $\log_{10}M = -0.0066 - 0.279\log_{10}L_\infty + 0{:}6543\log_{10}K + 0{:}0463\log_{10}T$; where T is the average temperature of the ecosystem (28.5 °C). The fishing mortality (F) was estimated as Z-M. Besides, exploitation rate (E) was determined as: $E = F/Z = F/(F + M)$ (Gulland, 1983). Consequently, exploitation rate producing maximum yield (E_{max}), exploitation rate at which the secondary increase of relative yield-per-recruit (Y'/R) is 10 % its virgin biomass ($E_{0.1}$) and the exploitation rate under which the stock is reduced to half its virgin biomass ($E_{0.5}$) were calculated following knife-edge selection (Beverton and Holt, 1979).

2.6. Recruitment pattern

Recruitment pattern of *P. heterolepis* was assessed from the analysis of the total time series of LFDs and growth parameters using VBGF models.

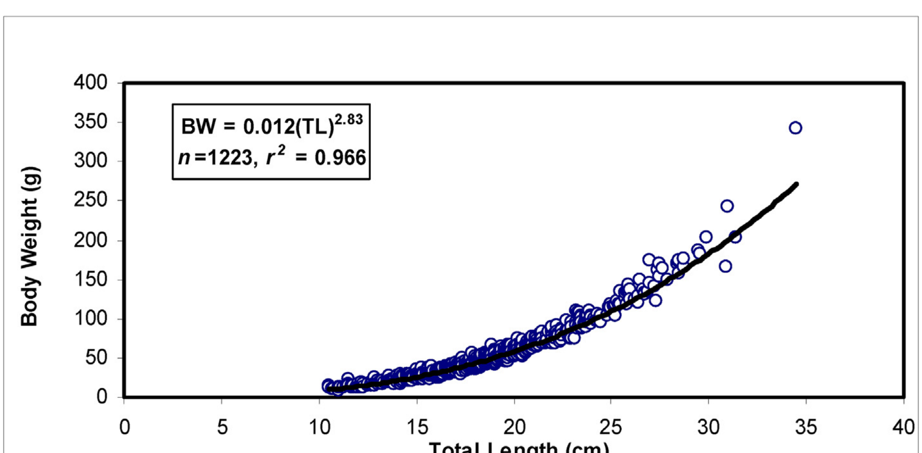

Figure 2. Growth pattern of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

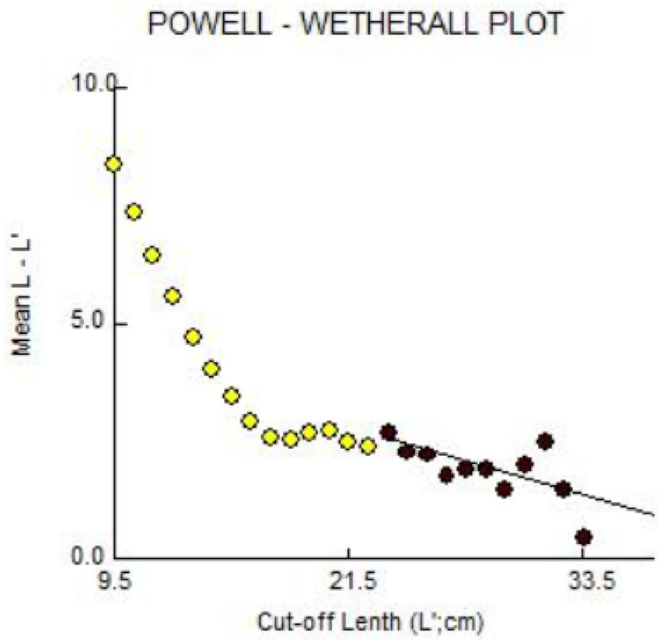

Figure 3. Powell-Werherall Plot for the length frequency data of *Panna heterolepis* from the Bay of Bengal, Bangladesh suggests that values of (L̄-L′) plotted against a series of cut-off points, L′ as a straight line. Black dots are exploited samples. The regression equation is Y = 1.03–0.255X, $r = 0.862$. Estimated L_∞ = 39.08 cm and $Z/K = 5.118$.

2.7. Relative yield-per-recruit (Y′/R), steady state biomass (SSB) and maximum sustainable yield (MSY)

The Beverton and Holt (1979) model was applied to assess the Y'/R of *P. heterolepis*. The recommended length at first capture (L_c) was predicted at $E_{0.5}$ level. The SSB was calculated using the length-structured virtual population analysis (VPA) routine in FiSAT II. Consequently, MSY of *P. heterolepis* was calculated as MSY = 0.5*SSB*Z (Gulland, 1983).

2.8. Environmental factors

In order to assess the status of water quality of the Bay of Bengal, different parameters i.e. temperature (°C), pH and DO (mg/l) were recorded monthly basis following APHA (2005) procedure. Besides, monthly rainfall data were collected from the meteorological station of Khulna, Bangladesh.

3. Results

3.1. Growth pattern

LFD revealed that the TL varied from 10.5 to 34.5 cm and BW ranged from 9.02 to 342.26 g (Table 1). The regression coefficients *a* and *b* for *P. heterolepis* were assessed from the length and weight data and calculated as $W = 0.012TL^{2.83}$ ($p < 0.001$; $r^2 = 0.966$; Figure 2).

3.2. Growth parameters

The study revealed the L_∞ of 39.08 cm TL. Further, the value of K was recorded as 0.13 year^{-1} for the unique data set (Table 2 and Figures 3 and 4). The length–frequency histograms and the von Bertalanffy Growth curve were shown in Figure 5. The $Ø'$, t_{max} and t_0 were found 2.30, 3.85 year and 0.108 year, respectively (Table 2).

3.3. Mortality

Total mortality (Z) was recorded 0.86 year^{-1} (Figure 6). Further, natural mortality (M) and fishing mortality (F) were calculated 0.44 and 0.42 year^{-1}, respectively (Table 2).

Table 2. Growth parameters (L_∞ and K), mortality (Z, M, F) and Fishery parameters (E, Lc and MSY) of *Panna heterolepis* Trewavas, 1977 in the Bay of Bengal, Bangladesh.

Description of Parameters	Values
Growth and reproduction	
Asymptotic length (L_∞)	39.08 cm TL
Growth coefficient (K)	0.13 year^{-1}
Life-span (t_{max})	3.85 year
Growth performance indexes ($Ø'$)	2.30
Age at zero length (t_0)	0.108 year
Age at first sexual maturity (t_m)	0.69 years
Mortality parameters	
Total mortality (Z)	0.86 year^{-1}
Natural mortality (M),	0.44 year^{-1}
Fishing mortality (F)	0.42 year^{-1}
Fishery parameters	
Exploitation ratio (E)	0.490
E_{max}	0.471
$E_{0.1}$	0.364
$E_{0.5}$	0.268
Total length at first capture (L_c)	14.96 cm TL
Maximum sustainable yield (MSY)	10234.47 metric ton

3.4. Recruitment pattern

The recruitment of *P. heterolepis* population is more or less continuous throughout the sampling period with a major peak in April–May (Figure 7).

3.5. Relative yield-per recruits (Y′/R), steady state biomass (SSB) and maximum sustainable yield (MSY)

From Y′/R analysis, the estimated values of E, E_{max}, $E_{0.1}$, and $E_{0.5}$ were 0.490, 0.471, 0.364 and 0.268 respectively (Figure 8; Table 2).

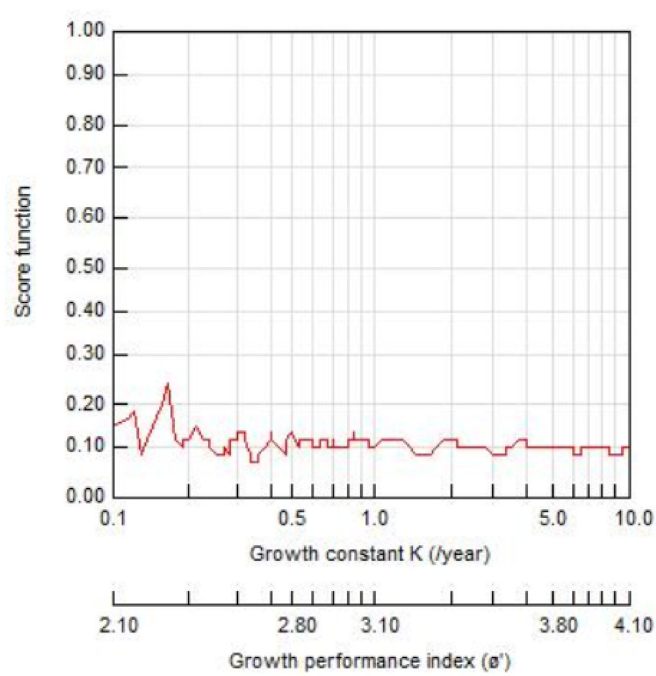

Figure 4. K-scan routine for determining best growth curvature giving best value of asymptotic length with growth performance indices for *Panna heterolepis*.

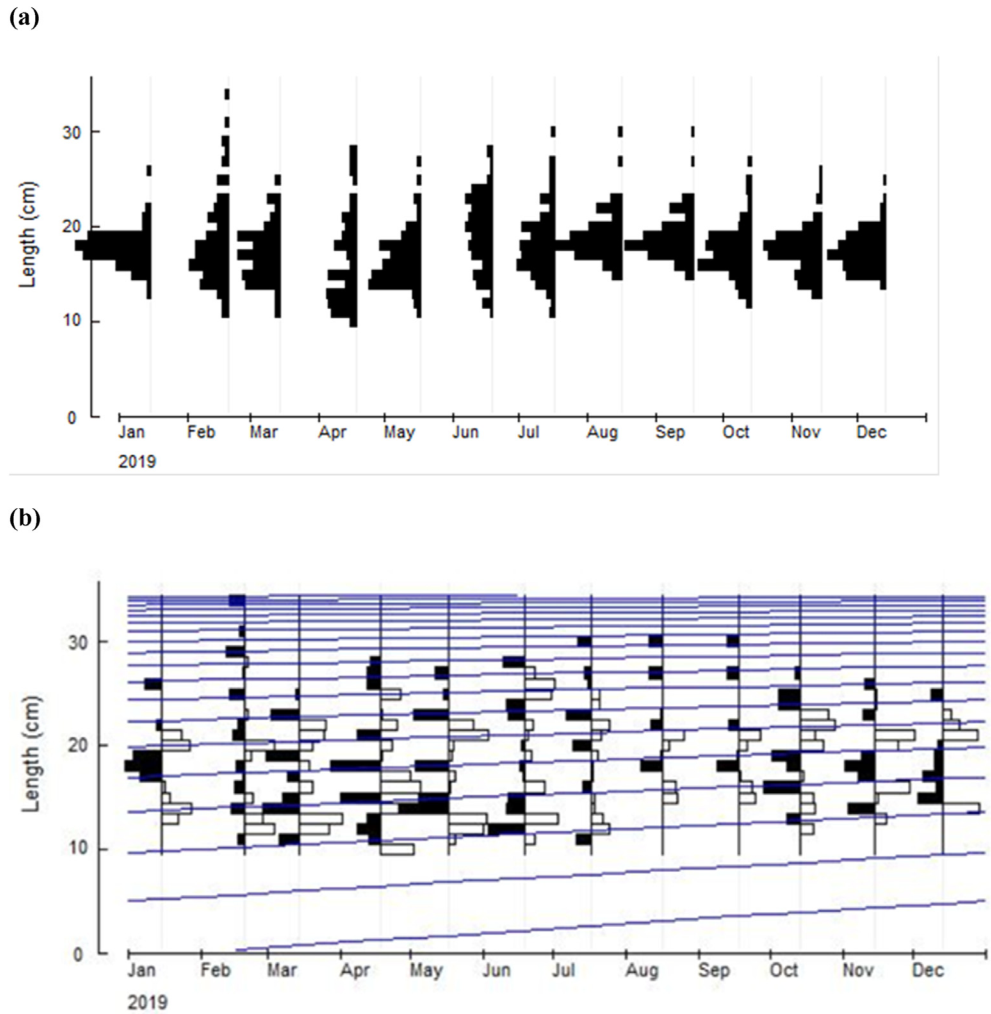

Figure 5. Total length (TL) frequency distribution and growth curve of *Panna heterolepis*. (a) Histogram showing distribution of TL frequency data of collected specimens and (b) von Bertalanffy growth curve (parameters values: L_∞ = 39.08 cm and K = 0.13 year^{-1}) superimposed on the restructured length frequency histogram of the *Panna heterolepis*.

Moreover, the calculated TL of *P. heterolepis* at first capture (L_c) was 14.96 cm (Figure 9). The predicted total SSB was 23801.09 metric tons. Consequently, the MSY of *P. heterolepis* was estimated at 10234.47 metric tons.

3.6. Environmental factors

We observed four environmental factors namely temperature (°C), rainfall (mm), DO (mg/l) and pH. The maximum and minimum water temperature was documented 34.4 °C in May–June and 19.8 °C in January, respectively with an average of 28.5 °C. The peak rainfall was occur in August (370 mm) but no precipitation was recorded in January. Further, the highest DO was found in July (6.15 mg/l) and the lowest DO was recorded in December (5.42 mg/l). However, minimum pH was found in May and September (6.76) and the maximum pH was recorded in the month of July (7.32).

4. Discussion

Stock assessment is essential to obtain the highest benefit from a natural stock without hampering the wild population. Information on stock assessment of *P. heterolepis* is absent in literature from Bangladesh and elsewhere. In our study, a large number of specimens (1223) were sampled using local gears including gill net for successive twelve months from the Bay of Bengal, Bangladesh. However, absence of individuals smaller than 10.50 cm TL may be attributed to the selectivity of fishing gear (Hossain et al., 2016a, b). The highest length of *P. heterolepis* was recorded 34.50 cm from the sampling site. Our study revealed a length of 28.20 cm in standard length (SL) specifically higher than the report (21.40 cm) of Sasaki (1995). Therefore, this study recorded the maximum length (34.50 cm in TL) for *P. heterolepis* (Sabbir et al., 2020b).

Carlander (1969) stated that *b* values may range between 2.0 to 4.0 for fishes. On the other hand, Froese (2006) reported that the *b* values of LWRs should range from 2.5 to 3.5. Our experiment recorded a negative allometric growth pattern ($b = 2.83$) for *P. heterolepis* population, which is comparable to Froese (2006) for teleost fishes. However, *b* values often differ for same species because of consolidation of various factors i.e. sex, development of gonad, growth variations in different body parts, physiological condition, food availability and preservation methods (Le Cren, 1951; Hossain et al., 2015).

It is crucial to determine the growth parameters for predicting future yields and stock biomass from a particular aquatic ecosystem (Dadzie et al., 2017). We estimated the L_∞ higher than our largest specimen might be attributed to von Bertalanffy model being insufficient for determining the growth of fish species because fish do not grow linearly

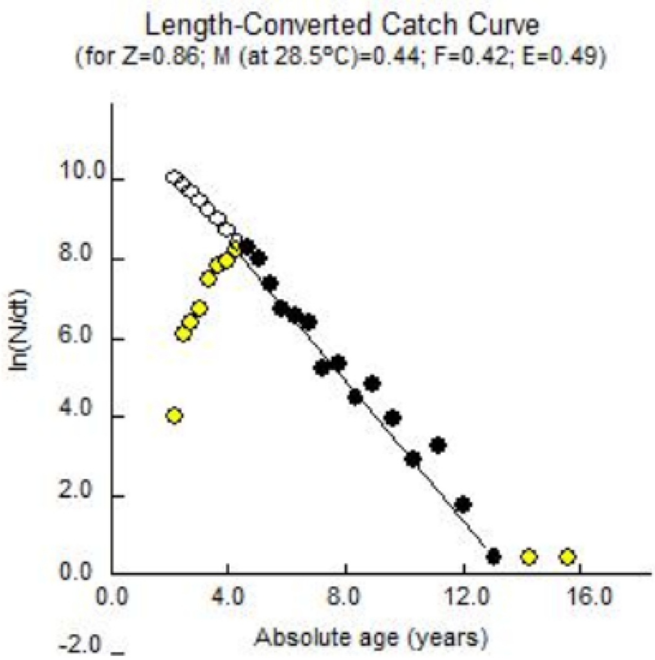

Figure 6. Length-converted catch curve of *Panna heterolepis* in the Bay of Bengal, Bangladesh. Note: only black dots are considered for computation of total mortality.

(Vigliola et al., 1998). Fish grow more rapidly at Juvenile stage and growth rate becomes slower at older stage. Consequently, the growth performance index ($\varnothing'$) is a more consistent method for a fish population to compare the growth performance as it considers L_∞ along with K simultaneously (Pauly and Munro, 1984). However, the calculated $\varnothing'$ for *P. heterolepis* was 2.30. Further, we observed the maximum age or life span (t_{max}) was 3.85 year and age at zero length (t_0) was 0.108 year. There was no previous data on growth parameter of *P. heterolepis* to compare our findings.

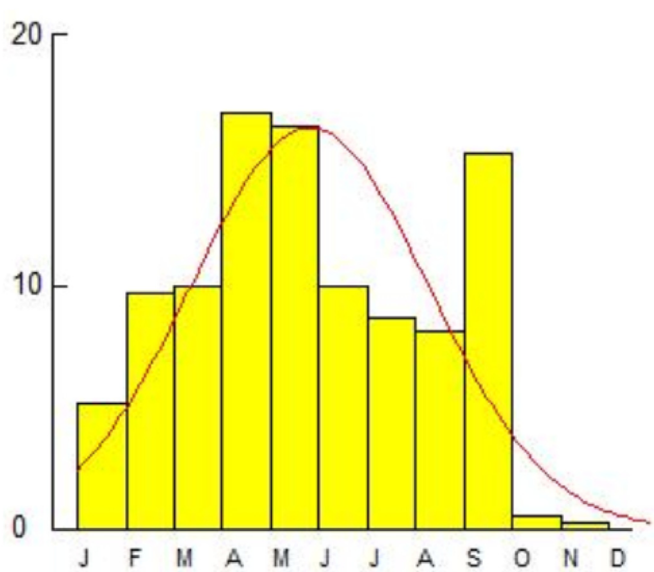

Figure 7. Recruitment of *Panna heterolepis* in the Bay of Bengal, Bangladesh. The histogram shown relative percentage of recruits per month whilst bell-shaped curves show the one recruitment peak.

Assessment of the mortality rate is crucial for evaluating the abundance of a fish stock which helps to set harvest limits to obtain maximum benefit for the stakeholders of the resource. Total mortality (Z) was recorded 0.86 year^{-1}. We found that the natural mortality (M =0.44 year^{-1}) rate is almost similar to fishing mortality (F = 0.42 year^{-1}). Consequently, the standing stock is not quite sustainable with the existing fishing strategy. We found the maximum allowable exploitation rate (E_{max} = 0.471) is close to the observed exploitation level (E = 0.490). According to Gulland (1983) and Pauly (1983), the exploitation of this species is at optimum level in the Bay of Bengal, Bangladesh. Similarly, we found that the Z/K ratio was 5.118 (Figure 3) which denoted that the exploitation level was very high (Barry and Tegner, 1989). Pauly and Munro (1984) stated that juveniles of a certain species would be higher in the catch composition if the L_c/L_∞ ratio was lower than 0.5. Our study recorded the L_c/L_∞ ratio was 0.38. Consequently, the fishing composition was dominated by smaller sizes of fish.

Recruitment typically refers to a new cohort in the catch due to becoming big or old enough to be vulnerable to the fishery. Peak pawning season was estimated in February (Sabbir et al., 2021). Thus, our study recorded that there were major recruitment peaks in the population during April–May and they overlapped in time to provide a continuous pattern throughout the year. Finally, the MSY of *P. heterolepis* was calculated as 10234.47 metric tons, if the recommended length at first capture (L_c = 14.96 cm TL) is maintained. Though, the estimated length at first capture was similar to size at first sexual maturity (15.0 cm TL) (Sabbir et al., 2021).

A good number of researches have been documented the distributional changes of marine fisheries stock due to environmental changes (Alheit et al., 2005; Perry et al., 2005). However, in the Bay of Bengal, such studies are absent. Temperature is thought to be the most imperative environmental factor influencing the distribution of larval accumulations of marine and freshwater fish species (Houde and Zastrow, 1993; Jakobsen et al., 2009). Likewise, rainfall is another important factor prompting the hydrological events through runoff and river inflow (Patrick, 2016). During the sampling period, the highest and lowest surface water temperature was documented in June–July (34.4 °C) and in January (19.8 °C), respectively. The highest rainfall was observed in August and no precipitation was occurred in the month of January. Besides, DO is an important ecological parameter for metabolic activities of fish (Timmons et al., 2001). The minimum DO level requirement should remain 3.5 mg/l for coastal and marine fish stocks for their survival (EPA, 2000). Likewise, pH is a critical ecological parameter for marine and freshwater habitat. Both acidic (pH $<$ 4.5) and alkaline (pH $>$ 9.5) condition hinder the growth and reproduction of fish (Ndubuisi et al., 2015). In the present study, monthly DO level fluctuated from 5.42 to 6.15 mg/l and pH varied from 6.76 to 7.32 indicating a suitable habitat for *P. heterolepis* in the Bay of Bengal, Bangladesh (Sabbir et al., 2020a).

5. Conclusion and recommendations

The study describes the growth pattern, growth parameters, mortality, recruitment, exploitation rate and MSY of *P. heterolepis* from the Bay of Bengal, Bangladesh. Overfishing may be the most focal threat for the wild population of *P. heterolepis* if fishing activity is not maintained with the finding range (E_{max} = 0.47). Illegal gear should be banned and mesh size should be increased to limit catching mature smaller individuals to provide them opportunity to spawn as the L_c and L_m are the same in size. If it is not done, future stock will be hampered due to lack of spawner. The temperature of the world environment is increasing every year. So, long term management policy should be taken for sustainable management of wild stock of *P. heterolepis* considering the emerging climate change. However, the findings of our study might be a potential tool for fishery biologists to initiate alternative management approaches to conserve this prominent fish species from possible future collapse.

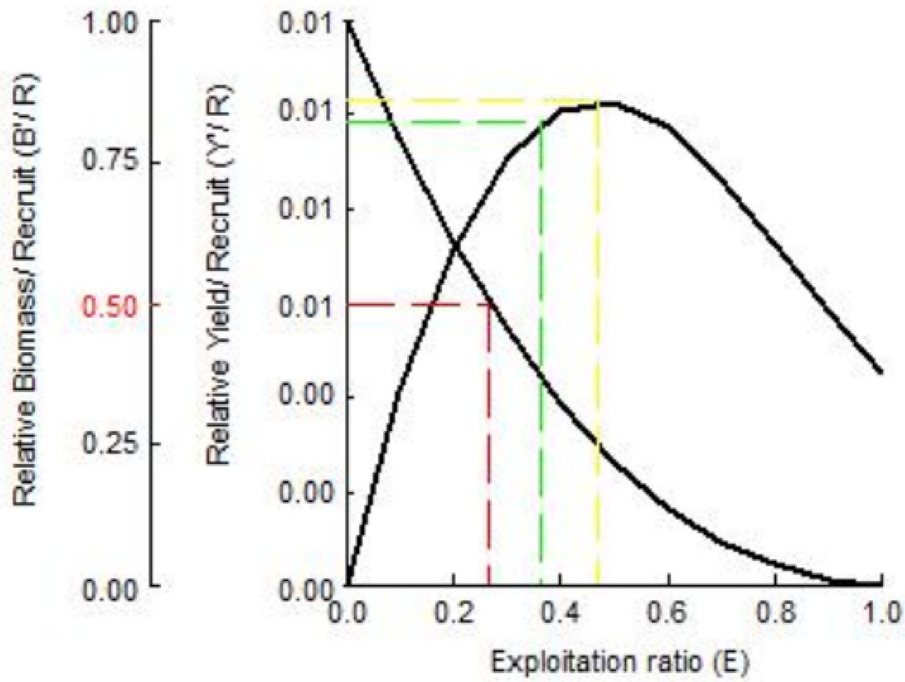

Figure 8. Yield-per-recruit and average biomass per recruit models, showing levels of yield index of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

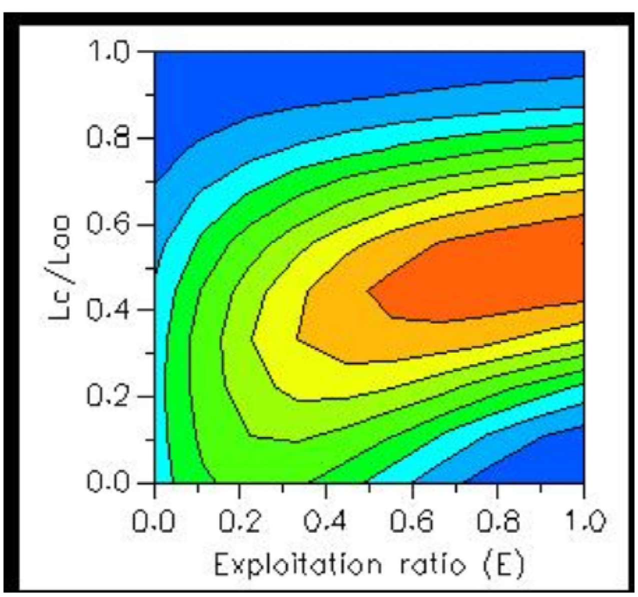

Figure 9. Yield Isopleths, showing optimum fishing activity of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

Declarations

Author contribution statement

Wasim Sabbir; Md. Ashekur Rahman; Md. Yeamin Hossain: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Md. Rabiul Hasan; Zannatul Mawa; Obaidur Rahman; Sumaya Tanjin; Most. Shakila Sarmin: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Funding statement

Dr. Md. Yeamin Hossain was supported by PIU-BARC, NATP-2, PBRG-156; Wasim Sabbir was supported by MoST-GoB for NST-Ph.D.

Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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