STUDY ON THE MORPHOMETRIC VARIATIONS IN PARADISE THREADFIN FISH (*Polynemus paradiseus*) COLLECTED FROM GEOGRAPHICALLY DISTINGUISHED COASTAL AREAS OF BANGLADESH

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Roll No. 0120/01

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Session: 2020-2021

A thesis submitted in the partial fulfillment of the requirements for the degree of Master of Science in Marine Bioresource Science

Department of Marine Bioresource Science
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AUGUST 2022

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This is to certify that we have examined the above Master's thesis and have found that is complete and satisfactory in all respects and that all revisions required by the thesis examination committee have been made

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DEDICATED TO MY

BELOVED PARENTS

AND

FAMILY MEMBERS

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ABBREVIATION

DFA	Discriminant Function Analysis
PCA	Principle Component Analysis
GM	Geometric Morphometrics
GMA	Geometric Morphometric Analysis
ANOVA	Analysis of Variance
SPSS	Statistical Package for Social Science
F Value	Variation between sample means / variation within the samples
P	Level of Significance
SD	Standard Deviation
NS	Not Significant
PCC	The Percentage of Correctly Classified
DF	Degrees of Freedom
LDA	Linear Discriminant Analysis
i.e	That is
e.g.	For Example
et al.	Associates

Abstract

The Paradise Threadfin Fish, or *Polynemus paradiseus*, is a valuable aquatic species found in the estuaries of several different rivers in Bangladesh. Despite the species' widespread range, there is a lack of information about its morphometric variations among populations from separate locations. This research was carried out to examine the morphometric variations of *P. paradiseus* using the truss network method and body shape morphometrics. The wholeseller or the fisherman from the fisheries ghat in the Chattogram district, the BFDC fishery ghat in the Cox's Bazar district, the chairman ghat in the Noakhali district, the Rupsha wholesale fish market in the Khulna district, and the Fuljhuri fish market in the Borguna district provided a total of 366 samples of the species. Using the Sigmascan pro software platform, we took digital pictures of the samples and used them together with 14 morphometric factors to build a truss network consisting of 32 distance variables. After transforming the truss measurements, factor analysis and a cross-validation discriminant analysis were performed. Factor analysis revealed a statistically significant difference between ten of fourteen morphometric lengths and twenty-six of thirty-two truss network measurements for both males and females at the 0.05, 0.01, and 0.001 levels of significance. The factor analysis showed that the *P. paradiseus* population in these five areas varies significantly in terms of its morphology; Both discriminant function analysis (DFA) and principal component analysis (PCA) suggested that the population from Khulna and Borguna districts differs phenotypically from the Chattogram, Noakhali, and Cox's Bazar populations. The Bay of Bengal and the estuaries may have different physical and biological conditions, which might explain the existence of discrimination among different stocks. These morphological differences are crucial in making the right call for effective management, conservation, and widespread seed production to ensure long-term viability.

Keywords: Paradise threadfin fish; morphometric; truss network; discriminant analysis; principle component analysis

Chapter-1: Introduction

1.1 Background of the study

About 41 species in 8 genera make up the family Polynemidae (Motomura, 2004). Most species are found in estuaries and coastal waterways, while others, such as *Polynemus* species and *Polydactylus macrophthalmus*, only exist in freshwater rivers. Polynemids are customarily found on sandy and muddy bottoms at depths of less than 150 meters, while juveniles have been seen in tide pools and seagrass meadows. The pectoral filaments of the *Polynemus* species common in estuaries and rivers are noticeably longer than the body. Pectoral filaments are often stretched forward to find food while swimming and may serve as a substitute for vision (Motomura, 2004).

Figure-1: *Polynemus paradiseus*

Tapasi, Topse, Muni, Ramsos, and Rishi are a few of the names for *Polynemus paradiseus* used in Bangladesh. The term "paradise threadfin fish" refers to this species as well. It is found naturally throughout Bangladesh, India, Pakistan, and Sri Lanka (Talwar and Jhingran, 1991). This species has a narrow, long body and small eyes. The pectoral fins are bifurcated, with the upper half having unbranched rays and the lower half having seven free filamentous rays, the top three of which are the longest (Talwar and Jhingran, 1991), a longer upper lobe and forked caudal fin, complete lateral line, grayish dorsal fins and a golden body (Shafi and Quddus, 2001). Because of its exceptional flavor and delectability, the market price for this species is rather high. A short time ago, *P. paradiseus* could be found nearly continuously throughout the year in coastal waters, estuaries, and major rivers like the Padma and Meghna, as well as in the Gangetic river system that runs through India and Bangladesh (Talwar and Jhingran, 1991). Now, however, this fish can no longer

be found in those bodies of water, and it is therefore becoming critically endangered along with other native species (Allendorf and Phelps, 1980; Sarkar and Bhattacharya, 2003; Roozbehfar et al., 2012; Siddik et al., 2013). This fishery has been steadily deteriorating over the last several years, seemingly owing to habitat degradation, overexploitation, and a lack of effective management (IUCN, 1998; Hadijah et al., 2014). Despite the economic importance of fish, their numbers have been on the decline in Bangladesh due to human activities such as overfishing, pollution, and the destruction of fish habitats, among other ecological changes. Knowing the population structure status of this fish is the only way to reverse this trend, both naturally and artificially.

The application of morphometric characteristics is thought to be among the most accessible, most affordable, and most popular methods for identifying and describing stocks of fish (Cadrin and Silva, 2005; Chaklader et al., 2015; Siddik et al., 2016) while figuring out how fish assemblages are structured and separating different fish populations (Cheng et al., 2005; Siddik et al., 2015). Even though molecular markers provide a more precise indication of the genetic and physiological variations across stocks, morphometric variances are still a crucial tool in stock description and identification. By identifying shape changes, morphometric characteristics may be utilized to measure a property of evolutionary importance (Chaklader et al., 2016a). Consequently, studies of fish morphology may enhance population management and conservation strategies, as well as knowledge of species' ecology, behavior, and stock assessment (Muchlisin et al., 2014; Anvarifar et al., 2011; Chaklader et al., 2016b).

The term "landmarks" refers to a few randomly chosen spots on a fish's body that can be used to assess individual fish morphology. A landmark is a connection point with an item that corresponds to two populations both within and outside of it (Barlow, 1961; Swain and Foote, 1999). Truss network systems built from landmarks considerably improve the accuracy of stock identification. Because of the evaluation of the phenotypic variation of fish or other biotic or abiotic organisms, landmark point determination is needed. It is feasible that the multiple stocks of a species may be differentiated from one another based on form, meristic, and morphological differences if they have been isolated for long enough. Short-term environmental disparities may be of more interest to researchers if the features are taken into account, and the results of this study have the potential to improve fisheries

management (Ihssen et al., 1981; Templeman, 1983; Smith and Jamieson, 1986; Turan, 2004; Turan et al., 2004a b).

Information on the biology of fish and population structure is a prerequisite for better understanding the population stock structure and developing management and conservation strategies. Despite having economic and ecological significance, there are very few studies on the morphometric divergence of paradise threadfin fish species in Bangladesh. This research aims to compare paradise threadfin fish from five distinct collection sites to identify any morphological differences.

1.2 Significance of the study

Morphometric analysis of fish is a crucial technique for the quantitative study of the shape and size of fish. It tends to delineate the morphometric variations of various fish populations through several multivariate analyses. This research will assist in understanding various morphometrics in the populations, which are the most readily observable indicators of how well a species has evolved to adapt to its environment. To ascertain its impact on the immediate surroundings, close observation is required. The segregation of this species' populations is evidenced by the varying degrees of importance for distinct physical characteristics. These morphological differences also assist to effective management, conservation, and widespread seed production to ensure long-term viability of the species.

1.3 Objectives of the research

The aims of the proposed research are as follows:

- To delineate the stock structure of the paradise threadfin fish (*Polynemus paradiseus*) population collected from the different coastal areas of Bangladesh
- To figure out which features are most useful for defining the *polynemus paradiseus* stock structure discrimination

Chapter-2: Review of Literature

Based on a figure (Motomura et al., 2002b) and from the description of Edwards (1743-1751), *Polynemus paradiseus* (Linnaeus, 1758), was first discovered in Bengal, India. According to a phenotype (NRM 47529, 198 mm typical length), it is also found in Gariahat, Calcutta, West Bengal, India (Motomura et al., 2002). There are a number of names for this species as like *Polynemus risua* (Hamilton, 1822) (locality type: near Lukhipur, India; kinds unknown), *Polynemus toposui* (Hamilton, 1822) (locality type: estuary of Ganges River, West Bengal, India; kinds unknown), *Polynemus aureus* (Hamilton, 1822) (locality type: Calcutta, West Bengal, India; kinds unknown). *Polynemus longifilis* (Cuvier in Cuvier and Valenciennes, 1829) (locality type: Pondicherry and the Ganges River, India; Manila, the Philippines (Motomura et al., 2002). FAO declared some common name for the species: English - Paradise threadfin; France - Barbure paradis; Spanish - Barbudo paraíso.

It is a species of modest size with body depth at 1st dorsal-fin origin 20 to 28% (mean 24%) of typical length; head length 24 to 27% (mean 26%) of typical length. Posterior margin of preopercle serrated. The anal fin contains two spines and 12 soft rays, the first dorsal fin has seven spines, and the pectoral fin has fifteen to eighteen rays (all rays unbranched), the second dorsal fin has one spine and fourteen or fifteen soft rays; its posterior tip extends to or just below the level of anal-fin origin, and its length is between 30 and 35 percent (mean 33 percent) of typical length. However, in juveniles (less than around 100 mm typical length), it spans slightly beyond anal-fin origin. The initial pectoral filament, which is the shortest and does not extend to the level of the posterior tip of the pelvic fin, is followed by six others that are either somewhat shorter or do not exist at all. Fourth pectoral filament barely reaching the base of the caudal fin or reaching the level of the posterior anal fin; fifth to seventh pectoral filaments longer than their whole length; third pectoral filament barely approaching or not reaching level of anal-fin origin. Sixth pectoral filament is the biggest, length 181 to 248% (mean 208%) of typical length; caudal fin deeply forked; higher and lower lobes not filamentous; upper lobe 39 to 49% (mean 44%) and lower lobe 33 to 47% (mean 40%) of usual length, nose pointing nearly straight occipital profile. The upper jaw limit measures 13 to 15% (mean 14%) of the typical length, which is greater than the caudal peduncle base [9 to 12% (mean 10%) of the typical length]; the depth of

the posterior margin of the maxilla measures 3 to 4% (mean 4%) of the typical length, which is greater than the diameter of the eye [1 to 2% (mean 2%) of the typical length]; the lip on the lower jaw is well improved; large bands of villiform teeth on the ectopterygoids, palatines, and vomer. Scale rows above lateral line 6 or 7, below 10 to 12; pored lateral-line scales 66 to 71; lateral line simple, reaching from upper end of gill opening to mid-distal edge of caudal-fin membrane. Gillrakers totaling 12 to 14 on the upper limb and 17 to 20 on the lower leg. There is no swim bladder (Motomura, 2004).

From the eastern Indian to the western Pacific Oceans, *Polynemus paradiseus* extends over continental shelves from western India to Thailand. Two specimens from Indonesia (ANSP 11498, 135 to 147 mm mean length) lacked complete locality and other collecting information. It may be found in offshore seas (from depths of less than 27 m) and estuary waters, however it has been observed frequently entering fresh water for spawning (David, 1954). The species feeds on crustaceans, small fishes and benthic organisms. Sexes of the species are separate (Kagwade, 1970). Males mature at 110 mm overall length, whereas females do so at 120 mm, according to research. They hypothesized that the species spawns in the Hooghly River in India from April to September, with the majority of the females retrieved in October being spent (Mukhopadhyay et al., 1995).

The foundation of morphometric studies has been a set of conventional measures over the past 50 years (Rohlf, 1990). For morphometric measurements with the goal of species and/or stock distinction, the truss network system is being employed (Parsons et al., 2003; Turan et al., 2004; Mustafić et al., 2008; Akbarzadeh et al., 2009; AnvariFar et al., 2011). A Truss Network System has been utilized as an alternative, particularly for stock distinction (Strauss and Bookestein, 1982). The fish body is included in the uniform network using the truss network technique, which enhances the likelihood of retrieving morphometric variations within and across species. (Turan, 2000). In comparison to a typical set of data, a regionally unbiased network of morphometric measurements over a fish's two-dimensional outline should provide additional details regarding regional body variations. There is proof that the truss network approach is significantly more effective than conventional measures for describing morphological variation amongst closely related fish species (e.g.stocks). Previously, researchers believed that morphometric character variation was solely

hereditary, but more recent research has shown that it is also influenced by environmental variables such as water physico-chemical parameters, habitat kinds, and substrate types (Cabral et al., 2003; Nahar et al., 2015; Sharker et al., 2015). Morphometric variations are still viewed as an essential tool for stock description and identification, despite molecular markers being more reliable in revealing genetic and physiological differences across stocks (Costa et al., 2003; Murta, 2000). By identifying shape changes, morphometric features may be utilized to quantify a trait with evolutionary importance (Chaklader et al., 2016a). Therefore, research on fish morphology may help develop more effective management and conservation methods for a population (Muchlisin et al., 2014) and it also can result in a greater comprehension of species evolution, ecology, behavioral characteristics, and stock evaluation (Anvarifar et al., 2011; Chaklader et al., 2016b).

There has been a lot of research done on the species *Polynemus paradiseus* based on its species biology, genetic and seasonal variation, and proximate composition. Hiyoko Motomura spent his whole life to find its biological pattern and geographical distribution. He identified total 8 species from the genus *Polynemus* with also their species biology as well as their geographical distribution and habitats (Motomura, 2004). A research occurred by Bariah Ahmed (Ahmed, 2019) where he differentiated this species into two cluster on the basis of their genetic variation. He found that population from Paira river and Kirtonkhola is different from the population of the Tetulia river (Ahmed, 2019). Only one research conducted on the basis of morphometric analysis was done by Md. Reaz Chakladar (Chaklader et al., 2016). He studied the morphological characteristics of the paradise threadfin (*Polynemus paradiseus*) from the southern coast of Bangladesh, including length-weight relationships (LWRs), sex ratio, condition factor (KF), and allometric growth. Between January and October of 2014, local fisherman helped gather a total of 221 specimens, measuring 8.30 to 13.70 cm in typical length (TL) and 11.64 to 50.67 g in body weight (BW). The samples' total sex ratio (male: female=1:0.99, X^2=0.004, $P < 0.05$) showed no discernible deviation from the predicted value of 1:1. The mean variation of male continuously surpassed that of females throughout the year, indicating a size superiority of males over females, according to the length-frequency distribution. The LWR's allometric coefficient “b” considerably departed from 3, showing that both males and females experienced allometric growth. Significant

variations in slope and intercept between the sexes were found in the analysis of covariance (ANCOVA) ($P < 0.001$). Fish on Bangladesh's shore were flourishing, according to KF by month in both sexes (Chaklader et al., 2016).

Much research has also been conducted on morphometric analysis of several fish species in Bangladesh in recent time. The researcher employed landmark-based morphometric features, truss network measures, and meristic counts from two rivers (the Jamuna and the Halda) and a hatchery to assess the kalibaus (*Labea calbasu*) population in Bangladesh (Hossain et al. 2010). Using allozyme electrophoresis and the truss network technology to simultaneously examine the morphological variations between three *Liza abu* stocks, the Tigris river stock was isolated from the other two (Turan et al., 2004a). *Labeo rohita* has several defining physical traits as they age and before they do. Linear relationships were found between total length and the body's pre-pectoral, pre-dorsal, pre-ventral, pre-anal, and head dimensions (Islam et al., 1983). Study looked into the Yamuna River in northern India to learn more about the *rita rita* (Hamilton) (Devi et al., 1991). Total length, fork length, standard length, head length, pectoral fin-base length, and caudal peduncle depth were measured. Male and female were shown to have just as many different personality types. The forked length and head length varied by 5%, whereas the standard length and depth of the body at the base of the pectoral fins varied by 1%. A linear relationship was discovered between standard length and particular body features (Devi et al., 1991). Based on morphometric and meristic data, the researcher analyzed the taxonomic variation of Rohu and Mrigal populations in Bangladesh and concluded that Rui and Mrigal populations bred in hatcheries might be genetically different from their wild counterpart (Hasan et al., 2007). The climbing perch *Anabas testudineus* population from the Khulna region was more significant than the other four populations in terms of total length, standard length, post-orbital length, eye length, and length of the base of the dorsal fin (Hassan et al., 2005). Researchers studied morphological characters of four hatchery populations of Thai Pangas (*Pangasius hypopthalmus*) from the Mymensingh region in Bangladesh and found that four morphometric characters (BDA; PEL; FL; HL; HW; and AFR; CFR) was significantly higher than the other three populations (Khan et al., 2004).

Almost two dozen characteristics were examined, including fourteen meristic and twenty-three morphometric characteristics, all in connection with the skull, spine, and

dorsal and anal fin rays. It is impossible to extrapolate a biogeographic explanation from the morphological data showing a substantial variation between the four groups. Subsequently, some research (Ahmed, 2019; Motoruma, 2004; Chakladar, 2015; Nahar, 2015) has conducted on this species on the basis of genetic variations, length-weight relationship and biological distribution. But multivariate analysis of morphological lengths among male and female population has not done yet. This research focused on phenotypical differentiation among the populations and elucided stock structure.

Chapter-3: Materials and Methods

3.1 Study area

Fresh and unscathed samples were collected from several regions. Samples were gathered from location-1: Fishery ghat, Chattogram (N 22.319378, E 91.838729); location-2: BFDC fishery ghat, Cox's Bazar (N 21.452368, E 91.968225); location-3: Chairman ghat, Noakhali (N 22.523996, E 91.088953); location-4: Rupsha wholesale fish market, Khulna (N 22.801434, E 89.581104) and location-5: Fuljhuri fish market, Borguna (N 22.215134, E 90.074900). Those samples were brought into the laboratory and took the picture through a camera placing into photo lab. These pictures merged into ascending format and testified through measuring software for accumulating analytical data. The locations from which samples were collected for this study are demonstrated in figure-2.

Samples were collected for this study from September 2021 to December 2021 after the corona pandemic. Biological samples were randomly selected, and 366 fish samples were used for analysis. From Fishery ghat, Chattogram, we collected total 94 samples. From the others location like BFDC fishery ghat, Cox's Bazar, we collected 75 samples; from Chairman ghat, Noakhali, total 64 samles. The other two location, Kulna and Borguna, we collected around 65 and 68 samples respectively.

3.2 Methods of the study

3.2.1 Sample collecting and sorting

The collected fish samples were then brought to the laboratory and sorted out as the intact samples. Organized fish samples were put into a tray and decorated in an orderly for capturing photos using the photo lab.

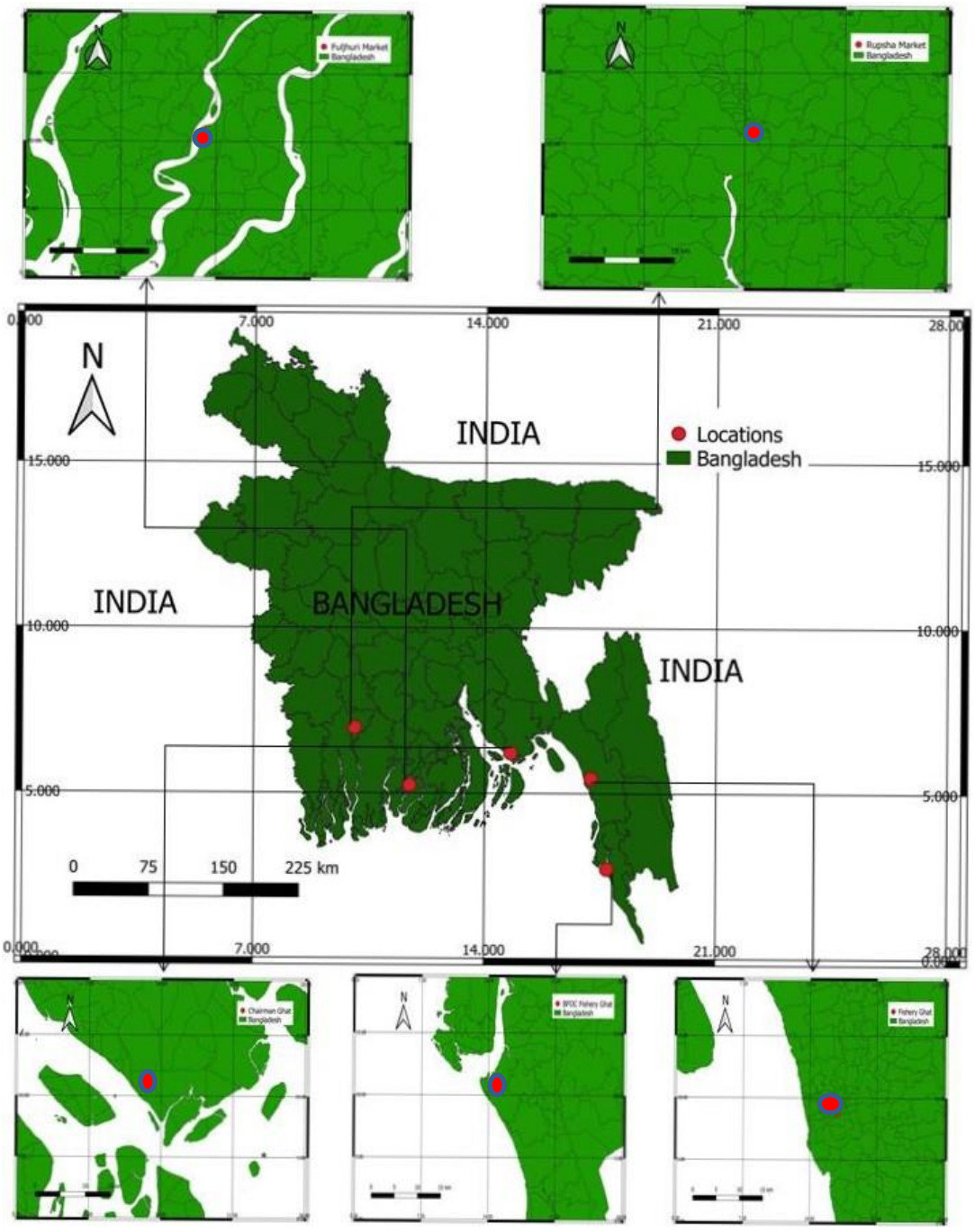


Figure-02: Locations of sample collection

Figure-3: Sorting vigorous sample

Figure-4: Arranging the samples orderly

Figure-5: Arranged Samples

3.2.2 Quantitative research and sex identification

The camera was set up in the portable photo lab to capture pictures of the biological samples. Those images were transferred into the computer and used to ordain landmarks for truss networking. A data sheet was prepared initially to keep up the records of landmark.

Figure-6: Photo Lab

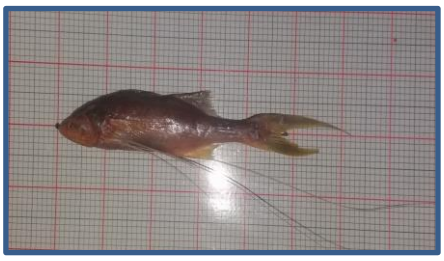


Figure-7: Clicked image in photo lab

Sex can be easily identified by observing the external characteristics of a mature female fish with ripened egg. However, determining the sex of the fish is essential for this study. The acetocarmine gonad squash method is one of the most well-known methods. Creating an acetocarmine solution requires blooming 0.5 grams of carmine in 100 milliliters of 45% acetic acid for 2 to 4 minutes (Guerrero III et al., 1974).

After capturing images of the samples, non-identified male and female samples were dissected with fine scissors, and the belly part was opened up using forceps. Then the gonad was revealed exactly beneath the fish body's dorsal portion. The gonad was taken out with forceps smoothly and replaced on a slide. A small part of the gonad was cut off with a blade and kept on another slide. Acetocarmine stain was carefully added to the gonadal specimen and covered with a cover slip. Then the slide was put under a microscope to determine the gender of the fish.

Figure-8: Dissecting sample

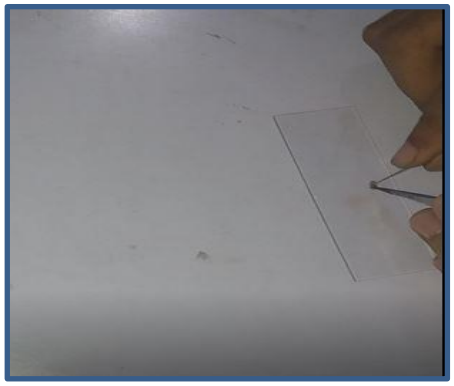


Figure-9: Set up on the slide

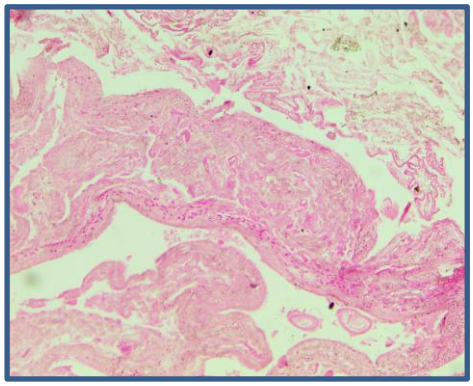


Figure-10: Microscopic view of male gonad

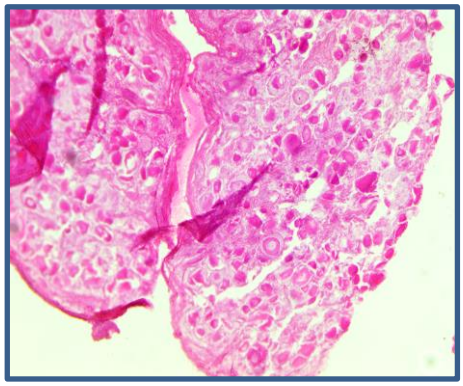


Figure-11: Microscopic view of female gonad

3.2.3 Landmarks adjustment and branding

A total of 14 points and 32 landmarks' positions are listed below. These points and distances were measured in the laboratory with the help of Sigma scan pro software and used to evaluate morphometric distortion and truss network.

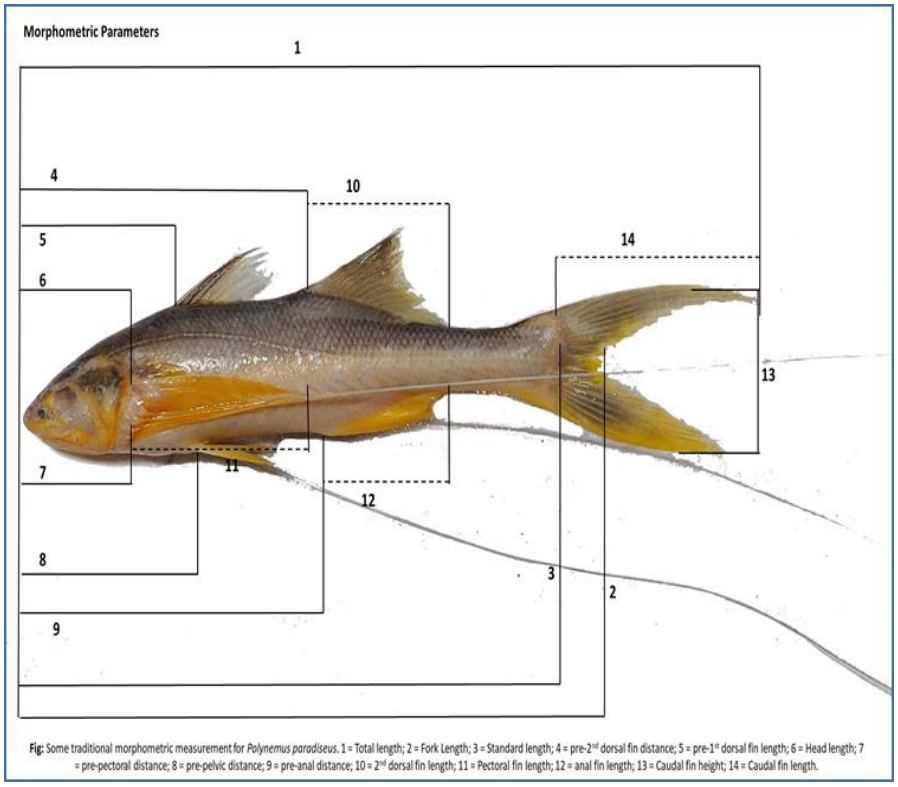


Figure-12: Morphometric lengths (Table-1)

Table-1: Morphometric lengths

Parameters	Indicator	Description
1	TL	The whole length
2	FL	The scale of a fork
3	SL	The Typical Length
4	2PDFD	The proximity of the snout to the fish's second dorsal fin
5	1PDFD	The snout to the 1st dorsal fin measurement
6	HL	Size of the Head
7	PPecFD	How far is the snout from the first pectoral fin
8	PPelFD	Distinction before pelvic fins
9	PAFD	The Relative Proximity of the Anterior Pre anal Fin to the snout

10	2DFL	The size of the second dorsal fin
11	PecFL	Total Length of the Pectoral Fin
12	AFL	The size of the anal fin
13	CFH	Tail fin height
14	CFL	Size of the caudal fin

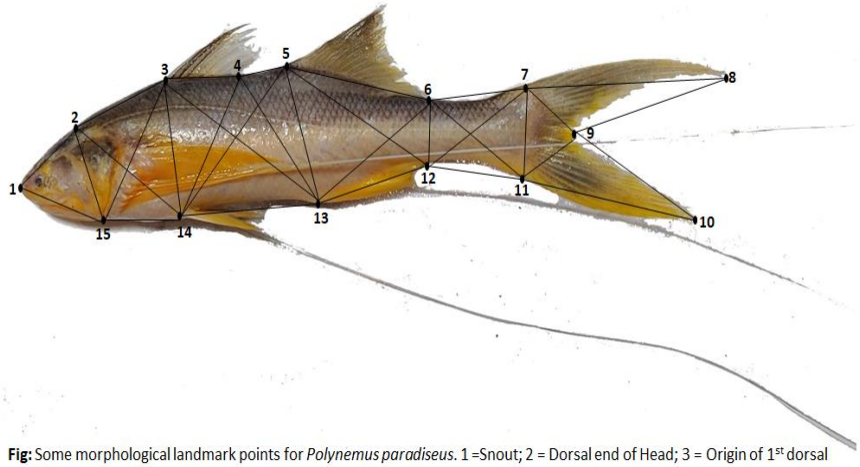


Fig: Some morphological landmark points for *Polynemus paradiseus*. 1 =Snout; 2 = Dorsal end of Head; 3 = Origin of 1st dorsal fin ; 4 = End of 1st dorsal fin ; 5 = Origin of 2nd dorsal fin; 6 = End of 2nd dorsal fin; 7 = origin of upper caudal fin; 8 = End of upper caudal fin ; 9 =Middle end of Caudal fin; 10 =End of lower caudal fin; 11 = origin of lower caudal fin; 12 =End of anal fin; 13 = Origin of anal fin; 14 = Origin of pelvic fin; 15= Ventral end of Head

Figure-13: Landmarks points (Table-2)

Table-2: Landmarks points and their description

SL NO	Landmarks Points	Description
1	D1-2	How far is the mouth from the first dorsal fin
2	D2-3	How far back the first dorsal fin begins from the back of the head
3	D3-4	Size of the first dorsal fin
4	D4-5	The length from the base of the first dorsal fin to the bottom of the second dorsal fin.
5	D5-6	Length of the second dorsal fin
6	D6-7	The vertical measurement from the tip of the second dorsal fin to the base of the upper caudal fin in an adult male.
7	D7-8	The upper caudal fin length is measured from the base of the fin to the tip.
8	D8-9	How far down the caudal fin can one see from its most anterior and posterior points
9	D9-10	How far down the caudal fin do you have to go before it reaches the floor

10	D10-11	The length from the base of the tail to its tip
11	D11-12	The length of the anal fin from its base to its tip.
12	D12-13	Measurement of the Anal Fin
13	D13-14	The span between the pelvic fins and the anal fins
14	D14-15	Measured from the base of the pelvic fin to the bottom of the head's ventral fin
15	D1-15	The horizontal measurement from the tip of the snout to the back of the head
16	D2-15	How far the ventral end of the skull is from the dorsal end
17	D3-14	It is measured from the base of the first dorsal fin to the bottom of the pelvic fins.
18	D2-14	How far back the pelvic fins are from the tail
19	D3-15	How far the head's ventral end is from the base of the first dorsal fin
20	D3-13	The span between the first and second dorsal fins' origins.
21	D4-13	The span between the base of the first dorsal fin and the beginning of the second dorsal fin.
22	D4-14	It is measured from the base of the pelvic fin to the bottom of the first dorsal fin.
23	D5-14	Length of the pelvic fin from its origin to the base of the second dorsal fin
24	D5-13	The span between the second dorsal fin and the tail fin
25	D5-12	The length of the anal fin measured from its base to its tip
26	D6-13	distance between the beginning of the anal fin and the second dorsal fin
27	D6-12	distance between the second dorsal fin's end and the anal fin's end
28	D6-11	From the end of the second dorsal fin to the end of the tail fin
29	D7-12	From the beginning of the upper caudal fin to the end of the anal fin
30	D7-11	From the beginning of the upper caudal fin to the front of the lower caudal fin.
31	D7-9	Distance from the top of the tail to the middle of the tail
32	D9-11	How far is it from the middle of the caudal fin to where the lower caudal fin starts?

*****D= Distance

3.2.4 Size Adjustment

Data sets were created by using Sigmascan pro software to measure morphometric and meristic properties prior to the commencement of initial investigation. The following figure-14 shows how the measurement was collected.

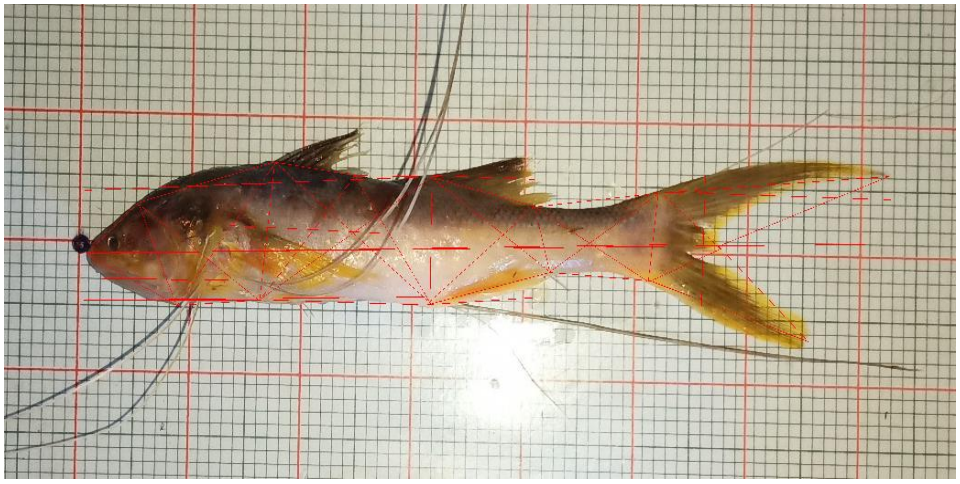


Figure-14: Landmark data collection through Sigmascan pro

Most data distortions were disregarded before analysis. Scientists provided a method that was used to adjust the available data for the size impact (Elliott et al., 1995). The equation is as follows:

$$M_{adj.} = M\ (L_s/L_o)^b$$

Here,

M_{adj} : proportional sizing,

M : basic sizing,

Ls : the average length of all fish samples in each study.

Lo : whole fish length

The slope of the regression of log M on log Lo was used to estimate parameter b for each character across all fish groups. After that, we connected the efficacy of the transformed values and the TL to the size-adjusted values.

3.2.5 Statistical Analysis

To demonstrate the morphological changes across different geographical location, samples of *P. paradiseus* were compared. Later, by comparing male and females of the species, the biological variations between the sexes of *P. paradiseus* were

discovered. Based on size-adjusted morphological and landmark distance data, a univariate analysis of variance (ANOVA) was employed to assess the statistical significance of morphological differences ($P < 0.01$). Meristic variables were compared using the Kruskal-Wallis test, which does not pre-suppose a normal distribution. All metric-free morphological and landmark distance data were subjected to a discriminant Functional Analysis (DFA) and a Principal components analysis (PCA). In order to reduce the number of chosen morphological characteristics to a few composite measures of morphological attributes, we investigated the variance between the population according to specified areas and measured features using this PCA. PCAs were used to estimate the specimen distribution patterns over the five designated locations using R's 'FactMineR' package (Sebastien et al., 2008), version 3.5.2 (R development core team, 2018). Because they accounted for the majority of the variance, we only employed the first and second PCAs. Every graph was created using the "ggplot2" software (Wickham, 2009). The linear discriminant function analysis was also used to calculate the percentage of paradise threadfin fish that were correctly categorized based on the population and the five geographic regions of the species. Cross-validation was used to compute the projected actual error rates of the classification functions using the percentage of correctly classified (PCC) data. Additionally, morphometric distances between the individuals of the species and its five areas were inferred for cluster analysis using the Euclidean distance as a measure of dissimilarity and the UPGMA (unweighted pair group method with arithmetical average) as the clustering technique (Veasey et al., 2001). SPSS version 26.0 and Microsoft Office Excel 2010 were also used for statistical analyses.

Chapter-4: Result

The straightforward descriptive portion of the comparison of differenet morphological data between male and female samples of the species *P. paradiseus* acquired from water bodies in Bangladesh is presented in this section. Here, based on our research, we give the specifics of systematic analytical observations of the morphology.

4.1 Analysis of variance for male and female samples

There was no significant correlation at the significance level ($p>0.05$) or 95% confidence interval between typical length and other measurements (adjusted size), indicating size effects were successfully removed through algometric transformation (Apendix A and B). Then univariate (ANOVA) analysis was performed through the measurements, and caudal fin height (CFH), caudal fin length (CFL) along with 28 truss network landmarks showed significant difference at the level of significance ($p<0.5$*; $p<0.01$**; $p<0.001$***) for the male population (Appendix-A). Three stars (***) make highly significant whereas one star (*) makes slightly significant relationship among group means of the variables.

Table-3: Tests of equality of group means for the male population

Variables	Wilks' Lambda	F	df1	df2	Sig.
CFH	.827	10.082	4	193	.000***
CFL	.800	12.078	4	193	.000***
D 1-2	.937	3.253	4	193	.013*
D 2-3	.814	10.995	4	193	.000***
D 3-4	.895	5.631	4	193	.000***
D 4-5	.901	5.315	4	193	.000***
D 5-6	.829	9.986	4	193	.000***
D 7-8	.882	6.474	4	193	.000***
D 8-9	.940	3.090	4	193	.017*
D 9-10	.736	17.278	4	193	.000***
D 10-11	.542	40.811	4	193	.000***
D 11-12	.857	8.060	4	193	.000***
D 12-13	.786	13.105	4	193	.000***
D 13-14	.716	19.175	4	193	.000***
D 14-15	.898	5.457	4	193	.000***
D 1-15	.949	2.602	4	193	.037*
D 2-15	.891	5.927	4	193	.000***
D 3-14	.806	11.605	4	193	.000***
D 2-14	.885	6.297	4	193	.000***

D 3-13	.943	2.893	4	193	.023*
D 4-14	.932	3.537	4	193	.008**
D 5-14	.907	4.929	4	193	.001**
D 5-13	.945	2.799	4	193	.027*
D 5-12	.831	9.797	4	193	.000***
D 6-13	.810	11.292	4	193	.000***
D 6-11	.868	7.316	4	193	.000***
D 7-12	.841	9.090	4	193	.000***
D 7-11	.790	12.808	4	193	.000***
D 7-9	.876	6.829	4	193	.000***
D 9-11	.600	32.218	4	193	.000***

In the case of Land-mark distances, twenty-eight (1 to 2, 2 to 3, 3 to 4, 4 to 5, 6 to 7, 8 to 9, 9 to 10, 10 to 11, 11 to 12, 12 to 13, 13 to 14, 14 to 15, 1 to 15, 2 to 15, 3 to 14, 2 to 14, 4 to 13, 4 to 14, 5 to 14, 5 to 13, 5 to 12, 6 to 13, 6 to 11, 7 to 12, 7 to 11, 7 to 9, 9 to 11) truss measurements were significantly different among samples in varying degrees ($p<0.05$ or $p<0.01$ or $p<0.001$) among five different groups of *P. paradiseus* revealed through univariant statistics (Table-03).

Fork length (FL), 2nd pre dorsal fin distance (2PDFD), 1st pre dorsal fin distance (1PDFD), pre pectoral fin distance (PPecFD), pre pelvic fin distance (PPelFD), Pre anal fin distance (PAFD), 2nd dorsal fin length (2DFL), pectoral fin length (PecFL), anal fin length (AFL), caudal fin height (CFH), caudal fin length (CFL) along with 25 truss network landmarks showed significant difference at the level of significance ($p<0.5$*; $p<0.01$**; $p<0.001$***) for the female population (Appendix-B).

Table-4: Tests of equality of group means for the female population

Variables	**Wilks' Lambda**	**F**	**df1**	**df2**	**Sig.**
FL	.917	3.670	4	163	.007**
2PDFD	.914	3.830	4	163	.005**
1PDFD	.920	3.520	4	163	.009**
PPecFD	.738	14.497	4	163	.000***
2DFL	.823	8.745	4	163	.000***
PecFL	.705	17.019	4	163	.000***
AFL	.912	3.949	4	163	.004**
CFH	.406	59.608	4	163	.000***
CFL	.858	6.718	4	163	.000***
D 3-4	.874	5.849	4	163	.000***
D 4-5	.898	4.651	4	163	.001**
D 5-6	.757	13.086	4	163	.000***
D 6-7	.943	2.477	4	163	.046*

D 7-8	.798	10.288	4	163	.000***
D 8-9	.862	6.547	4	163	.000***
D 9-10	.830	8.351	4	163	.000***
D 10-11	.664	20.578	4	163	.000***
D 11-12	.879	5.633	4	163	.000***
D 12-13	.910	4.051	4	163	.004**
D 13-14	.833	8.158	4	163	.000***
D 14-15	.941	2.552	4	163	.041*
D 2-15	.762	12.718	4	163	.000***
D 3-14	.747	13.784	4	163	.000***
D 2-14	.851	7.155	4	163	.000***
D 4-14	.848	7.316	4	163	.000***
D 5-14	.880	5.531	4	163	.000***
D 5-13	.890	5.041	4	163	.001**
D 5-12	.829	8.425	4	163	.000***
D 6-13	.849	7.258	4	163	.000***
D 6-12	.909	4.073	4	163	.004**
D 6-11	.771	12.124	4	163	.000***
D 7-11	.649	21.999	4	163	.000***
D 7-9	.831	8.267	4	163	.000***
D 9-11	.717	16.060	4	163	.000***

In the case of Land-mark distances, twenty-five (3 to 4, 4 to 5, D 5-6, 6 to 7, 8 to 9, 9 to 10, 10 to 11, 11 to 12, 12 to 13, 13 to 14, 14 to 15, 2 to 15, 3 to 14, 2 to 14, 4 to 13, 4 to 14, 5 to 14,5 to 13, 5 to 12, 6 to 13, 6 to 12, 6 to 11, 7 to 11, 7 to 9, 9 to 11) truss measurements were significantly different among samples in varying degrees ($p<0.05$ or $p<0.01$ or $p<0.001$) among five other groups of *P. paradiseus* revealed through univariant statistics (Table-04).

Table-5: Predicted group membership result for the male population

		Locatio n T	Predicted Group Membership					
			1	2	3	4	5	Total
Original	Count	1	34	0	4	0	1	39
		2	0	49	3	1	1	54
		3	1	4	31	1	2	39
		4	0	0	0	32	2	34
		5	0	0	2	3	27	32
	%	1	87.2	.0	10.3	.0	2.6	100.0
		2	.0	90.7	5.6	1.9	1.9	100.0
		3	2.6	10.3	79.5	2.6	5.1	100.0
		4	.0	.0	.0	94.1	5.9	100.0
		5	.0	.0	6.3	9.4	84.4	100.0

Cross validated[b]	Count	1	29	1	8	0	1	39
		2	1	47	3	2	1	54
		3	4	5	26	3	1	39
		4	0	0	1	31	2	34
		5	0	0	6	6	20	32
	%	1	74.4	2.6	20.5	.0	2.6	100.0
		2	1.9	87.0	5.6	3.7	1.9	100.0
		3	10.3	12.8	66.7	7.7	2.6	100.0
		4	.0	.0	2.9	91.2	5.9	100.0
		5	.0	.0	18.8	18.8	62.5	100.0

For morphometric and landmark measures, discriminant function analysis (DFA) generated five sets of predicted group membership. The first group analyses in location 1 for original resolved 87.2%, and the other 4 locations determined 0%, 10.3%, 0%, and 2.6%, respectively, of the total variability for both morphometric and landmark measurements. In contrast, cross-validated resolved 74.4% for location 1 and other locations revealed 2.6%, 20.5%, 0%, and 2.6% respectively. They all explained 100% of the total variability for both original and cross-validated results. The following table shows the other predicted group membership with original and cross-validated results for the male population (Table-5).

Table-6: Predicted group membership result for the female population

		Location T	Predicted Group Membership					Total
			1	2	3	4	5	
Original	Count	1	29	0	0	0	0	29
		2	0	32	6	2	0	40
		3	0	4	31	1	0	36
		4	0	0	0	30	1	30
		5	0	2	2	1	27	32
	%	1	100.0	.0	.0	.0	.0	100.0
		2	.0	80.0	15.0	5.0	.0	100.0
		3	.0	11.1	86.1	2.8	.0	100.0
		4	.0	.0	.0	96.8	3.2	100.0
		5	.0	6.3	6.3	3.1	84.4	100.0
Cross validated[b]	Count	1	29	0	0	0	0	29
		2	0	25	12	2	1	40
		3	0	9	21	4	2	36
		4	0	0	1	24	6	30
		5	1	2	4	4	21	32
	%	1	100.0	.0	.0	.0	.0	100.0
		2	.0	62.5	30.0	5.0	2.5	100.0
		3	.0	25.0	58.3	11.1	5.6	100.0
		4	.0	.0	3.2	77.4	19.4	100.0
		5	3.1	6.3	12.5	12.5	65.6	100.0

The first group analyses in location 1 for original resolved 100.0% and other 4 location resolved 0%, 0%, 0% and 0% respectively of the total variability for both morphometric and landmark measurements whereas cross-validated resolved 100% for location 1 and other locations revealed 0%, 0%, 0% and 0% respectively. They all explained 100% of the total variability for both original and cross-validated results. The following table shows the other predicted group membership with original and cross-validated results for the female population (Table-6).

4.2 Principle Component Analysis

Bartlett's test of sphericity was used to look at the data's eligibility for principal component analysis, and it was found to be significant ($P<0.01$). The principle component (PC) analysis was used to discover which morphometric measurement best distinguishes between the populations. Twelve components with eigen values >1 were identified using principal component analysis from the fourteen morphometric data and the thirty-two truss network variables, which accounted for 80.96% of the variation across male samples. All male samples could be divided into two groups, with the first principal component (PC1) explaining 17.69% of the variance and the second PC2 explaining 15.1%. On the other hand, twelve components with eigen values >1 were identified using principal component analysis from the fourteen morphometric data and the thirty-two truss network variables, which accounted for 75.8% of the variation across female samples. Female samples could be broken down into two groups, with the first principal component (PC1) explaining 15.4% of the variance and the second PC2 explaining 12.0%.

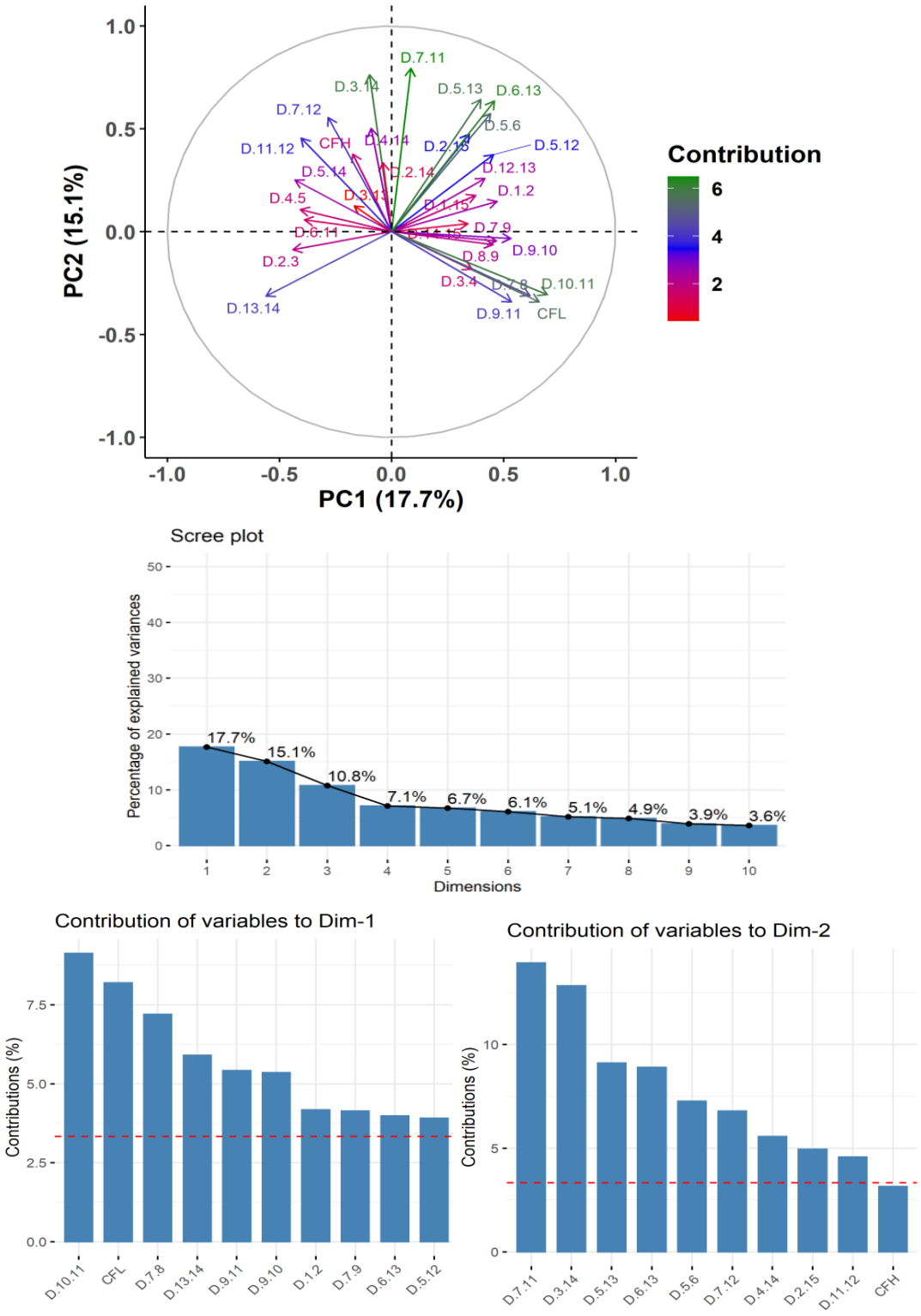
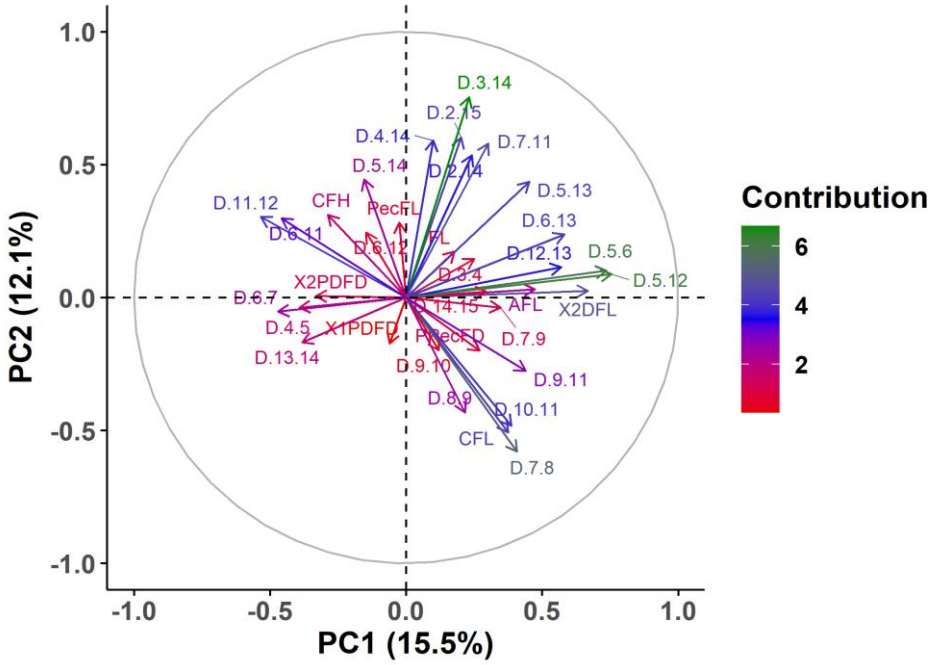
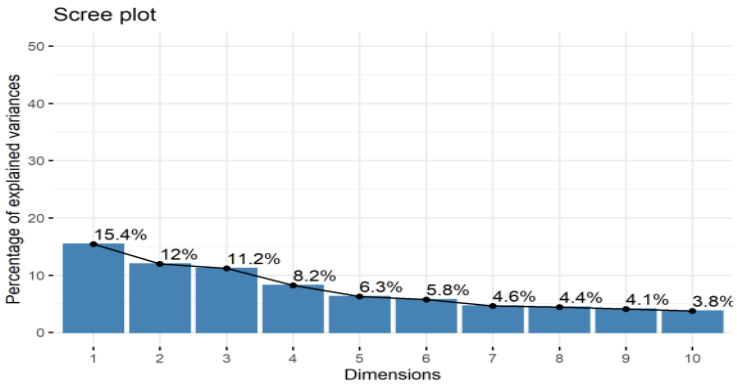


Figure-15: Principle component analysis for the male population





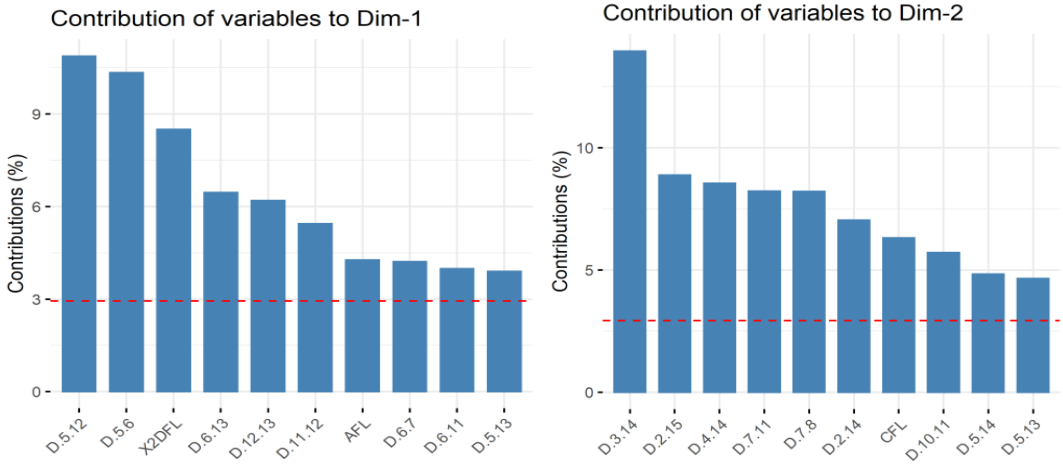


Figure-16: Principle Component Analysis for the female population

4.3 Linear Discriminant Analysis

From the PCA analysis, there is an overlap in the data, and the differences between the population can't be made clear. Because of this, a linear discriminant analysis was done to look at the dataset and tell the samples from different places apart. The result showed that 45.7% of the differences were due to LD1, 29.2% were due to LD2 for the male population and 56.46% of the differences were due to LD1, and 27.46% were due to LD2 for the female population. The following figure shows the difference between male and female samples.

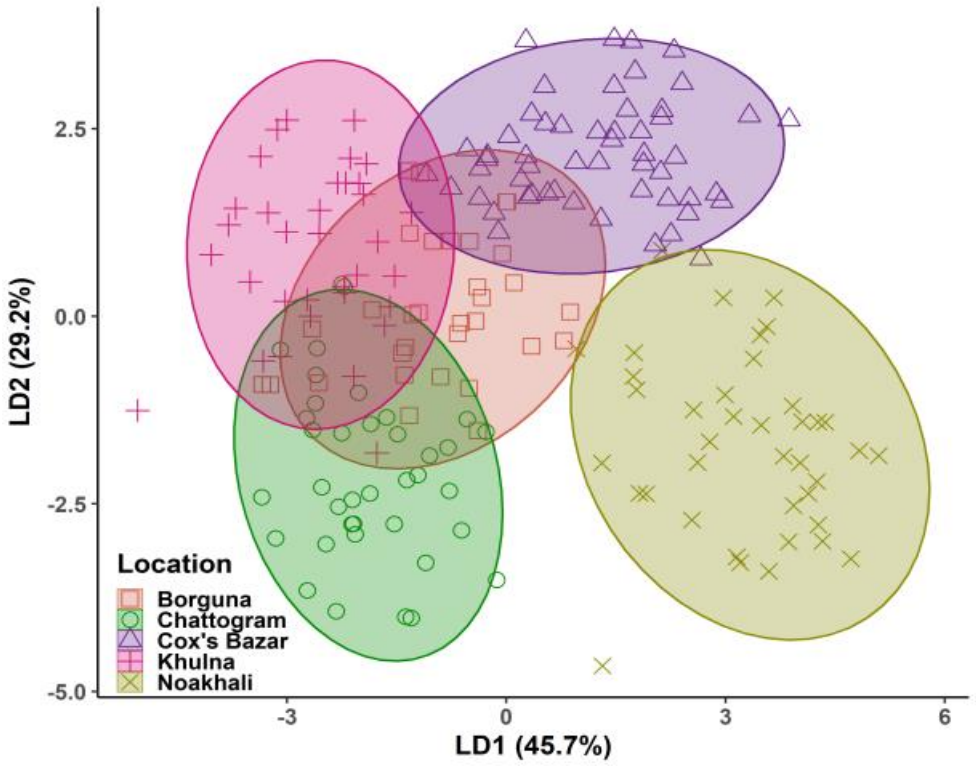


Figure-17: Linear discriminant analysis of male populations

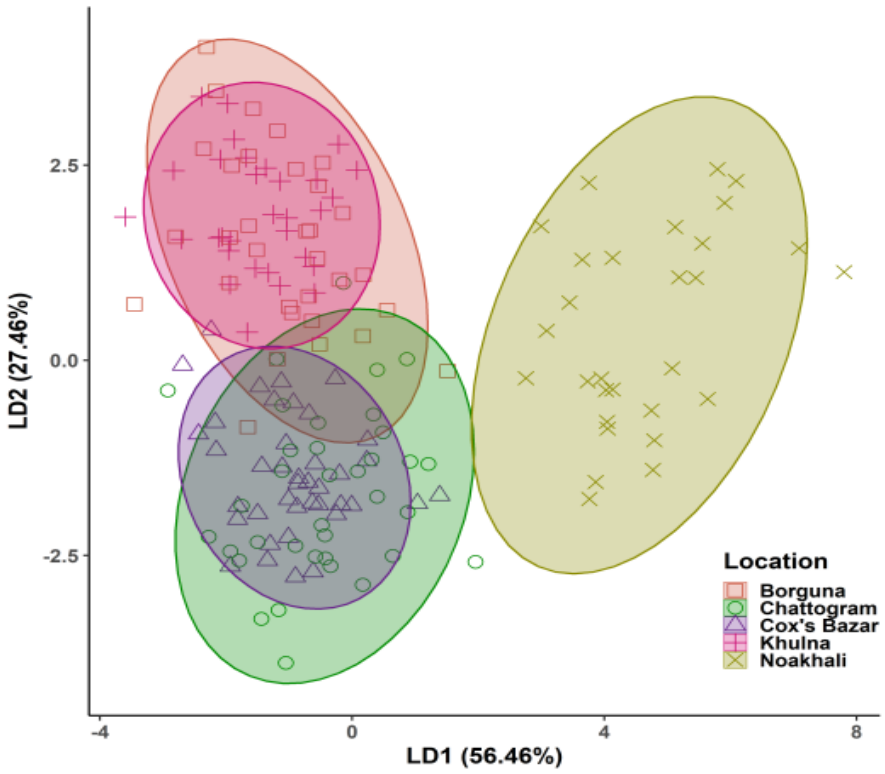


Figure-18: Linear discriminant analysis of female populations

4.4 Hierarchical Clustering

A dendrogram was constructed for *Polynemus paradiseus* populations from five locations based on geographical distances and morphological analyses among cluster centroids. Using the squared Euclidean dissimilarity and the UPGMA (unweighted pair group method with arithmetical average) for the clustering technique (Veasey et al., 2001), we identified two primary groups. Male samples from Khulna and Borguna form one cluster. In contrast, those from Chattogram, Cox's Bazar, and Noakhali form another, with the two former locations' clusters looking somewhat different from those of the latter. For female samples from Chattogram and Cox's Bazar form one cluster whereas those from Khulna, Borguna, and Noakhali form another, with the two former locations' clusters looking somewhat different from those of the latter.

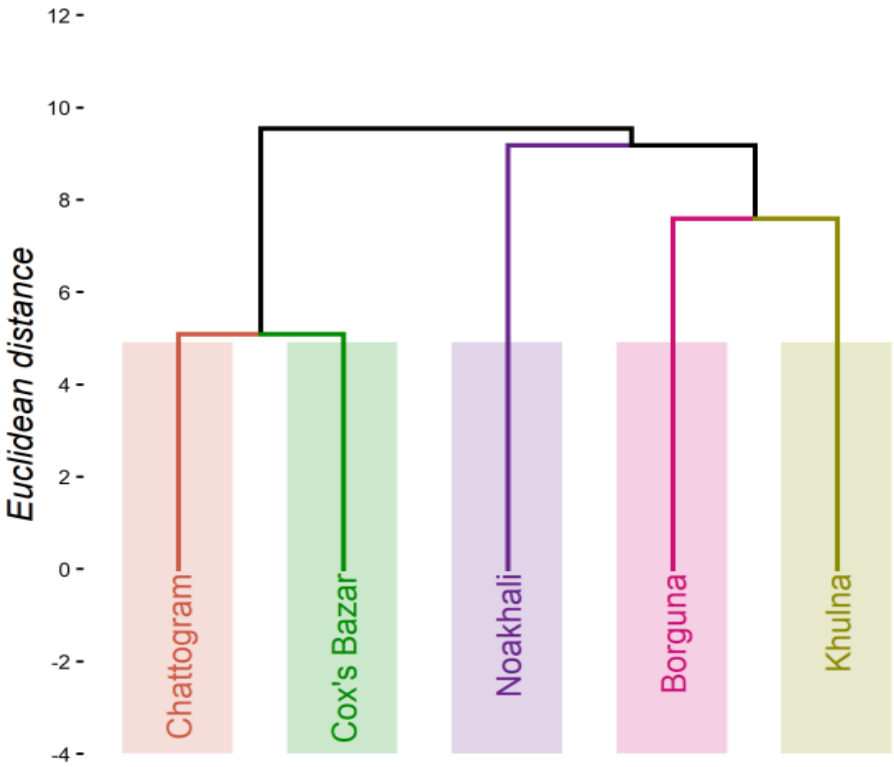


Figure-19: Hierarchical clustering using UPGMA process of male

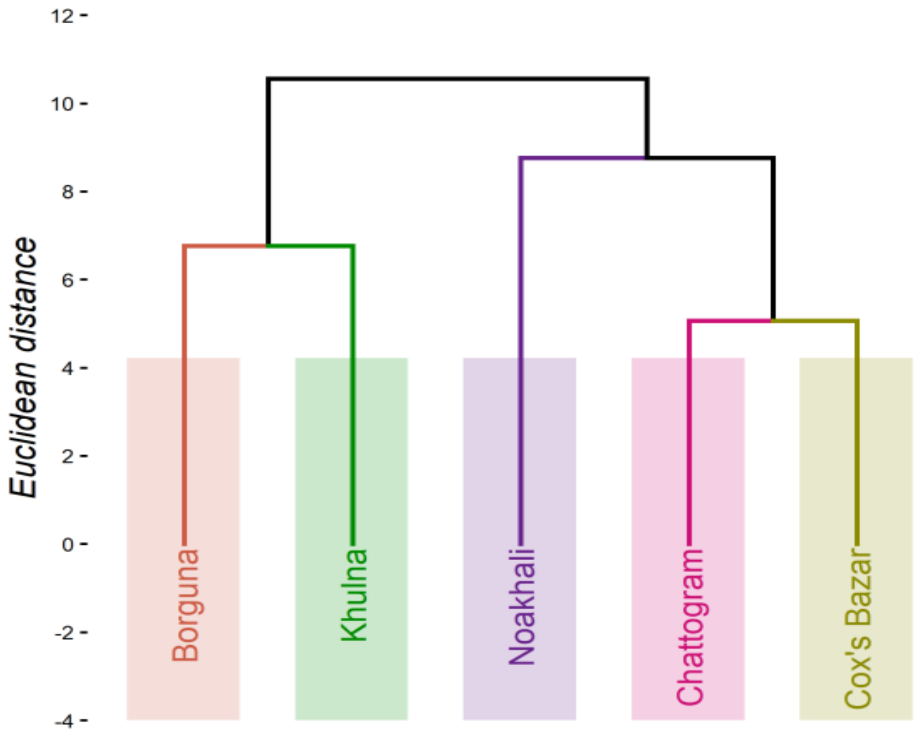


Figure-20: Hierarchical clustering using UPGMA process of female

Chapter-5: Discussion

Phenotypic variation occurs in the same raced biological organism. Morphometric analysis can determine phenotypic changes and estimate how much distortion occurs in an organism's body shape and size. Landmarks counting happen by mapping some homogenous point knitted together (Giducos et al., 2015).

The physical differences across the populations of *Polynemus paradiseus* may result from their distinct geographic locations, the great degree of environmental variables that now exists in their habitats or populations may have descended from various progenitors. Fish are susceptible to environmental changes and swiftly adapt by modifying their fundamental morphometrics to match new environmental circumstances (Allendorf and Phelps, 1988). It is generally known that morphological traits may be highly flexible in response to environmental variations (Swain et al., 1991). The physical heterogeneity among the populations from various sites may, therefore, be explained by the unique ecological characteristics of these habitats. Six populations of *Capoeta gracilis* in Iran's Aras, Sefidrud, Shirud, Tonekabon, Haraz, and Gorganrud river systems have reported experiencing this kind of prejudice (Samaee et al., 2006). Researchers described the differences in the *Labeo rohita* stocks of the Ganga basin caused by unusual hydrological conditions, such as variations in alkalinity, current pattern, temperatures, and turbidity, as well as the closeness of the stocks because of their shared habitat characteristics and environmental effects (Mir et al. 2013). Tentulia and Meghna rivers' ecological characteristics, particularly their salinity, were almost identical to those of the Baleswar river. Variations in *Labeo rohita* might be due to differences in the saltiness of the Tentulia, Meghna, and Baleswar rivers, which were 3.5 ppt, 6.0 ppt, and 0.6 ppt, respectively (Dasgupta et al. 2014). Habitat differences significantly impact morphological differentiation in diverse populations (Ferrito et al., 2007).

Analysis of Variance (ANOVA) showed that out of fourteen morphometric measurements, ten morphometric lengths [TL, FL, 2PDFD, 1PDFD, PPecFD, 2DFL, PecFL, AFL, CFH, CFL] of female population and seven morphometric length [TL, PPecFD, PPelFD, 2DFL, PecFL, CFH, CFD] of male population were significantly different in varying degrees ($p<0.05$ or $p<0.01$ or $p<0.001$) among these all populations of *Polynemus paradiseus*. Researchers (Turan et al., 2004a; Hossain et

al., 2010; Parvej et al., 2014; Rahman et al., 2014; Hossain et al., 2015) also discovered variations in morphological differences in various populations from various habitats in *Liza abu, Rhinomugil corsula, Eutropiichthys vacha, Labeo calbasu*, and *Heteropneustes fossilis* respectively.

In the truss network, twenty-eight characters of female samples and twenty-five characters of male samples out of 32 distances were significantly different ($p<0.05$or <0.01 or <0.001) for populations of *Polynemus paradiseus* in those locations. Hossain et al. 2010 found four of 22 truss network measurements in kalibaus (*Labeo calbasu*) populations gathered from the Jamuna, the Halda, and a hatchery in Bangladesh had significant differences ($p<0.05$ or <0.001). Additionally, 16 of 25 truss measures taken on anchovies (*Engraulisen crasicolus* L.) in the Black, Aegean, and Northeastern Mediterranean seas revealed significant variations ($p <0.05$) (Turan et al., 2004b). In populations of *Eutropiichthys vacha* from Kaptai Lake, Meghna River, and Tanguar Haor in Bangladesh, the researcher discovered significant variations ($p <0.001$) in 4 of 17 morphometric features and only 1 of 22 truss network measures (Parvej et al. 2014).

Stock management systems may be concerned with whether discriminant function analysis (DFA) may be used to distinguish between several stocks of the same species (Karakousis et al., 1991). Another multivariate technique, PCA, which included visual analysis of projected PC1 and PC2 values for each specimen, was used to guarantee this differentiation. In terms of morphometric traits and truss measurements in *Polynemus paradiseus*, both discriminant function analysis (DFA) and principal component analysis (PCA) suggested that the population from Khulna and Borguna district differs phenotypically from the Chattogram, Noakhali, and Cox's Bazar populations. This inter-population variation may be explained by the distinct geographic locations of each population as well as the physiological and environmental constraints that each population faces, such as salinity, temperature, turbidity, water pressure, current flow, and food availability (Allendorf, 1988; Swain et al., 1991). PCA was used on populations of freshwater shrimp *Macrobrachium vollenhovenii* collected from rivers in Côte d'Ivoire and found significant morphometric variation due to river length and geographic location (Konan et al.,

2010). Additionally, populations of the same species from various geographic locations had distinct morphologies (Paugy and Lévêque, 1999).

Fisher (1936) developed LDA as a method for determining the linear combinations of variables that performed the best when categorizing or dividing data. Using these linear combinations, researchers may determine which factors contribute the most to group separation and the most probable categorization for a case with unobserved group membership. It accounted for 83.92% of the variance for female populations and 74.9% of the variance for male populations. The LDA plot clearly showed that populations from Chattogram, Cox's Bazar and Noakhali districts were significantly different from Khulna and Borguna districts. Populations from Noakhali district were slightly different from the populations of Chattogram and Cox's bazar districts. Intra-colonial diversity in the scleractinian coral *Acropora millepora* was analyzed using a LDA biplot, which revealed that tiny colonies primarily influenced the size class separation (Conlan et al., 2018). In contrast, other variables drove the separation of more enormous colonies (Conlan et al., 2018). In a research along the Bangladeshi coast, the species diversity and stock structure of the mud crab *Scylla sp.* were examined. Using LDF analysis, *S. olivacea* and *S. serrata* could be distinguished from one another (Asaduzzama et al., 2021).

Utilizing morphological analysis and centroids of *Polynemus paradiseus* populations obtained from five different locales, the dendogram was constructed. Along male samples showed the same hierarchical clustering, but there was a change in females that Noakhali district's samples clustered with Khulna and Borguna districts instead of Chattogram and Cox's Bazar districts. These changes in habitats might be the result of genetic and environmental factors. A dendrogram constructed using information on the physical features seen in populations of Japanese charr, *Salvelinus leucomaenis* (Nakamura, 2003); Mullet, *Rhinomugil corsula* (Hossain et al., 2015); *Eutropiichthys vacha* (Parvej et al., 2014); and *Labeo calbasu* (Hossain et al., 2010) from different habitat.

The implications of these results for the management of the paradise threadfin fish stocks in the countries where they occur are quite profound. There is considerable gene flow between the paradise threadfin fish in the Bay of Bengal and this means that Bangladesh and Indian fisheries managers need to cooperate in developing joint

management strategies for the paradise threadfin fish. There are major political impediments to the development of this type of arrangement. Each country should at least be aware that changes in the available biomass within their waters may be due to fishing pressure in neighbouring countries. Consequently, in both aquaculture and open-water management, it is essential to select genetically superior stocks along with better features. More research especially morphometric studies and investigations of the impacts of environmental factors is needed for conservation and mass seed production of selected stocks to pave the way to saving this species from extinction.

Chapter-6: Conclusion

The morphometric variation of different variables among the population of *Polynemus paradiseus* found significant differentiation at 5%, 1% and 0.01% level of siginicance. At 0.01% level of significance, the variables show maximum variability and greater than 5% level of significance , those variables can't be justified or those resemble similarity. The maximum variability found in the length from the base of the tali to its tip and the length from the beginning of the upper caudal fin to the front of the lower caudal fin for male population whrereas anal fin length and the length of the base of first dorsal fin to the bottom of the caudal fin for female populations. Truss network measurements show significant variations and hierarchical clustering using UPGMA process successfully separates male and female populations.

The morphometric features employed allowed for some differentiation between the groups under study. In order to achieve this, a condensed set of field-friendly morphometric traits (variables with high discriminatory power) was used. Principal component and discriminant function analyses were used to find these variables. Since figuring out how populations to connect is a big part of managing, breeding, and saving species, it seems like typical length, dorsal fin length, and caudal fin length could be used for this purpose in the subtropical climate we have now.

These findings provide crucial morphological data that can be used to categorize and distinguish this *P. paradiseus* better accurately. This study did not determine whether environmental influences, genetic factors, or a mix of the two are to blame for the morphological variations seen amongst populations of the same species. The current findings could act as a springboard for more research in this area. This research provides foundational data on the diversity of *P. paradiseus* populations across various aquatic settings in Bangladesh. It suggests that morphometric features and truss measurements can be used to provide reliable data for stock discrimination of *P. paradiseus* to ensure the long-term viability of the *P. paradiseus*. The study's findings will serve as the basis for stock management, allowing for better oversight of the fisheries and the development of more effective long-term conservation plans. The researchers behind this study are sure their findings will be valuable to fishermen, biologists, and taxonomists.

Chapter-7: Recommendations

A new way to figure out morphometric length and truss network distance is to use digital tools for geometric morphometric analysis. It is a better way to evaluate meristic counts than the usual ways used in the past. The result gets more complex, showing exactly how the variables are different. If you do an excellent job of analyzing, the following steps will help with future research:

- When taking a photo that has to be used for calculating measures, a camera with a higher resolution will ensure the highest possible image quality.
- The samples are needed to be sorted carefully, and any damaged samples are to be discarded.
- Be extremely careful while handling the sample since rough treatment might potentially cause the external component to get damaged.
- Students are responsible for understanding how to use such software programs; failing to do so may result in incorrect calculations.
- Students require a broad understanding of PCA, DFA and other statistical approaches for this research.
- The higher the total number of samples, the more accurate the results. To conduct proper research, researchers must utilize the most significant number of samples possible.
- The *Polynemus paradiseus* fish were collected from several different places for this investigation. However, researchers might research this species in addition to studies on other fish caught in the same place.
- As the last point, there is a need for increased costs for improved research.

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Appendices

Appendix-A: Analysis of variances (ANOVA) of male population (To identify differences among mean variables)

Morphometric Parameters	Location					F Value	Level of Significance
	1 (mean±SD)	2	3	4	5		
TL	17.16±.33	16.78±.45	16.99±.48	16.53±.36	16.83±.60	9.927	0***
FL	13.29±.21	13.26±.18	13.33±.36	13.27±.12	13.36±.11	1.562	0.186NS
2PDFD	6.95±.25	7.16±.22	7.17±1.6	7.00±.14	6.94±.19	0.938	0.443NS
1PDFD	3.94±.17	4.04±.14	4.14±1.4	3.93±.15	3.88±.18	0.874	9.480NS
HL	2.29±.19	2.21±.22	2.44±1.56	2.15±.11	2.31±.18	0.904	0.463NS
PPecFD	3.07±.13	2.96±.23	3.10±.66	2.79±.12	3.02±.21	4.774	0.001**
PPelFD	4.00±.22	3.72±.17	3.87±.27	3.74±.12	3.92±.18	14.39	0***
PAFD	7.20±.24	7.16±.31	7.18±1.04	7.30±.18	6.93±.24	2.353	0.055NS
2DFL	2.83±.27	2.60±.22	2.74±.65	2.74±.23	2.80±.28	2.678	0.033*
PecFL	3.54±.34	3.70±.27	3.75±.36	3.57±.25	3.81±.28	5.023	0.001**
AFL	2.41±.23	2.32±.23	2.42±.82	2.32±.16	2.45±.25	0.895	0.468NS
CFH	2.23±.51	2.59±.24	2.55±.32	2.65±.23	2.65±.37	10.08	0***
CFL	5.21±.32	4.85±.38	5.02±.63	4.52±.34	4.79±.54	12.07	0***
D1-2	1.75±.20	1.51±.11	1.70±.74	1.57±.14	1.65±.15	3.253	0.013*
D2-3	2.52±.25	2.80±.15	2.71±.30	2.70±.12	2.63±.18	10.99	0***
D3-4	1.72±.20	1.67±.22	1.77±.53	1.45±.24	1.62±.22	5.631	0***
D4-5	1.35±.31	1.52±.25	1.37±.27	1.59±.26	1.41±.25	5.315	0***
D5-6	2.79±.32	2.54±.26	2.69±.35	2.84±.18	2.86±.28	9.986	0***
D6-7	2.39±.31	2.43±.21	2.44±.21	2.39±.21	2.47±.31	0.586	0.673NS
D7-8	5.14±.31	4.81±.34	5.04±.95	4.57±.36	4.76±.54	6.474	0***
D8-9	3.93±.25	3.94±.32	3.99±.43	3.69±.34	3.89±.62	3.090	0.17*
D9-10	3.43±.30	3.39±.27	3.60±.40	2.98±.30	3.53±.45	17.27	0***
D10-11	4.87±.34	4.51±.29	4.76±.47	3.85±.34	4.52±.37	40.81	0***
D11-12	2.16±.24	2.42±.24	2.49±.59	2.53±.17	2.54±.33	8.060	0***
D12-13	2.51±.24	2.27±.22	2.38±.21	2.37±.19	2.60±.29	13.10	0***
D13-14	3.15±.28	3.51±.24	3.26±.36	3.45±.23	3.04±.27	19.17	0***
D14-15	2.26±.23	2.06±.14	2.16±.32	2.13±.13	2.19±.16	5.457	0***
D1-15	1.98±.13	1.93±.13	2.00±.13	1.97±.13	2.02±.12	2.602	0.037*
D2-15	1.93±.11	1.88±.10	1.94±.17	1.97±.07	2.00±.09	5.927	0***
D3-14	2.56±.15	2.61±.15	2.64±.20	2.78±.15	2.74±.16	11.60	0***
D2-14	3.01±.17	3.20±.16	3.22±.28	3.30±.13	3.25±.17	6.297	0***
D3-15	3.38±.16	3.36±.13	3.38±.28	3.43±.10	3.38±.15	0.912	0.458NS
D3-13	4.26±.24	4.38±.21	4.31±.39	4.40±.17	4.25±.26	2.893	0.023*
D4-13	3.11±.21	3.20±.18	3.16±.32	3.25±.18	3.18±.22	1.962	0.102NS
D4-14	2.93±.19	2.98±.19	3.00±.14	3.04±.14	3.07±.16	3.537	0.008**
D5-14	3.90±.31	4.04±.22	3.96±.31	4.14±.15	3.99±.14	4.929	0.001**
D5-13	2.68±.13	2.57±.15	2.65±.33	2.62±.10	2.69±.16	2.799	0.027*
D5-12	3.34±.20	3.12±.20	3.24±.25	3.37±.16	3.38±.23	9.979	0***
D6-13	3.04±.26	2.79±.28	2.94±.27	3.00±.15	3.13±.22	11.29	0***
D6-12	1.31±.09	1.29±.09	1.37±.37	1.30±.09	1.37±.13	1.630	0.168NS
D6-11	2.53±.31	2.73±.17	2.78±.40	2.79±.18	2.85±.27	7.316	0***
D7-12	2.72±.20	2.82±.21	2.88±.20	2.98±.15	2.98±.34	9.090	0***
D7-11	1.61±.11	1.55±.10	1.64±.25	1.71±.08	1.76±.12	12.80	0***
D7-9	1.64±.17	1.49±.14	1.56±.19	1.49±.11	1.60±.15	6.829	0***
D9-11	1.81±.15	1.57±.12	1.61±.22	1.46±.08	1.51±.18	32.21	0***

Appendix-B: Analysis of variances (ANOVA) of female population (To identify differences among mean variables)

Morphometric Parameters	Location					F Value	Level of Significance
	1 (mean±SD)	2	3	4	5		
TL	17.21±.37	16.97±.38	17.24±.38	16.73±.44	16.96±.61	7.191	0***
FL	13.47±.15	13.42±.17	13.53±.13	13.45±.13	13.65±.57	3.670	0.007**
2PDFD	7.01±.17	7.13±.20	7.13±.14	7.11±.14	7.03±.14	3.830	0.005**
1PDFD	3.95±.20	4.01±.13	4.04±.13	3.94±.21	3.92±.14	3.520	0.009**
HL	2.25±.18	2.19±.25	2.21±.15	2.22±.21	2.32±.16	2.045	0.090NS
PPecFD	3.19±.17	2.93±.27	3.05±.19	2.83±.17	2.98±.16	14.497	0***
PPelFD	3.89±.18	3.80±.63	3.87±.16	3.74±.14	3.91±.20	1.412	0.232NS
PAFD	7.50±.34	7.37±.73	7.40±.29	7.49±.22	7.30±.22	1.279	0.280NS
2DFL	2.98±.19	2.69±.18	2.75±.22	2.81±.21	2.81±.26	8.745	0***
PecFL	3.54±.42	3.77±.26	3.84±.25	3.81±.22	3.92±.31	17.019	0***
AFL	2.34±.29	2.24±.23	2.42±.22	2.32±.26	2.45±.25	3.949	0.004**
CFH	1.67±.43	2.85±.33	2.73±.40	2.75±.30	2.93±.38	59.608	0***
CFL	4.95±.35	4.84±.38	5.08±.41	4.54±.41	4.83±.59	6.718	0***
D1-2	1.59±.15	1.62±.10	1.61±.13	1.57±.11	1.65±.14	1.743	0.143NS
D2-3	2.73±.23	2.74±.15	2.80±.15	2.70±.21	2.75±.22	1.204	0.311NS
D3-4	1.90±.19	1.72±.19	1.68±.22	1.77±.25	1.66±.22	5.849	0***
D4-5	1.22±.27	1.47±.24	1.43±.24	1.42±.31	1.43±.22	4.651	0.001**
D5-6	3.04±.31	2.62±.20	2.79±.27	2.87±.19	2.91±.30	13.086	0***
D6-7	2.39±.28	2.55±.26	2.47±.27	2.40±.14	2.42±.29	13.086	0***
D7-8	5.03±.39	4.86±.36	5.07±.40	4.50±.39	4.92±.44	2.477	0.046*
D8-9	3.80±.33	3.94±.37	4.05±.45	3.60±.39	3.97±.42	10.288	0***
D9-10	3.36±.23	3.48±.28	3.50±.39	3.18±.36	3.62±.33	6.547	0***
D10-11	4.73±.34	4.51±.28	4.70±.34	4.07±.40	4.61±.29	8.351	0***
D11-12	2.19±.25	2.46±.26	2.35±.31	2.45±.21	2.45±.27	20.578	0***
D12-13	2.40±.31	2.30±.24	2.36±.26	2.46±.24	2.52±.26	5.633	0***
D13-14	3.63±.36	3.66±.27	3.59±.30	3.63±.19	3.32±.24	4.051	0.004**
D14-15	2.13±.24	2.03±.13	2.10±.16	2.10±.15	2.15±.18	8.158	0***
D1-15	1.97±.16	1.97±.13	2.01±.11	2.00±.12	2.04±.10	2.552	0.041*
D2-15	1.92±.10	1.94±.08	1.98±.07	2.02±.07	2.04±.10	1.774	0.137NS
D3-14	2.89±.22	2.83±.18	2.76±.15	3.04±.19	3.00±.16	12.718	0***
D2-14	3.31±.19	3.24±.20	3.30±.17	3.41±.14	3.43±.15	13.784	0***
D3-15	3.41±.16	3.46±.19	3.46±.10	3.49±.17	3.51±.15	7.155	0***
D3-13	4.61±.22	4.55±.30	4.57±.18	4.65±.20	4.57±.20	1.887	0.115NS
D4-13	3.27±.20	3.29±.18	3.34±.15	3.35±.21	3.39±.17	1.058	0.379NS
D4-14	3.31±.26	3.26±.19	3.16±.19	3.44±.24	3.27±.18	2.261	0.065NS
D5-14	4.17±.32	4.23±.28	4.15±.19	4.39±.14	3.23±.14	7.316	0***
D5-13	2.82±.13	2.71±.18	2.73±.10	2.79±.13	2.84±.17	5.531	0***
D5-12	3.53±.24	3.24±.21	3.37±.22	3.41±.24	3.48±.23	5.041	0.001**
D6-13	3.05±.25	2.85±.31	2.93±.21	3.04±.19	3.15±.25	8.425	0***
D6-12	1.29±.08	1.38±.24	1.39±.12	1.35±.05	1.43±.13	7.258	0***
D6-11	2.54±.24	2.81±.22	2.74±.24	2.85±.15	2.92±.24	4.073	0.004**
D7-12	2.79±.21	2.92±.33	2.89±.26	2.95±.18	2.93±.26	12.124	0***
D7-11	1.65±.11	1.59±.10	1.62±.11	1.75±.08	1.78±.13	21.999	0***
D7-9	1.54±.16	1.48±.14	1.56±.13	1.48±.11	1.65±.16	8.267	0***
D9-11	1.73±.16	1.56±.13	1.64±.13	1.48±.08	1.60±.13	16.060	0***

Brief Biography of the author

This is Mahir Shahrea; son of Ataur Rahman and Anisa Khanam from Jamalpur Sadar Upazila under Jamalpur district of Bangladesh. He passed the Secondary School Certificate Examination in 2012 from Government Laboratory High School, Mymensingh and Higher Secondary Certificate in 2014 from Shahid Syed Nazrul Islam College, Mymensingh. He obtained his B. Sc. in Fisheries (Hons.) Degree in 2019 from Faculty of Fisheries, Chattogram Veterinary and Animal Sciences University (CVASU), Chattogram, Bangladesh. Now, he is a candidate for the degree of MS in Marine Bioresource Science under the Department of Marine Bioresource Science, Faculty of Fisheries, CVASU. He has a great interest on scientific research on Marine Science.