Landmark-based morphometric variations of stinging catfish (*Heteropneustes fossilis*) between two isolated stocks.

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Fisheries and Marine Resource Technology Discipline

Khulna University, Khulna

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A Thesis

By

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DECLARATION

The results submitted in this thesis with the above mentioned title are entirely of the candidate's own investigations and no part of the results has been accepted for any degree nor is it concurrently submitted for any degree.

26.09.19

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DEDICATED TO
MY
BELOVED PARENTS

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Abstract

The experiment was conducted to evaluate the population status of two isolated stocks of stinging catfish (*Heteropnuestes fossilis*) by observing the landmark-based morphometric variations. The total of 120 *H. fossilis* were collected from the Kopotakkho River, Kotchadpur in Jhenaidah and a hatchery, Sheikhpara in Jashore during February to March, 2019. The distance was about 50 km between two isolated stocks and age of samples was approximately six months. Ten morphometric characters and seven truss distances were measured. Significant differences were found for ten morphometric measurements such as standard length (ST), tail length (Tail L), anal fin length (AL), head width (HW), maximum barbel length (BLmx), minimum barbel length (BLmn), post-dorsal length (PsDL), pre-dorsal length (PrDL), head length (HL) and four truss measurements such as dst 2-7, dst 2-8, dst 3-7, dst 4-7 between two stocks ($p<0.01$). However three truss measurements such as dst 3-8, dst 4-8 and dst 5-6 did not show any significant differences between two stocks ($p<0.01$). There was a high degree of variation in morphological characteristics among two different stocks of *H. fossilis*. The variation between the hatchery and river stocks may have been due to environmental as well as genetic variations. The work is important for a prerequisite for developing management and conservation strategies of the species and may be applicable for studying short-term and environmentally induced variations. Moreover, these outcomes may helpful in performing selective breeding program for better seed production.

Table of Contents

Chapter 1

1. Introduction

1.1. Study of background:

Fisheries in Bangladesh have both prospects and challenges. Fisheries sector represents one of the most productive and dynamic sectors in Bangladesh. The fisheries sector of Bangladesh is playing an increasingly significant role in the economy for the last few decades. Bangladesh is one of the world's leading fish producing countries with a total production of 42.77 lakh MT in FY 2017-18, whereas inland open water (capture) contributes 28.45 percent (12.17 lakh MT) and inland closed water (culture) contributes 56.24 percent (24.05 lakh MT) to total production (DoF, 2018) and it ranked 3rd in inland open water capture production and 5th in world aquaculture production (FAO, 2018). This sector is contributing a very significant role in the socio-economic development and deserves potential for future development in the agrarian economy of Bangladesh. It contributes 3.57 percent to our national GDP and around one-fourth (25.30 percent) to the agricultural GDP. This sector provides major (60%) share of animal protein. More than 11 percent of total population of Bangladesh is engaged in this sector on full time and part time basis for their livelihoods (DoF, 2018). Bangladesh is blessed with vast and rich fisheries resources. Fish is of the most important one in the diversified fisheries resources of the country. Freshwater fishes are very rich in species diversity having more than 260 indigenous fish species (Rahman *et al.*, 2014). Among the 260 indigenous fish species, stinging catfish (*Heteropneustes fossilis*) is one of them which are highly nutritive and rich source of animal proteins. It contributes 84282 MT productions of total fish production (culture 27390 MT and capture 56892 MT) and 2.33 percent of total fish percent (DoF, 2018).

Catfish are a diverse group of ray-finned fish which have their prominent barbels as resemble a cat's whiskers. Catfish are of considerable commercial importance and many of the larger species are farmed or fished for food. Many of the smaller species, particularly the genus *Corydoras*, are important in the aquarium hobby. Many catfish are nocturnal, but others (many Auchenipteridae) are crepuscular or diurnal and all of species are the air-breathing in their environment (Kate *et al.*, 2001). There are some types of catfish found in Bangladesh such as stinging catfish or shing (*Heteropneustes fossilis*), walking catfish or magur (*Clarias batrachus*), african catfish (*Clarias* *gariepinus*), amazon sailfin catfish (*Pterygoplichthys pardalis*). Among of them, Shing and magur are indigenous species in our country and they are allowed to culture by government. But african catfish (*C. gariepinus*) and amazon sailfin catfish (*P. pardalis*) are prohibited to culture by government in Bangladesh (Protection and Conservation of Fish Rule, 1985). *Heteropneustes* spp., the stinging catfishes of family Heteropneustidae, are distributed in freshwater habitats of Bangladesh, India, Myanmar, Nepal, Pakistan, Sri Lanka, Thailand and Vietnam (Levêque *et al.*, 2007). The species can be distinguished by their elongated and compressed bodies, small mouth with fleshy lips, short dorsal fin, pectoral fin with serrated spine and ribbon-like longer anal fin. There are some nominal species of *Heteropneustes* such as *Heteropneustes fossilis* (Bloch), *H. microps*, *H. kemratensis* and *H. longipectoralis* (Hossain *et al.*, 2013). The stinging catfishes are often inhabited in ponds, ditches, canals, flooded rice fields, swamps, marshes, waterlogged areas and rivers of Bangladesh. The air-breathing apparatus enables the fish to survive in low water depth, even in turbid and oxygen deficit conditions (Rahman, 1989).

Among the air-breathing catfishes, stinging catfish (*H. fossilis*) is very popular and high valued fish in Bangladesh. This fish is locally known as Shingi or Shing. It is deliberated to be highly nourishing, edible and tasty and well preferred because of its less spine, less fat and high digestibility in many parts of Indian subcontinent (Khan *et al.*, 2003). Due to high nutritive value the fish is suggested in the diet of sick and convalescents. Being a lean fish it is very suitable for people for whom animal fats are undesirable (Rahman *et al.*, 1982). It is an omnivorous, demersal and predatory in nature. Generally, during the dry season, *H. fossilis* lives in semi-liquid and semi-dry mud and even when the mud dries up due to having an air sac as an accessory respiratory organ; it takes its body above the bottom of fissures and crevices. It is capable of breeding in the onset of the monsoons in ponds, ditches, beels, canals, haors, baors and rivers when sufficient rain-water accumulates (Shafi *et al.*, 1982). But due to over exploitation and ecological changes in its natural habitats; this species have become threatened. Indiscriminate destructive practices have caused havoc to aquatic bio-diversity in Bangladesh (Hussain & Mazid, 2001).

Stinging catfish is an excellent source of protein, fat, calcium, phosphorus and water. Each 100 g contains- protein 23.0 g, fat 0.6 g, calcium 670 mg, phosphorus 650 mg and water 79.3% (Siddique, 1996). They are also an excellent source of vitamin B-12, B vitamins, niacin and pantothenic acid. They used as food fish in Bangladesh which have high economic importance and of great demand because of medicinal value (Talwar, 1991). It recommends for patients after recovery from malaria for its invigorating qualities and also may help lower your risk of heart disease mainly by lowering triglycerides and countering inflammation, as well as help lower your risk of cancer and arthritis (Bhuiyan, 1964).

Stinging catfish (*H. fossilis*) is very popular in Bangladesh. It has high market value. A number of attempts have been taken in different study to develop culture systems of this fishes in cages but the survivability and growth rate was not satisfactory which ultimately decreased production. Presently, Shing is one of the threatened fish in Bangladesh and hither to very little attention has been paid to develop culture techniques (IUCN Bangladesh, 2000). This fish has enormous aquaculture potential and it could be easily grown in ponds and small ditches. All these have drawn attention what is existing status of *H. fossilis* in our country for further research and culture (Rahman *et al.*, 2014). The government encourages the small scale people for increase production of stinging catfish as well as conservation. Besides, the exotic catfish such as African catfish are prohibited for conservation indigenous catfish in Bangladesh (DoF, 2018).

Phenotypic plasticity in a species which leads to a prerequisite for developing management and conservation strategies of any species (Turan *et al.*, 2006) and may be applicable for studying short-term and environmentally induced variations (Begg *et al.*, 1999 & Tzeng, 2004). Morphometric and meristic characters of fish are the measurable and countable characters, respectively common to all fishes. Morphometric differences among stocks of a species are recognized as important for evaluating the population structure and as a basis for identifying stocks (Vishalakshi *et al.*, 2008 & Turan *et al.*, 2004). They are also help to know the habitats condition as well as environment condition of the surrounding areas.

Landmarks may define as some arbitrarily selected points which is selected on a fish's body and with the help of these arbitrarily points; the individual fish body shape can be analyzed. In other words, a landmark is a point of correspondence on an object that matches between and within populations (Barlow, 1961 & Swain *et al.*, 1999). Truss network systems constructed with the help of landmark points are powerful tools for stock identification. The study of differences and variability in respect of morphometric and meristic characters of fish stocks is important in phylogenetics and in providing information for subsequent studies on the genetic improvement of stocks (Solomon *et al.*, 2015). The variations may be more applicable for studying short term, environmentally induced disparities and the findings can be effectively used for improved fisheries management (Ihssen *et al.*, 1981 & Templeman, 1983). Therefore, it is essential to know the morphometric variations between two isolated stocks, the Kopothakho River, Kotchadpur in Jhenaidah (distance about 50 km between two stocks) and the hatchery, Sheikhpara in Jashore as preliminary base line information and there may be few attempts to evaluate the population structure based on genetic aspects of *H. fossilis*.

1.2. Objective of the study:

The main objective of the present study was:

- To determine the morphological variations in respect of morphometric characters between two isolated stocks of *H. fossilis*: the Kopotakkho River, Kotchadpur in Jhenaidah and the hatchery, Sheikhpara in Jashore.

Chapter 2

2. Review of Literature

Man is the only animal who can take advantage of knowledge. They have been accumulated knowledge through the centuries. Literature reviews are absolutely indispensable when planning a research study because they can help guide the researcher in an appropriate direction.

Rahman *et al.*, (2014) studied to observe the landmark-based morphometric and meristic variations to evaluate the population status of three different stocks of stinging catfish or shing (*Heteropnuestes fossilis*) from the Old Brahmaputra river, Mymensingh; the Tanguar haor, Sunamganj and a hatchery, Mymensingh. Six meristic, sixteen morphometric characters and twenty three truss distances were measured. Significant differences were found in three meristic counts ($P<0.05$). But morphometric and truss network measurements after plotting discriminant functions revealed high segregation among three different stocks of *H. fossilis*. Discriminant Function (DF) analysis of seven morphometric measurements of pre-dorsal length (PrDL), anal fin length (AFL), highest body depth (HBD), post-orbital length (PsOL), maximum barbel length (BLmx), mouth gap (MG) and peduncle length (PdnL) were contributed dominantly to the first DF and the rest of the characters of post-dorsal length (PsDL), pre-orbital length (PrOL), head length (HL), standard length (SL), lowest body depth (LBD), minimum barbel length (BLmn), caudal fin length (CFL) and eye length (EL) contributed to the second DF. The twenty three truss measurements, six were leading to the first DF and the rest seventeen contributed to the second DF. The dendrogram showed two major clusters: the Brahmaputra and Tanguar stocks in one cluster and hatchery stock in another cluster. There was a high degree of variation in morphological characteristics among three different stocks of *H. fossilis*.

Hossain *et al.*, (2010) studied to observe the landmark-based morphometric and meristic variations of the endangered carp, kalibaus (*Labeo calbasu*), from stocks of two isolated rivers, the Jamuna and Halda, and a hatchery and were examined to evaluate the population status of the endangered carp, kalibaus (*Labeo calbasu*). Morphometric characters along with truss network measurements and meristic counts were applied. Significant differences were observed in four (maximum body height, pre-orbital length, peduncle length, and maxillary barbel length) of 12 morphometric measurements, two (pectoral fin rays and scales above the lateral line) of 9 meristic counts, and four (8 to 9, 3 to 10, 2 to 10, and 1 to 11) of 22 truss network measurements among the stocks. For morphometric and landmark measurements, the 1st discriminant function (DF) accounted for 75.5% and the 2nd DF accounted for 24.5% of the among-group variability, and together they explained 100% of the total among group variability. For the morphometric and truss network measurements, plotting DFs revealed high isolation of the stocks. The dendrogram based on morphometric and truss distance data placed the Jamuna and hatchery in 1 cluster and the Halda in another cluster, and the distance between the Halda and hatchery populations was the highest.

Molla *et al.*, (2012) studied to evaluate the landmark-based morphometric and meristic analysis of pond, haor and estuary populations of *Glossogobius giuris* and were done to find out variations among the three stocks. Significant differences (*P<0.01) were observed in 13 general morphometric and 23 size adjusted landmark-based morphometric measurements among three stocks. Among the 11 meristic counts the first dorsal fin rays (D1FR), transverse scale above lateral line (TSALL), branchiostegal rays and number of vertebrae were same among fishes of these stocks. In case of pectoral fin rays (PcFR) and transverse scale on lateral line (TSOLL) the haor stock was significantly different from other two stocks. In discriminant space, pond stock was isolated from other two stocks. On the other hand, haor and estuary stocks showed very close relationship. A dendrogram based on the hierarchical cluster analysis using size adjusted general morphometric and landmark measurements formed two main clusterspond stock in one cluster and other two stocks (haor and estuary) remained in another cluster. It indicates that pond stock was separated. The second cluster explained that haor and estuary stocks had very close relationship.

Gain *et al.*, (2017) studied to evaluate its population status, landmark-based morphometric and meristic variations among three different stocks viz., hatchery (Jessore), baor (Gopalganj) and river (Faridpur) in Bangladesh were studied. Significant differences were observed in 10 of the 15 morphometric measurements viz., head length, standard length, fork length, length of base of spinous, pre-orbital length, eye length, post-orbital length, length of upper jaw, height of pelvic fin and barbel length, two of the 8 meristic counts viz., scales above the lateral line and pectoral fin rays and 10 of the 22 truss network measurements viz., 1 to 10, 2 to 3, 2 to 8, 2 to 9, 2 to 10, 3 to 4, 3 to 8, 4 to 5, 4 to 7 and 9 to 10 among the stocks. For morphometric and landmark measurements, the 1st discriminant function (DF) accounted for 58.1% and the 2nd DF accounted for 41.9% of the among-group variability. In discriminant space, the river stock was isolated from the other two stocks. On the other hand, baor and hatchery stocks formed a very compact cluster. A dendrogram based on the hierarchical cluster analysis using morphometric and truss distance data placed the hatchery and baor in one cluster and the river in another cluster and the distance between the river and hatchery populations was the highest.

Ahammad *et al.*, (2018) studied to observe the landmark-based morphometric and meristic analysis of three different stocks from the Atrai, the Jamuna and the Kangsha of Bhagna and were examined from a phenotypical point of view to evaluate the population structure and to assess shape variation. Ten morphometric and nine meristic characters were analyzed along with twenty two truss network measurements. One way ANOVA showed that all morphometric, meristic and truss network measurement were significantly different ($P<0.001$) among three different stock of the fish. For morphometric and landmark measurements, the first discriminant functions (DF) accounted for 98.6% and 97.9% and the second DF accounted for 1.4% and 2.1%, respectively among group variability, explaining 100% of total among groups variability. For the morphometric and truss network measurements, plotting discriminant functions showed a well separated clusters of the stocks indicating that the measurement were significantly different among three stocks. The dendrogram based on morphometric and landmark distances data showed two major clusters; the Atrai and Jamuna stocks in one cluster and the Kangsha stock in another cluster. High degree of variation was observed in morphological characteristics among three different stocks (the Atrai, Jamuna and Kangsha) of *L. ariza* due to their environmental variation and separate geographical location.

Khan *et al.*, (2012) Studied on the elemental profile of otoliths and truss network analysis for stock discrimination of the threatened stinging catfish (*Heteropneustes fossilis)* from the Ganga River and its tributaries. The study was undertaken to identify different stocks of the stinging catfish (*Heteropneustes fossilis)* inhabiting the Ganga, Yamuna and Gomti Rivers of India using the elemental profile of sagittal otoliths and truss network analysis of the entire body shape. Inductively coupled plasma-atomic emission spectrometry was used to estimate concentrations of 12 trace elements in otoliths, and 11 morphometric landmarks were chosen to construct a truss network of the fish in order to discriminate among stocks. A discriminant function (DF) analysis of elemental profiles showed that Ba, Pb, Zn, and Sr successfully discriminated *H. fossilis* populations from different rivers. DF-I, DF-II, and DF-III accounted for 76.1%, 17.9%, and 6%, respectively, of the among-group variability in the elemental profile of otoliths. In the analysis of truss landmarks, the principal components, PC-I and PC-II, respectively accounted for 39.1% and 13.4%, while DF-I and DF-II, respectively accounted for 59.7% and 25.5% of the among-group variability. The overall allocation success of individuals to their group of origin was high (98.7%) in the elemental profile of otoliths compared to truss measurements (72.3%). The truss network analysis distinguished separate stocks of fish in the 3 rivers; however, the elemental profile of otoliths further discriminated the stocks at the 2 sampling stations within the Ganga River.

Cavalcanti *et al.*, (1999) studied on the landmark based morphometric analysis in selected species of serranid fishes (Perciformes: Teleostei). Morphological differences among 6 species of marine fishes belonging to 2 subfamilies of the family Serranidae were studied by the geometric morphometric method of thin-plate splines and multivariate analysis of partial-warp scores. The decomposition of shape variation into uniform and nonaffine components of shape change indicates that major differences among species are related to both components of shape variation. Significant differences were found among species with respect to the uniform components, but there is no clear separation of taxonomic groups related to these components, and species are instead separated on the basis of body height and caudal peduncle length. Non-uniform changes in body shape, in turn, clearly differentiate the species of Serraninae and Epinephelinae. These shape changes are probably related to differences in habitat and feeding habits among the species.

Islam *et al.*, (2014) studied on the morphometric, meristic and landmark-based analysis of a rare croaking gourami (*Trichopsis vittata)* and to evaluate the population status with the help of the truss network systems. Nine morphometric and six meristic characters were analyzed along with thirty truss network measurements. Non parametric Kruskal- Wallis test was applied for comparing meristic counts and no significant differences were observed among the groups. Univariate statistics (ANOVA) showed no significant difference among three groups. For both morphometric and landmark measurements the first discriminant function (DF) accounted for 72.1% and 78.2% and the second DF accounted for 27.9% and 21.8%, respectively of the among group variability. With morphometric measurements 87.5% of group 1, 66.7% of group 2 and

75% of group 3 samples were correctly classified. As the truss network system revealed, all the samples were clearly separated from each other in the discriminant space.

Mahfuj *et al.*, (2019) studied to examine the meristic and landmark-based morphometric variations of barred spiny eel (*Macrognathus pancalus*) from four populations namely Dhakuria beel, Jessore (DBJ); Bohnni boar, Gopalgonj(BBG); the Arial kha river, Madaripur (AKRM) and the Nabaganga river, Jhenidah (NRJ) in Bangladeshi freshwaters. Six meristic counts were compared among four populations and significant differences were observed in number of caudal fin rays and number of pelvic fin rays in all meristic characters. The truss protocol was used in the present study based on six general morphometrics and fifteen truss measurements. Univariate statistics showed that five (standard length (SL), upper jaw length (UJL), lower jaw length (LJL), head depth (HD) and inter orbital (IO)) of six morphometric and eleven truss networks (viz. 2-3, 3-4, 5-6, 6- 7, 7-8, 1-8, 2-8, 3-8, 3-7, 4-7 and 5-7) among fifteen truss measurements differed significantly. Cannonical discriminate function analyses were conducted among samples and the populations were fully intermingled. Pooled within group correlation showed morphometric and landmark measurements; the first discriminant function (DF) accounted for 79%, the second DF accounted for 15.9% and third DF accounted for 5.1% of group variability. An euclidian dendrogram was prepared based on morphometric and truss measurements in four populations, where two clusters were mainly formed, in which first cluster formed by NRJ population was fully separated, and the second cluster was formed by two populations of AKRM and DBJ. Additionally, a subcluster BBG was formed with AKRM. On the basis of morphometric and truss measurements, 68.8%, 83.6%, 55.6% and 80% of original grouped cases were correctly classified in NRJ, AKRM, DBJ and BBG, respectively.

Hossain *et al.*, (2015) studied on the landmark-based morphometric and meristic variations of three different stocks (the Meghna, Padma and Ichamoti) of Mullet (Rhinomugil corsula). The study was examined from a phenotypical point of view to evaluate the population structure and to assess shape variation. Thirteen morphometric and seven meristic characters were analyzed along with twenty five truss network measurements. Eight (fork length, head length, pre-orbital length, post orbital length, highest body depth, lowest body depth, pelvic fin length and mouth gap) of 13 morphometric measurements, one (pectoral fin rays) of 7 meristic measurements and fourteen (1 to 2, 1 to 11, 1 to 12, 2 to 3, 2 to 12, 2 to 11, 2 to 9, 3 to 4, 3 to 11, 4 to 5, 4 to 7, 5 to 7, 7 to 8, 8 to 9) of 25 truss network measurements were significantly different ($p<0.05$ or

$p<0.01$ or $p<0.001$) among three different populations of Rhinomugil corsula samples. For morphometric and landmark measurements, the first discriminant functions (DF) accounted for 89.8% and 83.3% and the second DF accounted for 10.2% and 16.7%, respectively of among group variability, explaining 100% of total among groups variability. For the morphometric and truss network measurements, plotting discriminant functions did not show the well separated clusters of the stocks. The dendrogram based on morphometric and landmark distances data showed two major clusters: the Meghna and the Padma stocks in one cluster and the Ichamoti stock in another cluster. High degree of variation was observed in morphological characteristics among three different stocks (the Meghna, Padma and Ichamoti) of Rhinomugil corsula due to their environmental variation and separate geographical location.

Chapter 3

3. Materials and Methods

3.1. Fish collection:

During January-February 2019, a total 120 Stinging catfish (*H. fossilis*) were collected from the two isolated stocks: the hatchery, Sheikhpara in Jashore and Kopotakkho River, Kotchadpur in Jhenaidah. The age of samples was approximately same ages. The fish were transported in oxygenated container to the Wet Fish Laboratory of FMRT Discipline and kept temporarily in fiberglass tank at the Wet Laboratory Complex under the Fisheries department, Khulna University, Khulna, Bangladesh.

3.2. Measurements of morphometric traits:

The sample weight was done before morphometric measurement by using electronic weight. The sample size, mean weight and length were presented in Table 1. At first, fish was placed on a graph paper together with its ID and the photograph was taken by a digital camera (Canon DS126621). All the raw images were imported into *ImageJ* software (v1.50) for the measurements of some selected phenotypic traits (e.g. standard length, total length, tail length, head length, head width, anal fin length, maximum burble lengths, minimum burble length, pre-dorsal length, post-dorsal length) and seven different landmark distances (e. g. dst 2-7, dst 2-8, dst 3-7, dst 3-8, dst 4-7, dst 4-8, dst 5-6) fig. 9 were done with the help of "Truss network system" by using the same camera (Canon DS126621) and *ImageJ* (v1.50) software. Total length (the distance in cm from the tip of the snout to the tip of the longer lobe of the caudal fin, see fig. 1), standard length (the distance in cm from the fish snout to the tip of his caudal peduncle, see fig. 2) tail length (the distance in cm from the fish caudal peduncle to the end of the tail, see fig. 3), head length (the distance in cm from the snout to the end of the osseous plate at top, see fig. 4), head width (the distance in cm between the base of two pectoral fin , see fig. 5), anal fin length (the distance in cm from the base of the anal fin to the end, see fig. 6), pre-dorsal length (the distance in cm from the fish anterior base of dorsal pin to the tip of the snout, see fig. 7) and post-dorsal length (the distance in cm from the fish posterior base of dorsal pin to the tip of the longer lobe of the caudal fin, see fig. 7), maximum burble length (the distance in cm from snout to the end, see fig. 8) and minimum burble length (the distance in cm from snout to the end, see fig. 8) and seven different landmark truss measurement distances (fig. 9) measure carefully. The data were recorded in the excel shit for analysis.

Table 1

Group name	Sample (number)	Weight (g)	Total Length (cm)
Hatchery stock	60	20.58 ± 5.17	15.42 ± 1.41
River stock	60	15.64 ± 3.36	14.72 ± 1.63

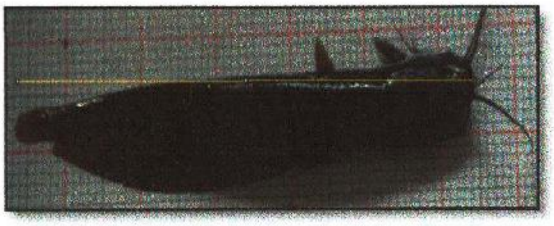


Fig 1: Measurement of total length (cm)

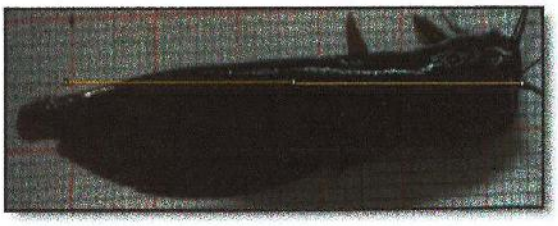


Fig 2: Measurement of standard length (cm)

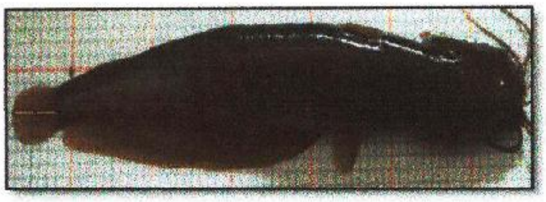


Fig 3: Measurement of tail length (cm)

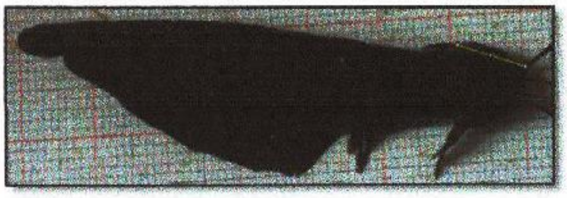


Fig 4: Measurement of head length (cm)

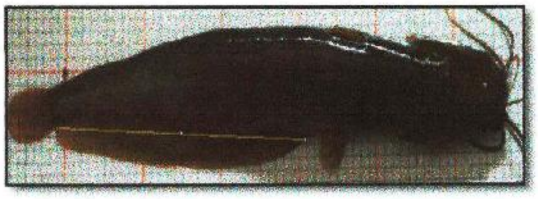
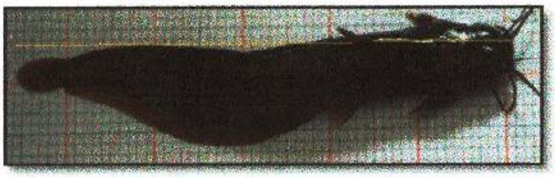


Fig 5: Measurement of head width (cm)

Fig 6: Measurement of anal fin length (cm)



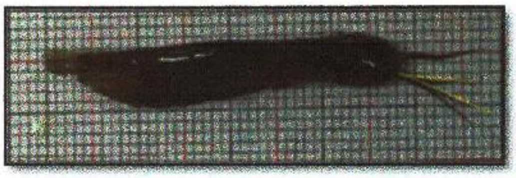


Fig 7: Measurement of pre-dorsal and post dorsal length (cm)

Fig 8: Measurement of maximum and minimum burbles length (cm)

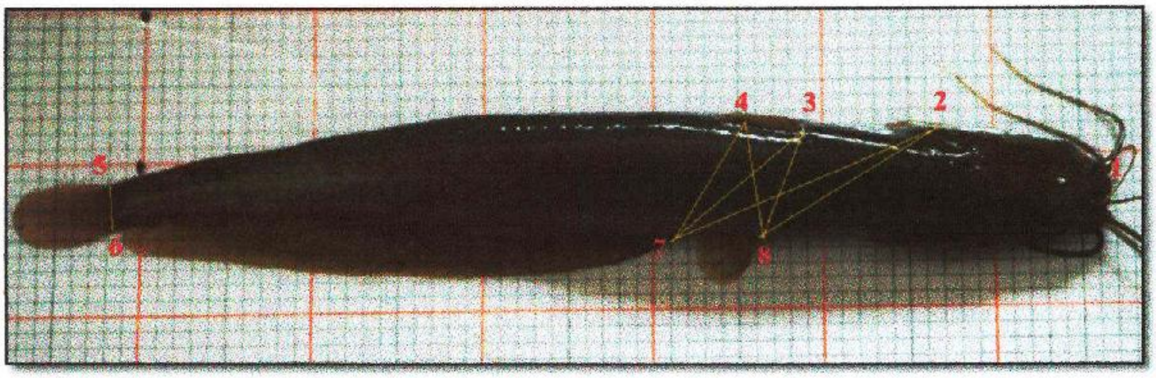


Fig 9: Measurement of seven different landmark truss measurement distances (cm)

3.3. Data analysis:

Prior to analysis, the size effects from the data set were eliminated. Variations were attributed to body shape differences and not to the relative sizes of the fish. In the present study, there were significant linear correlations among all the measured characters and the total length (TL) of the fish. Therefore, it was necessary to remove size-dependent variations from all of the characters. An allometric formula given by (Elliott *et al.*, 1995) with slight modification was used to remove the size effect from the data set:

$$M_{adj} = M\ (Ls\ /\ Lo)\ b$$

Where M is the original measurement, M_{adj} is the size-adjusted measurement, Lo is the TL of the fish and Ls is the overall mean of the TL for all fish from all samples. Parameter b was estimated for each character from the observed data as the slope of the regression of log M on log Lo, using all fish in all stocks. The efficiency of the size adjustment transformations was assessed by testing the significance of the correlation between a transformed variable and the TL. A univariate analysis of variance (ANOVA) was carried out to test the significance of morphological differences.

Chapter 4

4. Results

The choice of length measurement of whole or parts of fish is probably the most widely used technique in fisheries biology studies. The length is usually closely related to many of the other factors such as weight, age and maturity so that any of these may be easily determined, from the length data used, with a small key sample relating length with the factor concerned. Prior to analysis the data, the efficiency of the allometric formula in removing the size effect from the data was justified by using correlations between the total length and adjusted characters. Then, the ten transformed morphometric and seven truss measurements were found to be significantly correlated. The ten morphometric measurements was standard length (ST), tail length (TL), anal fin length (AFL), weigth (Wt), pre-dorsal length (PrDL), post-dorsal length (PsDL), head width (HW), maximum barbel length (BLmx), minimum barbel length (BLmn), head length (HL) and seven truss measurements (dst 2-7, dst 2-8, dst 3-7, dst 3-8, dst 4-7, dst 4-8, dst 5-6). Hence, all the measurements were considered for calculation.

4.1. Standard length:

Standard length is the straight-line measurement taken from tip of snout to the last vertebra which supports the tail fin of the fish. It is important for life history and morphological comparisons of fish populations from different locations, the estimation of weight for individual fish and for length classes of fish. It is also related to length–weight relationship (LWR), are useful in fishery management and stock assessment models. The fig. 10 showed that the higher value found in the hatchery stock (13.67±0.21 cm) than the value of river stock (13.48±0.15 cm) in case of standard length. The ANOVA test results indicated that there was significant difference between hatchery and river stock of stinging catfish (*Heteropneustes fossilis*) in case of standard length ($F_{(1,118)} = 35.17$, $p<0.01$). The subsequent post-hoc test revealed that there was also significant variation between the two treatment groups. The variation might be due to food availability and quality, size range, health and general fish condition, habitats and genetic variation.

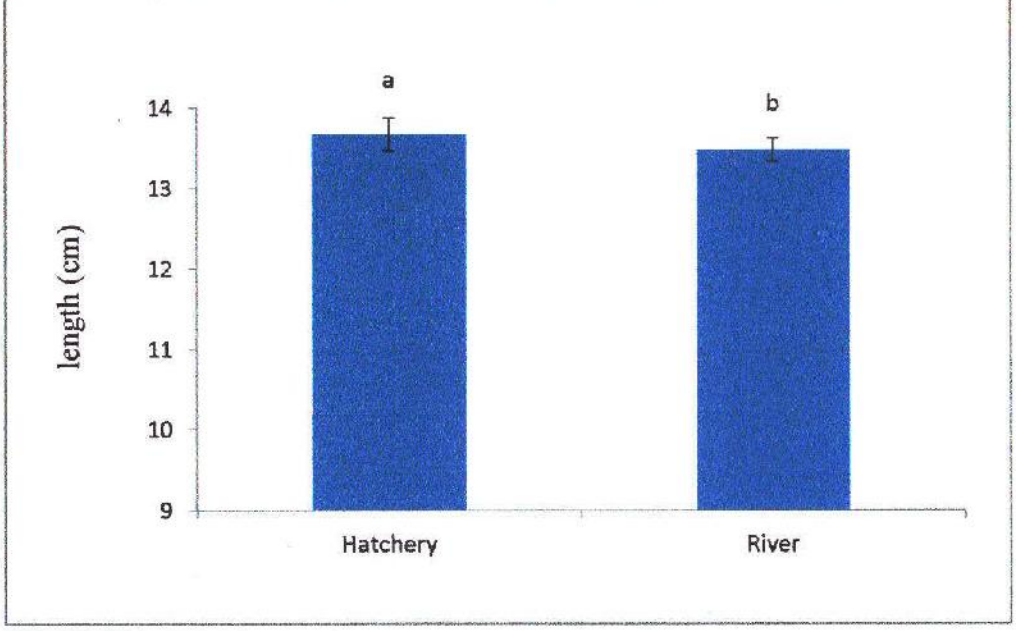


Fig 10: Standard lengths of stinging catfish (*Heteropneustes fossilis*).Values are the mean ± SD. Different letters indicate the means are significantly different.

4.2. Tail length:

Tail length is straight-line measurement taken from the last vertebra to end portion of tail. The main function of tail length is to help the fish swim. It is important for life history and morphological comparisons of fish populations from different locations and and is often used to determine the age and growth of the fishes. The fig. 11 showed the comparison between hatchery and river stocks of stinging catfish (*H. fossilis*) in tail length and found the higher value of river stock (1.55±0.12 cm) than the value of hatchery stock (1.43±0.10 cm). The ANOVA analysis results revealed that there was significant difference (fig. 11) between hatchery and river stock for tail length ($F_{(1,118)} = 40.93$, $p<0.01$). The subsequent post-hoc test was also performed to find out comparison between two groups and there was also significant variation. The phenotypic differences are possibly due to habitats and genetic variance, distance, food availability and quality, size range, health and general fish condition.

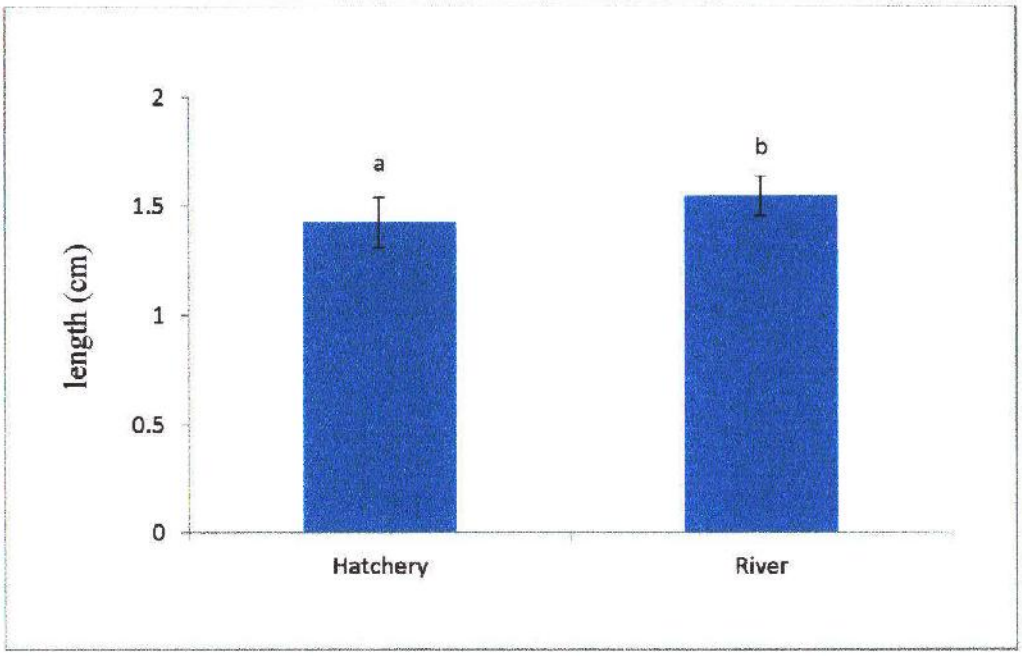


Fig 11: Tail length of stinging catfish (*Heteropneustes fossilis*).Values are the mean ± SD. Different letters indicate the means are significantly different.

4.3. Head width:

Head width is the straight-line measurement taken from the base line one pectoral fin to another pectoral fin. It helps to know the age, growth determination and health conditions of fish. It is also importance in the study of research purpose. The diagram exposed that of stock that collected from river possess is higher (1.78±0.14 cm) head width length than hatchery stock (1.61±0.15 cm) of stinging catfish (*H. fossilis*) for head width length. There was significant difference (fig. 12) between hatchery and river stock ($F_{(1,118)} = 46.26$, $p<0.01$). The post-hoc test subsequently revealed that there was an also significant variation between the two treatment groups. The factors such as habitats and genetic variance, distance, food availability, health condition of fish might be responsible for the variation.

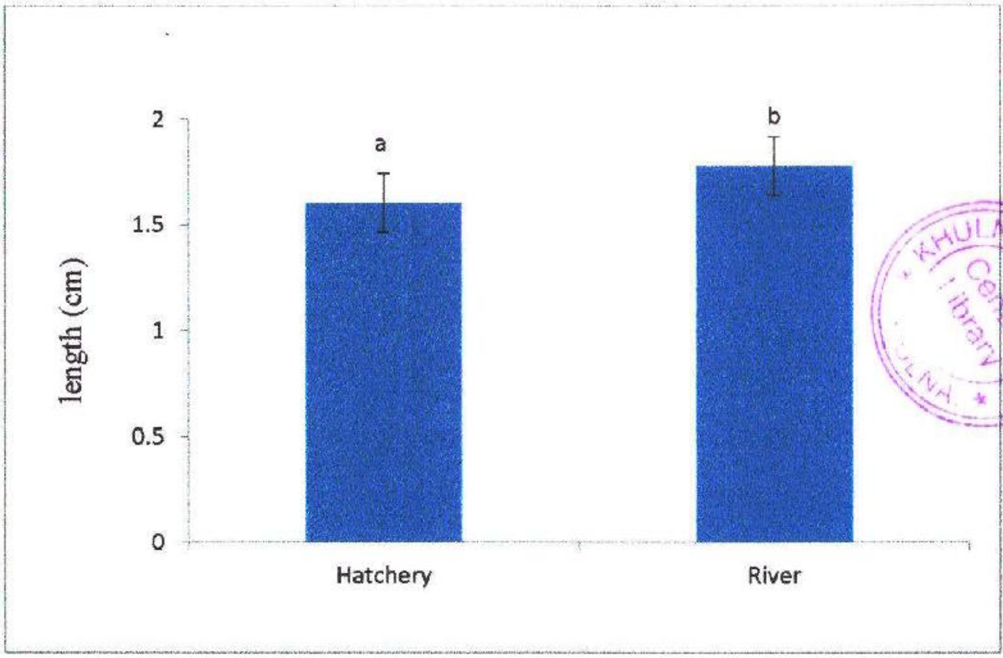


Fig 12: Head width length of stinging catfish (*Heteropneustes fossilis*). Values are the mean ± SD. Different letters indicate the means are significantly different.

4.4. Anal fin length:

Anal fin is the unpaired fin which is located on the ventral side of the body of a fish, posterior to the anus. It plays an important role in the swimming movements of fish. It assists to know the life history and morphological comparisons of fish populations from different locations. In the fig. 13 exposed that the mean value of hatchery and river stock was (7.86±0.41 cm) and (8.25±0.39 cm) respectively. The experiment was revealed highly significant difference (fig. 13) between the two treatments ($F_{(1,118)} = 30.19$, $p<0.01$). The subsequent post-hoc test was shown that the anal fin length has significantly variation from river stock to hatchery stock of stinging catfish (*H. fossilis*). Food availability, environmental condition, separate habitat as well as genetic variations are likely to be responsible for variations.

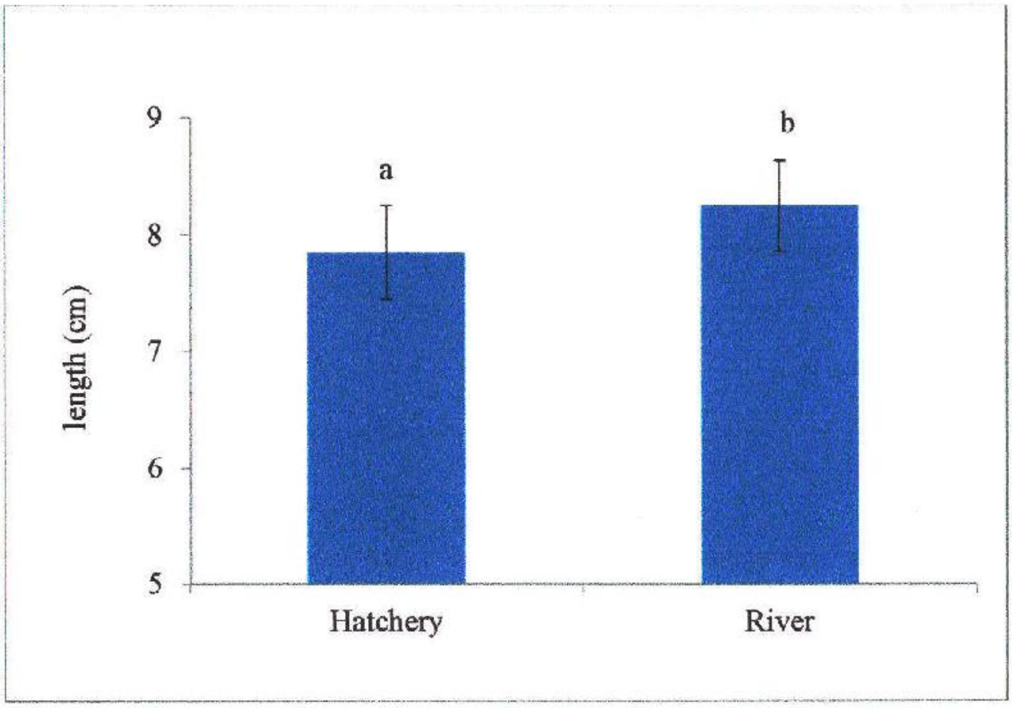


Fig 13: Anal fin length of stinging catfish (*Heteropneustes fossilis*).Values are the mean ± SD. Different letters indicate the means are significantly different.

4.5. Maximum barbel length:

Maximum barbel length is large whisker like which is located at the corners of the fish's mouth and it uses to locate food. It helps to determine the age and growth of the fishes as well as morphological comparison. The model revealed highly significant difference (fig. 14) in maximum barbel length between hatchery and river stock of stinging catfish (*H. fossilis*) ($F_{(1,118)} = 49.75$, $p<0.01$). The subsequent post-hoc test showed that river stock was significantly larger (4.08±0.53 cm) maximum barbel length than the hatchery stock (3.33±0.63 cm). The differences of phenotype are likely to the distance, habitats, food availability and genetic variation.

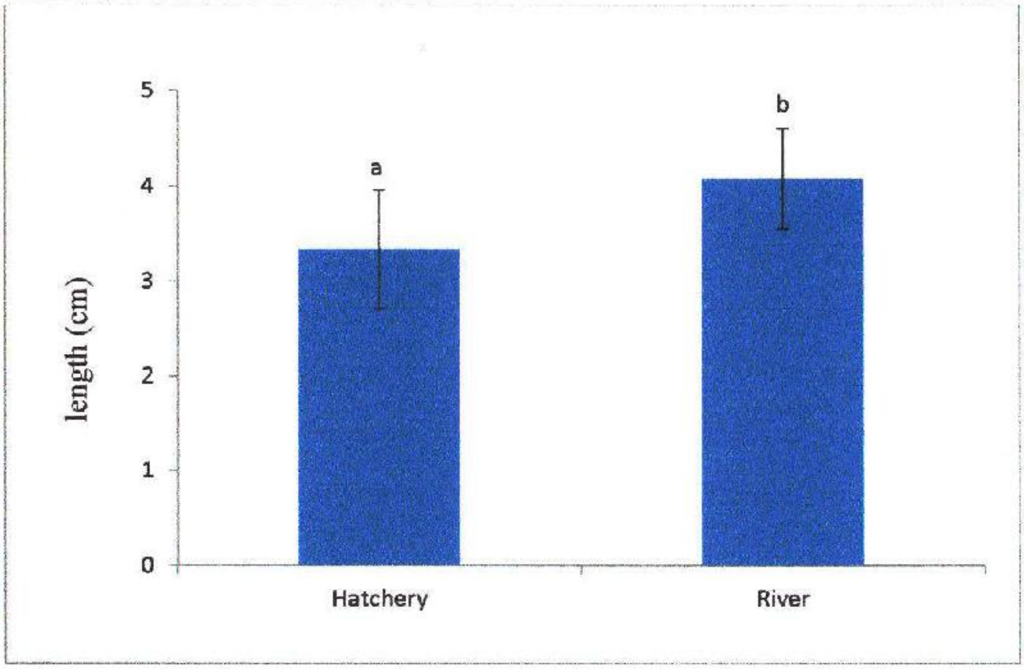


Fig 14: Maximum barbell length of stinging catfish (*Heteropneustes fossilis*).Values are the mean ± SD. Different letters indicate the means are significantly different.

4.6. Minimum barbel length:

Manimum barbel length is small whisker like which is located at the corners of the fish's mouth and it uses to locate food. It is important to estimate the age and weight of fish as well as morphological comparison two different groups. The figure exposed that there was higher value (1.48±0.12 cm) found of river sample and lower value of hatchery sample (1.40±0.16 cm). There was significant difference (fig. 15) between hatchery and river stock of stinging catfish (*H fossilis*) in minimum barbel length ($F_{(1,118)}$ = 49.75, $p<0.01$). The subsequent post-hoc test showed that there was also significant variation between the two stocks. Environmental condition, separate habitat as well as genetic variations are possibly responsible for variations.

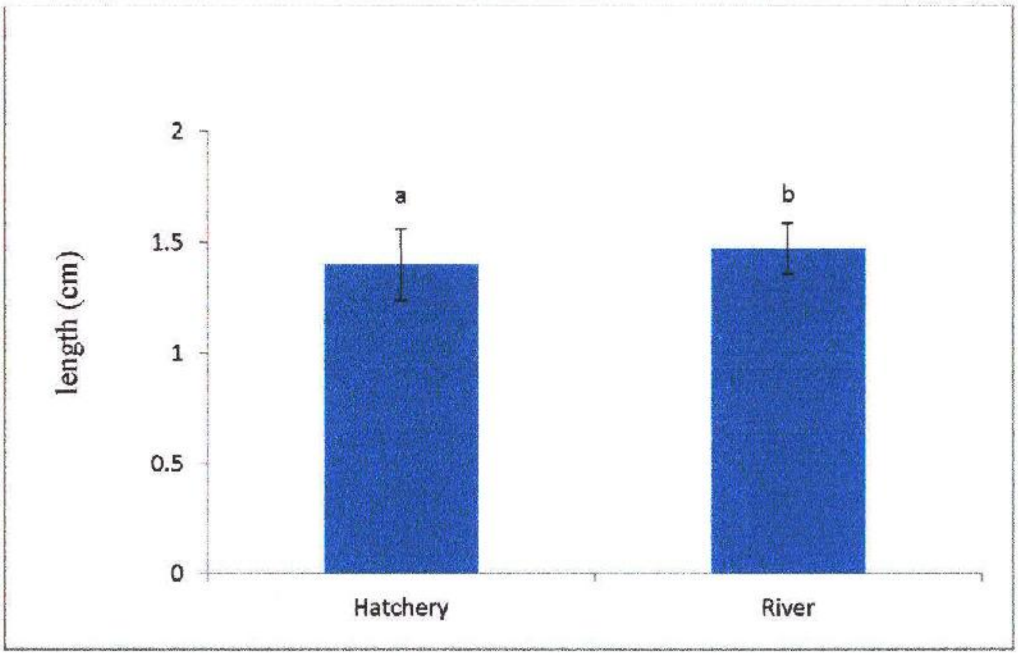


Fig 15: Minimum barbel length of stinging catfish (*Heteropneustes fossilis*).Values are the mean ± SD. Different letters indicate the means are significantly different.

4.7. Post-dorsal length:

Post-dorsal length is the straight-line measurement taken from behind the base length of dorsal fin to tail length. It assists to the morphological comparisons of fish populations from different locations, the estimation of weight and growth for individual fish and determination age of fish. In the fig. 16, I got that there was greater value of hatchery stock (8.85±0.33 cm) than the river stock (8.46±0.31 cm) in case of post-dorsal length. The analysis was revealed significant variations between the two different treatment groups in case of post-dorsal length of stinging catfish (*H. fossilis*) in post-dorsal length ($F_{(1,118)} = 44.48$, $p<0.01$). The subsequent post-hoc test was also performed to find out comparison between two groups and there was also significant variation with each other. The factors such as the habitat condition, their feeding strategies as well as separate geographical location and genetic variation are possibly responsible for the variations.

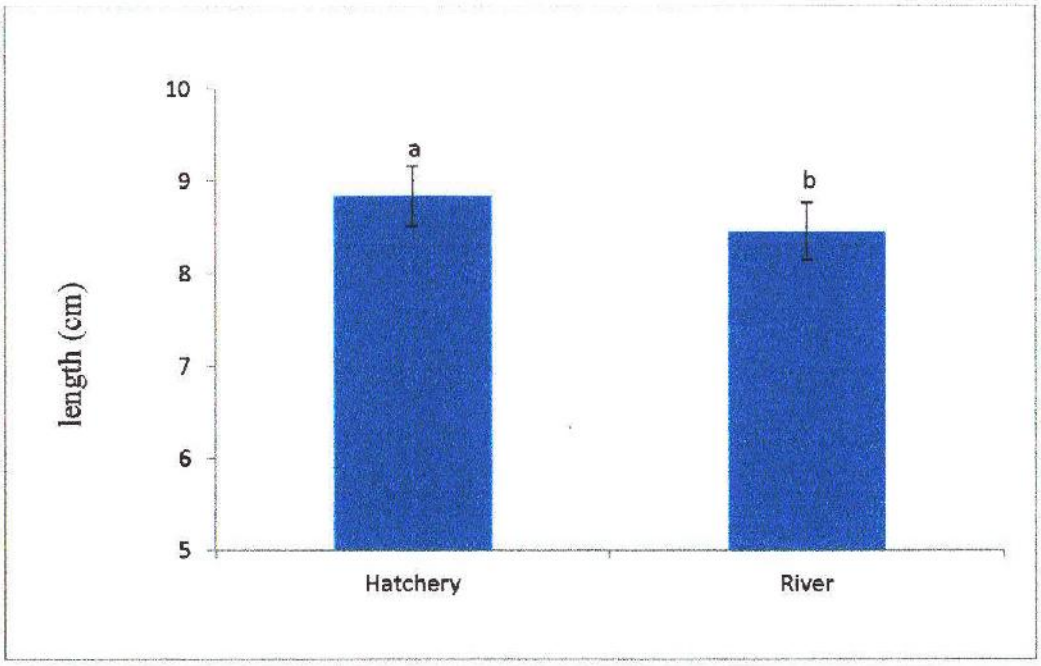


Fig 16: Post-dorsal length of stinging catfish (*Heteropneustes fossilis*).Values are the mean ± SD. Different letters indicate the means are significantly different.

4.8. Pre-dorsal length:

Pre-dorsal length is the straight-line measurement taken from front of snout to the insertion of first ray of dorsal fin. It is important as similar importance as post-dorsal length. The figure revealed the comparison between hatchery and river stocks of stinging catfish (*H. fossilis*) in pre-dorsal length and I found larger value of hatchery stock (4.33±0.21 cm) than the value of river stock (4.20±0.21 cm) of stinging catfish (*H. fossilis*). Significant difference (fig. 17) were observed between two different treatment groups in case of pre-dorsal length ($F_{(1,118)} = 15.33$, $p<0.01$). The post-hoc test subsequently showed that there was also significant variation between the two treatment groups. The variation might be due to habitats and genetic variation, food availability and feeding strategy, health and general fish condition.

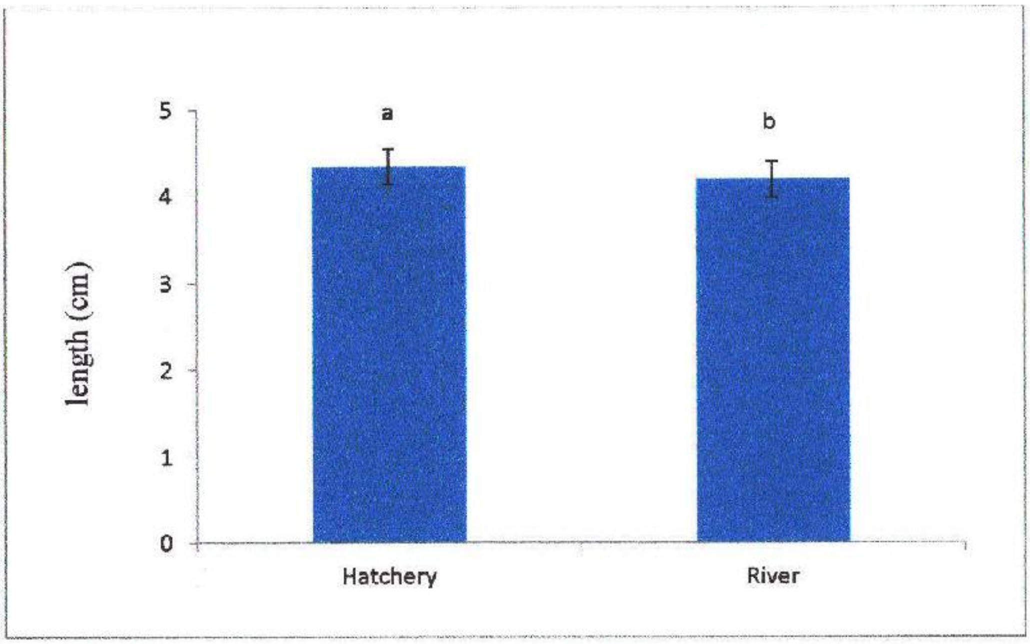


Fig 17: Pre-dorsal length of stinging catfish (*Heteropneustes fossilis*). Values are the mean ± SD. Different letters indicate the means are significantly different.

4.9. Head length:

Head length is the straight-line measurement taken from front of snout to the back of operculum. It helps to know the life history and morphological comparisons of fish populations from different locations, estimation of age and growth of fishes. In the fig. 18 showed that the value of hatchery sample (1.92±0.12 cm) was greater than the value of river sample (1.87±0.11 cm) in head length. There was significant difference between two treatment groups of stinging catfish (*H. fossilis*) for head length ($F_{(1,118)} = 6.56$, $p<0.01$). The subsequent post-hoc test revealed that there was also significant variation between the two stocks. The phenotypic discreteness might be responsible for the habitat condition, their feeding strategies as well as separate geographical location.

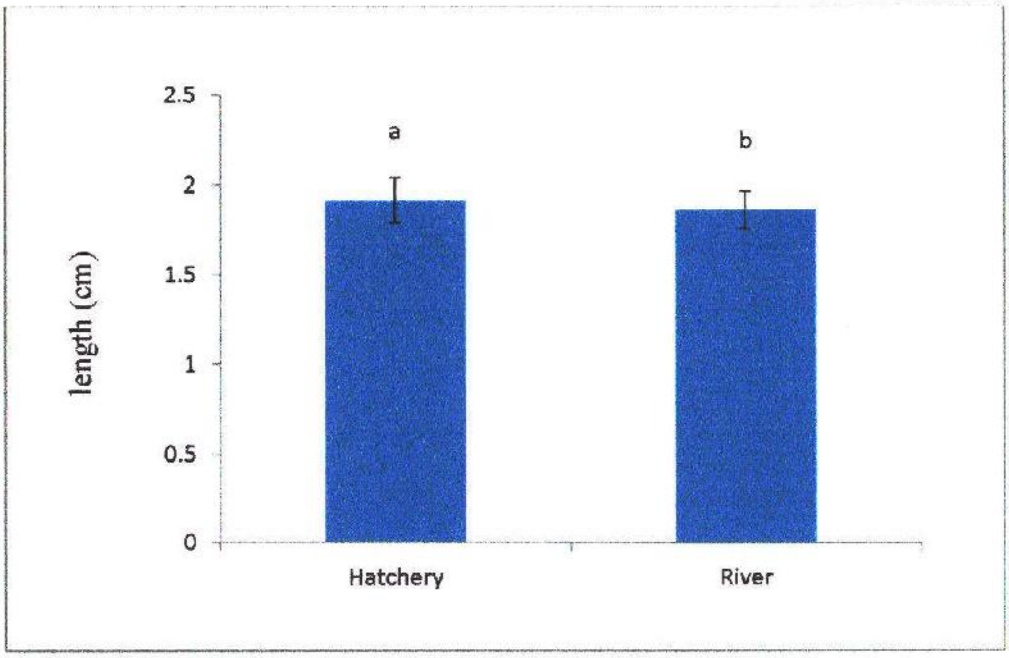


Fig 18: Head length of stinging catfish (*Heteropneustes fossilis*).Values are the mean ± SD. Different letters indicate the means are significantly different.

4.10. Weight:

Weight is the total body biomass of fishes. In my experiment, weight is one of them among the ten morphometric measurement. It is important to estimation of age, growth and health conditions of fish. It is also related to length–weight relationship (LWR), are useful in fishery management and stock assessment models. The model showed that the mean weight of hatchery stock (20.58±5.18 g) was higher than the river stock (15.64±3.37 g) of stinging catfish (*H. fossilis*). Significant difference (fig. 19) was observed between two treatment groups ($F_{(1,118)}$ = 6.56, p<0.01). The subsequent post hoc test revealed that the treatment groups also showed significant variation with each other. The variations are possibly due to environmental condition, separate habitat as well as genetic variations.

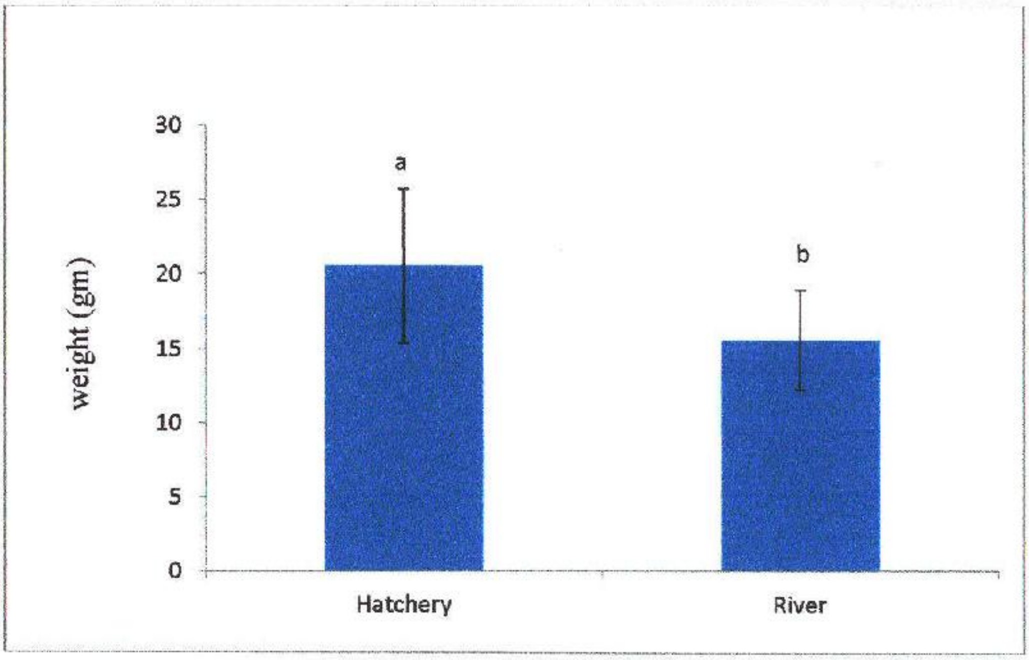


Fig 19: Weight of stinging catfish (*Heteropneustes fossilis*).Values is the mean ± SD. Different letters indicate the means are significantly different.

4.11. Seven truss measurement:

4.11.1. Dst 2-7: There were 120 sample sizes in my experiment and measured seven truss measurements in the sample. The dst 2-7 was important one of seven truss measurements in the experiment. The graphs was revealed that there was significant difference (fig. 20) in the parameter of dst 2-7 between two treatment groups ($F_{(1,118)} = 21.01$, $p<0.01$). The subsequent post-hoc test exposed that hatchery stock was larger (4.47±0.37 cm) than the river stock (4.14±0.42 cm). The differences of two stocks are likely to be separate habitats as well as close and open water areas.

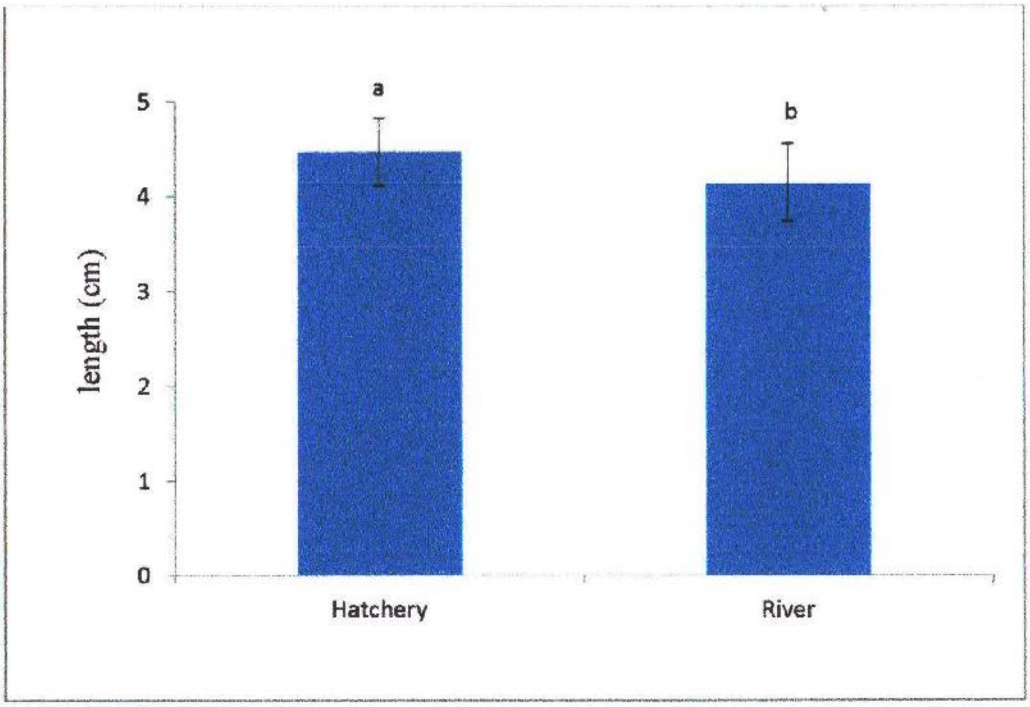


Fig 20: Dst 2-7 of stinging catfish (*Heteropneustes fossilis*).Values are the mean ± SD. Different letters indicate the means are significantly different.

4.11.2. Dst 2-8: The parameter of dst 2-8 was one of them in the seven truss measurement in the experiment. The result of dst 2-8 in the hatchery and river stock was (3.22±0.26 cm) and (3.00±0.24 cm) respectively. Significant difference (fig. 21) was observed between two stocks of stinging catfish (*H fossilis*) for dst 2-8 ($F_{(1,118)}$ = 22.08, $p<0.01$). The subsequent post-hoc test revealed that there was also significant variation with each other between two groups. The variation might be food availability, separate habitats and others environmental factors.

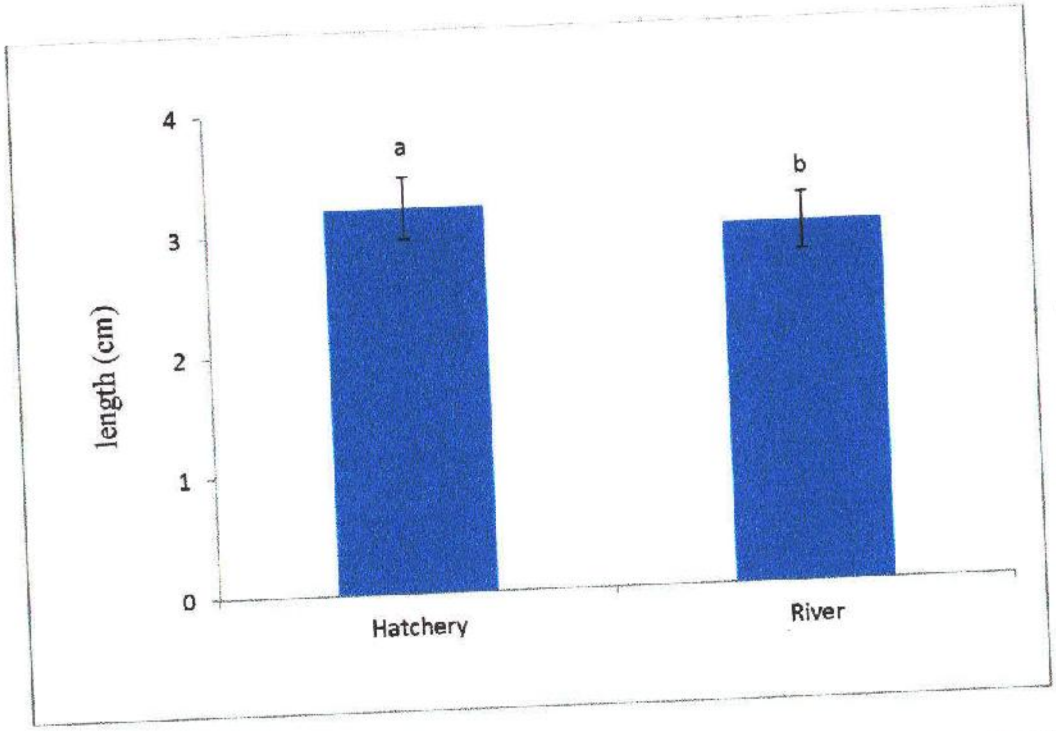


Fig 21: Dst 2-8 of stinging catfish (*Heteropneustes fossilis*).Values are the mean ± SD. Different letters indicate the means are significantly different.

4.11.3. Dst 3-7: In the seven truss measurement in the experiment, the parameter of dst 3-7 was important one. In the parameter of dst 3-7, I found greater value in hatchery stock (2.49±0.28 cm) than the value of river stock (2.12±0.19 cm) of stinging catfish (*H. fossilis*). The analysis results indicated that there was significant difference (fig. 22) between two groups in dst 3-7 ($F_{(1,118)}$ = 75.79, p<0.01). The subsequent post-hoc test revealed that there was also significant variation between the two stocks. The factors such as separate habitats and genetic variance, distance, food availability, health condition of fish are possibly responsible for the variation.

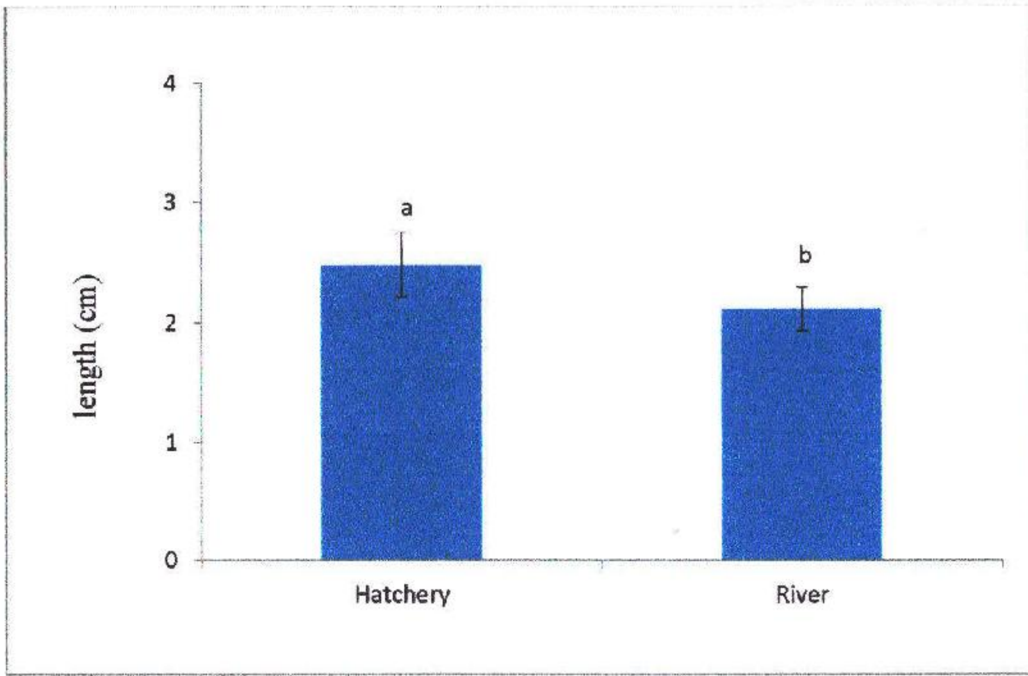


Fig 22: Dst 3-7 of stinging catfish (*Heteropneustes fossilis*). Values are the mean ± SD. Different letters indicate the means are significantly different.

4.11.4. Dst 3-8: The seven truss measurement measured in case of 120 sample size in the experiment. The dst 3-8 was most important one in the seven truss measurement. The graphs showed that the result of dst 3-8 was in hatchery stock (1.78±0.13 cm) and river stock (1.75±0.16 cm) of stinging catfish (*H. fossilis*) and there was no significant difference (fig. 23) between hatchery and river stock for dst 3-8 ($F_{(1,118)} = 1.45$, $p>0.05$).

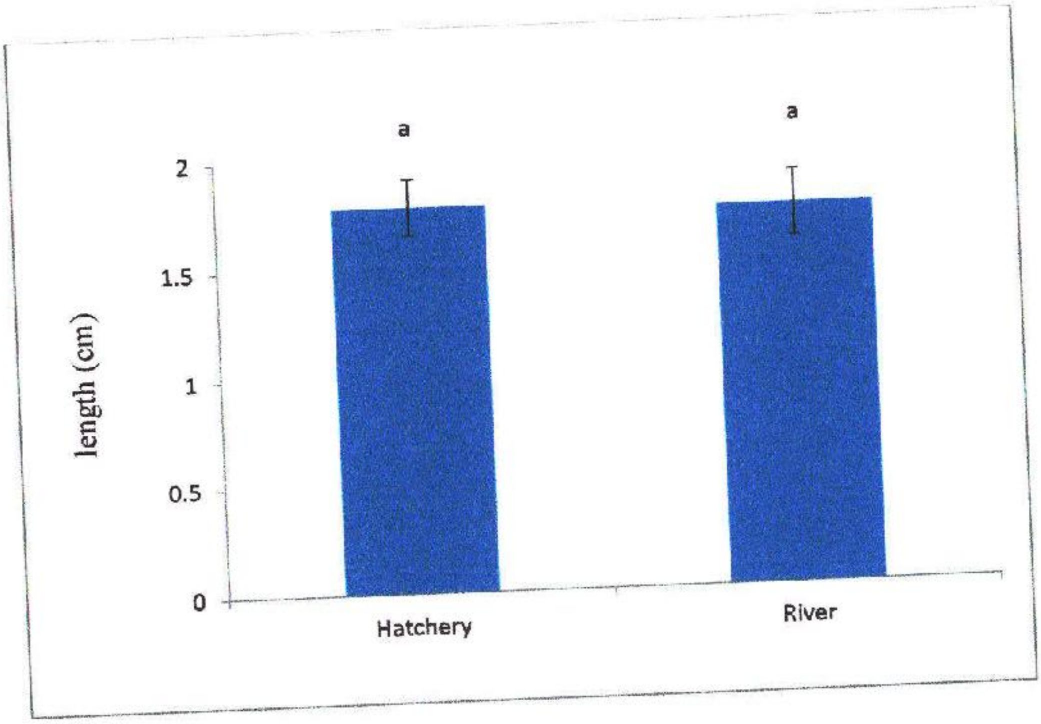


Fig 23: Dst 3-8 of stinging catfish (*Heteropneustes fossilis*).Values are the mean ± SD. Same letter indicate the means are not significantly different.

4.11.5. Dst 4-7: In the fig. 24, the mean value of hatchery and river stock was found (2.13±0.25 cm) and (1.94±0.19 cm) respectively in the dst 4-7. The figure was revealed significant difference between the river stock and hatchery stock of stinging catfish (*H. fossilis*) ($F_{(1,118)}$ = 22.36, $p<0.01$). The subsequent post-hoc test was also shown that the dst 4-7 of length was significantly variation with each other two treatment groups. The differences are possibly due to different habitats, size and fish health condition and environmental factors.

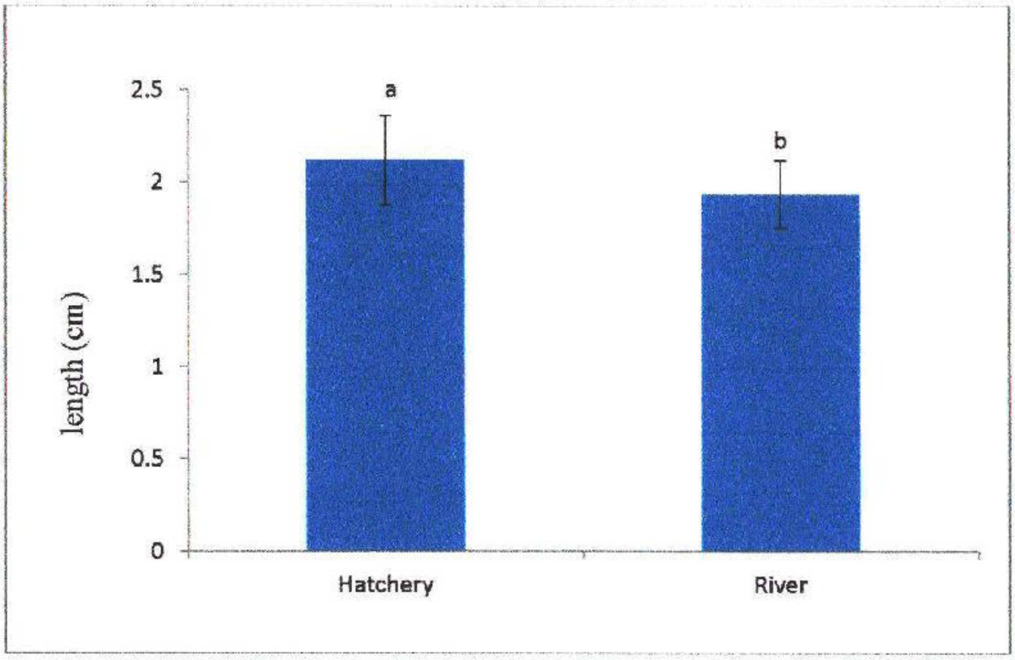


Fig 24: Dst 4-7 of stinging catfish (*Heteropneustes fossilis*).Values are the mean ± SD. Different letters indicate the means are significantly different.

4.11.6. Dst 4-8: The sketch revealed that the value of hatchery sample (1.82±0.19 cm) and the value of river sample (1.86±0.17 cm) in case of dst 4-8 of stinging catfish (*H. fossilis*). But the statistical result revealed that there was no significant difference (fig. 25) between two groups ($F_{(1,118)}$ = 1.45, p>0.05).

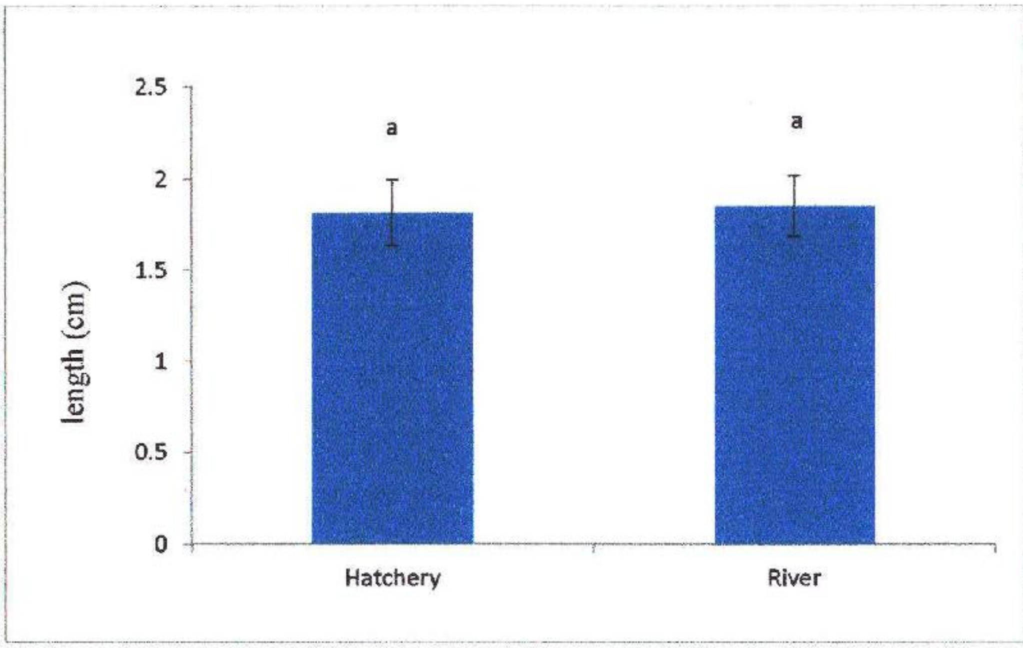


Fig 25: Dst 4-8 of stinging catfish (*Heteropneustes fossilis*).Values are the mean ± SD. Same letters indicate the means are significantly different.

4.11.7. Dst 5-6: The parameter of dst 5-6 was essential one parameter in the seven truss measurement in the experiment. The fig. 26 showed that the value of hatchery stock was 0.68±0.05 cm and the river stock was 0.70±0.08 cm. But ANOVA test result showed that there was no significant difference between hatchery and river stock of stinging catfish (*H. fossilis*) ($F_{(1,118)} = 3.42$, $p>0.05$).

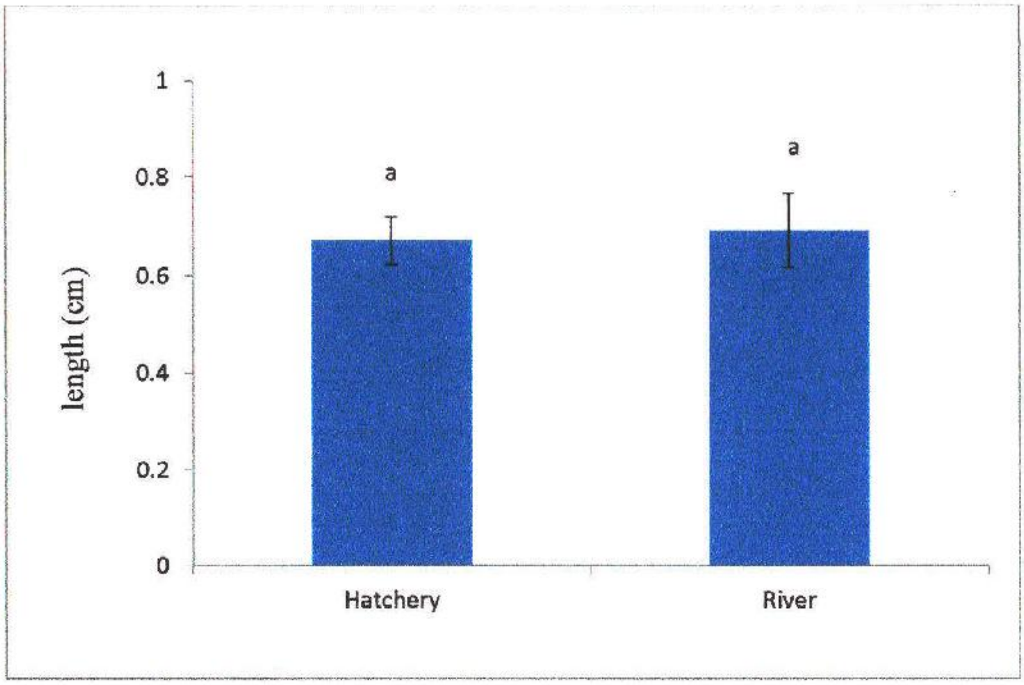


Fig 26: Dst 5-6 of stinging catfish (*Heteropneustes fossilis*).Values are the mean ± SD. Same letters indicate the means are significantly different.

Chapter 5

5. Discussion

In the present study, significant morphological variations were found between two isolated stocks the Kopotakkho River, Kotchadpur in Jhenaidah and the hatchery stock, Sheikhpara in Jashore of *H. fossilis*. These phenotypic variations were due to the habitat condition, food availability and their feeding strategies as well as separate geographical location. The similar results are found among the hatchery, Tanguar haor and the Old Brahmaputra stocks of *H. fossilis* (Rahman *et al.*, 2014) and for anchovy, *Engraulis encrasicolus* in the Black, Aegean and northeastern Mediterranean Seas (Turan *et al.*, 2004). Morphometric differences between two stocks were expected, because they were geographically separated and may have originated from different ancestors. Thus, it was not unlikely that obvious environmental variations exist between two stocks of *H. fossilis*. Fish are very sensitive to environmental changes and quickly adapt themselves by changing necessary morphometrics. It is well-known that morphological characters can show high plasticity in response to differences in environmental conditions, such as food abundance and temperature (Allendorf *et al.*, 1980; Swain *et al.*, 1991 & Wimberger *et al.*, 1992).

In general, fish demonstrate greater variances in morphological traits both within and between populations than any other vertebrates and are more susceptible to environmentally induced morphological variations (Allendorf *et al.*, 1987 & Wimberger *et al.*, 1992). The phenotypic plasticity of fish is very high. They adapt quickly by modifying their physiology and behavior to environmental changes. These modifications ultimately change their morphology (Ryman *et al.*, 1987). In a small country like Bangladesh, there are probably very small environmental changes from place to place. In spite of this, the hatchery population possessed a unique environment that differed from the Kopotakkho River of Bangladesh. However, due to small environmental differences the resulting morphological differences in fish may be so small that they might be impossible to discern with gross morphomeristic characters. Therefore, truss network measurements were engaged in this experiment. Truss network systems are a powerful tool for identifying stocks of fish species (Turan *et al.*, 2004). An unbiased network of morphometric measurements over a 2 dimensional outline of a fish removes the need to find the types of characters and optimal number of characters for stock separation and provides information over the entire fish form (Turan *et al.*, 2004).

The truss network system can effectively be used to distinguish between the hatchery and river stocks. In this case, more-significant differences were expected because of the two completely different habitats i.e., an open-water habitat and the other was closed water. Besides, food availability, distance, genetic variation and others environmental factors were responsible for the significant differences. Environmentally induced phenotypic variations however, may have advantages in the stock structure analysis of exploited species, especially when the time is insufficient for significant genetic differentiation to accumulate among populations. Genetic markers might not be sufficient to detect existing genetic variation among populations and also only a small proportion of DNA is analyzed by genetic markers.

As the hatchery owners used the fish as a brood collected from the close water source (wild) in the country, the hatchery stock was shown some proximity to river stocks. In this experiment, the result determined the dissimilarity between the stocks and significant correlations were observed between size and truss measurement characteristics between two stocks of *H. fossilis* except dst 3-8, dst 4-8, dst 5-6 ($p<0.01$). The differences between the hatchery and river stocks may have been due to environmental as well as genetic variations. So we can conclude that the morphological difference between the hatchery and wild stocks are possibly due to environmental condition, separate habitat as well as genetic variations.

Chapter 6

6. Conclusion

Morphometric adds a quantitative element to descriptions, allowing more rigorous comparisons. It enables one to describe complex shapes in a rigorous fashion and permits numerical comparison between different forms. Advancements in morphometric uses powerful tools for testing and displaying differences in shape, isolate shape from size variation and identifying stocks of specie with unique morphological characteristics. This has enabled a better management of species subunits and ensures better management of the fishery resources. The present study was conducted to evaluate the morphological variation in respect of morphometric characters between two isolated stocks of *H. fossilis*: the Kopotakkho River, Kotchadpur in Jhenaidah and the hatchery, Sheikhpara in Jashore. A univariate analysis of ten morphometric characters shown that all morphometric measurements and truss measurements were significantly differed ($p<0.01$) between the hatchery and river stock except dst 3-8, dst 4-8, dst 5-6. The results of this study are useful as preliminary baseline information of *H. fossilis* populations for further studies and the population structure of any species is a prerequisite for developing management and conservation strategies. In both aquaculture and open-water management, it is essential to select genetically superior stocks along with better features. More research especially genetic studies and investigations of the impacts of environmental factors is needed for conservation and mass seed production of this indigenous and commercially important aquaculture species, *H. fossilis* to save from being extinction.

Chapter 7

7. Reference

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Chapter 8

8. Annex

Weight (g)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	731.4	731.41	38.42	0.000
Error	118	2246.3	19.04		
Total	119	2977.7			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	20.574	A
River	60	15.637	B

Means that do not share a letter are significantly different

Standard length (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	1.071	1.07142	35.17	0.000
Error	118	3.595	0.03046		
Total	119	4.666			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	13.6669	A
River	60	13.4780	B

Means that do not share a letter are significantly different

Tail Length (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	0.4244	0.42436	40.93	0.000
Error	118	1.2235	0.01037		
Total	119	1.6479			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	1.5442	A
River	60	1.4252	B

Means that do not share a letter are significantly different

Head Width (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	0.8931	0.89310	46.26	0.000
Error	118	2.2780	0.01931		
Total	119	3.1711			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	1.7771	A
River	60	1.6046	B

Means that do not share a letter are significantly different

Anal Fin Length (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	4.688	4.6881	30.19	0.000
Error	118	18.325	0.1553		
Total	119	23.013			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	8.2478	A
River	60	7.8525	B

Means that do not share a letter are significantly different

Maximumu Barbel Length (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	16.78	16.7770	49.75	0.000
Error	118	39.79	0.3372		
Total	119	56.57			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	4.0778	A
River	60	3.3300	B

Means that do not share a letter are significantly different

Minimum Barbel Length (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	0.1559	0.15594	8.22	0.005
Error	118	2.2388	0.01897		
Total	119	2.3947			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	1.4716	A
River	60	1.3995	B

Means that do not share a letter are significantly different

Post-Dorsal Length (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	4.443	4.44339	44.48	0.000
Error	118	11.786	0.09989		
Total	119	16.230			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	8.8448	A
River	60	8.4599	B

Means that do not share a letter are significantly different

Pre-dorsal Length (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	0.6492	0.64920	15.33	0.000
Error	118	4.9979	0.04236		
Total	119	5.6471			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	4.3385	A
River	60	4.1914	B

Means that do not share a letter are significantly different

Head Length (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	0.08646	0.08646	6.56	0.012
Error	118	1.55462	0.01317		
Total	119	1.64108			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	1.9166	A
River	60	1.8629	B

Means that do not share a letter are significantly different

Seven truss measurement:

Dst 2-7 (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	3.139	3.1395	21.01	0.000
Error	118	17.631	0.1494		
Total	119	20.771			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	4.4645	A
River	60	4.1410	B

Means that do not share a letter are significantly different

Dst 2-8 (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	1.359	1.35907	22.08	0.000
Error	118	7.263	0.06155		
Total	119	8.622			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	3.2104	A
River	60	2.9976	B

Means that do not share a letter are significantly different

Dst 3-7 (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	4.071	4.07120	75.79	0.000
Error	118	6.339	0.05372		
Total	119	10.410			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	2.4840	A
River	60	2.1156	B

Means that do not share a letter are significantly different

Dst 3-8 (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	0.02869	0.02869	1.45	0.231
Error	118	2.33633	0.01980		
Total	119	2.36502			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	1.7791	A
River	60	1.7482	A

Means that do not share a letter are significantly different

Dst 4-7 (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	1.042	1.04186	22.36	0.000
Error	118	5.497	0.04659		
Total	119	6.539			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	2.1218	A
River	60	1.9354	B

Means that do not share a letter are significantly different

Dst 4-8 (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	0.04335	0.04335	1.45	0.231
Error	118	3.52877	0.02990		
Total	119	3.57211			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	1.8563	A
River	60	1.8183	A

Means that do not share a letter are significantly different

Dst 5-6 (cm)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Stock	1	0.01312	0.013118	3.42	0.067
Error	118	0.45307	0.003840		
Total	119	0.46619			

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Stock	N	Mean	Grouping
Hatchery	60	0.69189	A
River	60	0.67098	A

Means that do not share a letter are significantly different