ABUNDANCE AND DIVERSITY OF FISH LARVAE AT REZUKHAL ESTUARY OF THE COX'S BAZAR COASTS, BANGLADESH

Nargis Sultana

Roll No.: 0120/02

Registration No.: 854

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A thesis submitted in the partial fulfillment of the requirements for the degree of Master of Science in Fisheries Resource Management

Department of Fisheries Resource Management

Faculty of Fisheries

Chattogram Veterinary and Animal Sciences University

Chattogram-4225, Bangladesh

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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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Dr. Sk. Ahmad Al Nahid	**Shahida Arfine Shimul**
Supervisor	**Co-supervisor**

Dr. Sk. Ahmad Al Nahid

Chairman of the Examination Committee

Department of Fisheries Resource Management

Faculty of Fisheries

Chattogram Veterinary and Animal Sciences University

Chattogram-4225, Bangladesh

JUNE 2022

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ABSTRACT

The abundance and diversity of fish larvae in the Cox's Bazar Coasts, Bangladesh was investigated using a bongo net with a mouth diameter of 0.50 m, a length of 1.3 m, and a mesh size of 500 μm at the body. Fish larvae were collected from a research station named the Rezukhal estuary, Cox's Bazar Coasts from March 2020 to February 2021. A total of 15 families of larvae were identified consist of 2467 individuals from the selected station. The average number of fish larvae was 206/1000 m^3/month, and the highest abundance (1197 larvae/1000 m^3) was found in September. The lowest abundance (0 larvae/1000 m^3) was found in June. Based on the percentage of the catch, five (5) dominant families were identified as Engraulidae (45.76%), Clupeidae (42.97%), Mugilidae (5.76%), Ambassidae (2.67%), and Blenniidae (1.01%). The percentages by families of constant: accessory: accidental families were 13:20:67 among the total identified samples. The highest Shannon-Wiener diversity index (1.481) was calculated in February and the highest evenness (0.940) were observed in June and the highest family richness (1.618) was found in July. 15 larvae families were identified and the frequency of occurrence indicated their spawning seasons. The spawning season of the identified families was classified as Winter, Summer, and Monsoon based on monthly larval abundance. The families' highest number 4 (Mugilidae, Blenniidae, Myctophidae and Carangidae) comes from Winter; Monsoon season. Whereas the Summer, Winter (Hemiramphidae); Summer (Sciaenidae) included the lower number of taxa only 1 taxa were recorded. Study findings will contribute to decision-making on marine fisheries management in Rezukhal estuary, Cox's Bazar Coasts, Bangladesh to decision-maker.

Keywords: Larvae, Abundance, Diversity, Spawning seasons, Cox's Bazar Coasts.

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LIST OF ABBREVIATIONS

Acronym	Definition
EAF	Ecosystem Approach to Fisheries
EBMF	Ecosystem-Based Management of Fisheries
m^3	Cubic meter
µm	Micro meter
Mar	March
Apr	April
Jun	June
Jul	July
Aug	August
Sep	September
Oct	October
Nov	November
Dec	December
SD	Standard Deviation
SE	Standard Error
S	Summer
M	Monsoon
W	Winter
R1	Replication 1
R2	Replication 2
R3	Replication 3

CHAPTER-1: INTRODUCTION

Rezukhal is a mountainous stream that flows from the north Arakan Mountains, through the region of Bandarban, and eventually through the Cox's Bazar district of Ukhia. Towards Jaliapalong, the two portions of Rezukhal merge and at last fall into the Bay of Bengal (Iqbal et al., 2014). Rezukhal is a river in Ukhia, a part of the Cox's Bazar area, both economically and geographically important (Iqbal,1999). Estuaries are significant because fish are both permanent and temporary community members, with marine species feeding, breeding, growing, and protecting themselves in these ecosystems (Raz-Guzaman and Huidobro, 2002). The Rezukhal estuary has been found to play an essential role as a nursery ground, supplying sufficient food and relative protection to many commercially important species (Iqbal et al., 2014).

Fish larvae and eggs are known as ichthyoplankton. Ichthyoplankton is planktonic, which means it can't swim well on its own and must float with the ocean waters. Early-stage larvae have limited swimming abilities, but as they mature into juveniles, they improve their swimming capabilities and stop being planktonic (Stephens et al., 2006) and the planktonic stage lasts anywhere from a few weeks to a few months (Brothers et al., 1983; Victor, 1986). It has found in the sunlight zone of the water column, which is often referred to as the epipelagic or photic zone, and is less than 200 meters deep (Stephens et al., 2006).

In general, larvae and juveniles of fish in estuaries and coastal areas are euryhaline and spend just a brief time in these habitats, indicating that they are in the middle of an inshore-offshore migration (Yafiez-Aranclbia et al., 1980). Plankton dispersal did not affect the spread of fish larvae in nearshore seas. The rich species diversity reflects the embayment's varied geomorphology and hydrography. The association between the frequency of occurrence and the life history change of fish larvae, as well as the mismatch in peak abundance distributions between zooplankton and larvae, has been investigated (Tzeng et al., 1997). For temperate (Drake and Arias, 1991; Blabber, 2000; Shackell and Frank, 2000) and tropical estuarine ecosystems, the highly prolific character of estuarine niches (Nixon et al., 1986, Day et al., 1989) and their importance as nursery grounds for fish in early numerous life-history stages are well known (Franco-Gordo et al., 2003).

Emergent indicators for predicting future fishing stocks include the species composition and quantity of fish larvae and juveniles (Stephens et al., 1988). Fish eggs and larvae have played a key role in fisheries management and are expected to play a key role in supplementing and conserving fish stocks. Over the last 40 years, knowledge of fish’s early life has grown at a breakneck pace (Rutherford, 2002; Pattira et al., 2012). It is now evident that data derived from eggs and larvae of fish make a difference in contributions to fishery sciences that are critical for proper fish population assessment and management (Fuiman and Werner, 2002).

There are several reasons for studying ichthyoplankton. One of the purposes of ichthyoplankton field studies is to determine the number or biomass of exploitable populations (Heath,1992). Furthermore, understanding ichthyoplankton is necessary because, as a component of the pelagic food web (Raymont, 1983). It can serve as a vital connection between smaller planktonic and nektonic species. The ecological knowledge of fish larvae is essential to understanding the physiology of fishes (Leis and Rennis, 1983). The spawning behavior of adult fish, the hydrographic structure at various scales and the interaction with the reef topography, the duration of the larval period, the behavior of the larvae, larval mortality and growth, and their variation in space and time have all influenced the distribution of fish larvae (Leis, 1991).

Fish eggs and larvae taxonomy identification is a difficult task. It is further complex than distinguishing between the juvenile and adult stages of fish. It is due to several reasons. Firstly, due to the small size of fish eggs and larvae, only a stereoscopic microscope can be used to see features to identify them. Secondly, they go through morphological, meristic, morphometric, and pigmentary changes during their development. Lastly, some characteristics, like pigmentation patterns, can show significant regional and individual variation. Marinaro (1971) constructed incomplete dichotomous keys for the Western Mediterranean Sea to face these challenges. The body structure, coloring pattern, and meristic and morphometric traits are the most important characteristics for identifying larval fish. The shape of the larvae's bodies allows them to be categorized into numerous distinct categories. For example, larval with thin, elongated bodies (e.g., families Clupeidae, Engraulidae, Stomiidae); larvae with horizontally compressed bodies (all flatfishes, e.g., Families Bothidae, Pleuronectidae, Soleidae); most fish larvae (e.g., Families Gadidae, Triglidae, Gobiidae) have bodies with the classic fish form; unnaturally shaped bodies (e.g., Family Belonidae) or cranial armatures (e.g., Family Scorpaenidae), elongated fin rays (e.g., Families Carapidae, Lophiidae), stalked eyes (e.g., certain Myctophidae species), or early formed and massive fins (e.g., Family Tachinidae) (Russell, 1976).

Meristic characteristics, such as the number of myomeres, vertebrae, or fin rays, are countable features that exist in a series. Because they are species-specific, they have a high diagnostic value (at least when combined with many counts). Some drawbacks such as fin rays being perfectly produced in older larvae, which are rare in plankton samples (Tucker and Laroche, 1984). Due to the tremendous alterations that most species endure from their early larval stages to adulthood, identifying larval fish has been an important morphological difficulty in marine biology. The size of marine larval fish ranges from 2.5 to 3.0 mm soon after hatching to 10–30 mm during transformation, which can take anywhere from a few days to several months (Webb, 1999). Larval fish appear similar to adults during the early stages of development because they are at least partially developed and lack structures found in adults (e.g., fin scales), and they frequently have pelagic specializations that result in some of the most spectacular marine creatures known that will be lost as development progresses (Leis, 2015).

The quantity of different objects and the frequency with which they appear is referred to as diversity. As a result, the phrase applies to a wide range of habitats, species, genes, and relative abundance (Congress, 1987). Diversity is a property of multi-species populations that is also one of the most misunderstood and poorly estimated properties. Perhaps a widespread misunderstanding is that species diversity and richness are synonymous. They are separate, despite their similarities. Species richness refers to the overall number of species found in a sample, whereas diversity refers to how individuals are distributed among those species, also known as the species frequency distribution. Almost all quantitative measures of diversity, it turns out, are a mix of two factors: species richness and evenness, where evenness refers to how individuals are distributed evenly among species (Aslam, 2009).

Studies on larval fishes are frequently the most effective approach to delivering valuable information to fishery biologists and managers. These include determining the location of spawning grounds in space and time, determining fish larvae habitats, and discovering new fisheries. Larvae survey data can be used to obtain estimates of recruitment. Estimating or projecting recruitment under varying climatic factors is critical for effective fish stock management, especially in the face of very rapid climate change. Furthermore, the Ecosystem Approach to Fisheries (EAF), which recognizes the complete spectrum of interactions within a marine ecosystem, is being implemented has resulted in a surge in research aimed at better understanding recruiting and its processes (Katsanevakis et al., 2011). In addition, to apply the EAF, a comprehensive understanding of ecosystems and environmental influences on fish populations, particularly in their highly fragile early life stages, is essential. This knowledge is also necessary for adopting Ecosystem-Based Fisheries Management (EBMF), in which the order of management priorities is reversed from the traditional norm, focusing on the ecosystem's health rather than the fishing resources (Pikitch et al., 2004).

Early ichthyoplankton research concentrated on the geography and timing of spawning, as well as the survival of the young of commercially significant species, and data from far-flung oceanographic expeditions offered a global picture of ichthyoplankton diversity and distribution patterns. The importance of ichthyoplankton approaches in fisheries research has grown in response to a growing demand for fishery-independent stock assessment, which is the topic of a companion symposium in this issue. Ichthyoplankton study is vital in understanding the ecology and evolution of fish faunas and their constituent populations, as fisheries science has progressed beyond single-species ideas. This conference is based on the necessity to focus on ichthyoplankton assemblages as an integrated element of their environment, which is central to this knowledge (Moser and Smith, 1993).

Most of the previous biological studies in Rezukhal Estuary, Cox’s Bazar Coasts focused mainly on the seasonal variation in primary production, composition, and abundance of mesozooplankton (Achuthankutty et al., 1980; Nair et al., 1981; Madhupratap et al., 2003). However, little is known about the abundance and composition of fish larvae. Understanding the abundance and distribution of fish larvae in relation to environmental circumstances could fill a gap in the study of fish life cycle and provide useful information for fishery management. The larval stage is generally the most vulnerable to environmental changes. Any change in the quality or quantity of ecological factors would be detrimental to larval survival and could suggest future recruitment potential (Leis and Rennis, 1983). Although some information on fish larvae has been collected in some coastal regions of the Bay of Bengal, nothing is known about the distribution and abundance of fish larvae in the offshore portions of the Rezukhal Estuary, Cox's Bazar Coasts.

1.1 Significance of the study

- This study provides a complete understanding of the abundance and distribution of fish larvae in the Rezukhal Estuary, Cox's Bazar Coasts
- Provides a complete profile of larval families found from the Rezukhal Estuary, Cox's Bazar Coasts
- The present study helps to successfully identified fish larvae and their spawning seasons and biodiversity index in the Rezukhal Estuary, Cox’s Bazar Coasts of the Bay of Bengal, which will help in the decision-making regarding marine fisheries management in the Cox’s Bazar Coasts of the Bay of Bengal.

1.2 Scopes of the study

The findings might be used to assess current fish stocks and could also be useful as a guideline for future environmental studies.

1.3 Objectives

- To identify the larval fishes and assess their temporal distribution in the Rezukhal Estuary, Cox's Bazar Coasts
- To determine the spawning season of fish species based on larval abundance and determine the biodiversity indices of larval families

CHAPTER-2: REVIEW LITERATURE

Literature reviews act as a useful guideline for a particular topic. Experiment, it is essential to know the information about the previous related work. The goal of this chapter is to go over some of the previous research done by various researchers in the related field. The following information was briefly reviewed in favor of the present study which was done around the world and relevant to the study.

Many studies found that the presence, abundance, and species composition of fish larvae and juveniles in nearshore waters had influenced by the fish's spawning seasons and the Physico-chemical conditions present during onshore travel (Blaber and Whitfield, 1977; Blaber and Milton, 1990; Robertson and Duke, 1990).

A total of 14,584 fish larvae from 52 families were collected from the Bay of Bengal. It was divided among 18 families in the upper portion of the Bay, 19 families in the western part of the Bay, and 51 families in the Andaman Sea (Lirdwitayaprasit et al., 2008). In the Pendas River estuary in Peninsular Malaysia, 2687 larvae from 19 families were found, including 14 in the upper portion of the estuary, 17 in the middle estuary, and 16 in the lower estuary (Arshad et al., 2012). Over a year, 1336 larvae were collected from various locations in Mabahiss Bay on the Egyptian Red Sea coast, representing 57 species and 40 families from 13 fish orders (Abu El-Regal et al., 2014). In Yenliao Bay, Northeastern Taiwan, fish larvae were found in higher quantities near shore than offshore a total of 9969 larvae representing 80 groups and 138 species were found (Tzeng et al., 1997). In 1982 and 1983, Janekarn (1988) discovered 55 and 62 families of fish larvae on Thailand's west coast. Based on Janekarn and other research, he calculated the total number of 123 families of fish larvae on Thailand's west coast (Janekarn, 1992; Janekarn, 1988) and the northwest Indian Ocean, according to Nellen (1973), there were 102 fish larvae families in the Red Sea, the Arabian Sea, and the Persian Gulf.

The percentages by families of constant occurrence among the 18 families in the upper portion of the bay are as follows constant: accessory: accidental families were 28:22:50; 32:21:47 in the western portion of the Bay, and 27.5:27.5:45 in the Andaman Sea (Lirdwitayaprasit et al., 2008).

In the upper portion of the Bay of Bengal, 07 (Carangidae, Gempylidae, Cynoglossidae, Bothidae, Scombridae, Sphyraenidae, and Hemirhamphidae) of larvae was economically significant where Carangidae, Scombridae, and Gempylidae were the most common families among them. The western portion of the Bay of Bengal, with 08 (Synodontidae, Carangidae, Sphyraenidae, Gempylidae, Trichiuridae, Scombridae, Bothidae, and Cynoglossidae) of them being economic groupings and the Carangidae family was the most common, followed by the Bothidae and Gempylidae families and the Andaman Sea, Bothidae was the most common family, followed by Hemirhamphidae and Carangidae (Lirdwitayaprasit et al., 2008).

Among the 19 families of Pendas River estuary, Clupeidae was the most prevalent family, accounting for 41.07 % of all fish, followed by Blenniidae (24.45 %), Teraponidae (8.80 %), Gobiidae (5.40 %), Sillaginidae (3.22 %), Nemipteridae (1.72 %), and Mullidae (1.28 %) (Arshad et al., 2012). In Mabahiss Bay, the Egyptian Red Sea, larvae of the families Mullidae with 489 larvae accounting for 43.2 % and Clupeidae with 226 larvae accounting for 20.2 % dominated the collection of all collected larvae. Gerreidae larvae were abundant, accounting for 11.4 % of the total. The most abundant families were Tripterygiidae and Phosichthyidae, which accounted for 8.2 % and 5.4 % of the total, respectively (Abu El-Regal et al., 2014). According to Chamchang (2006), the Myctophidae family was the most prevalent in the Andaman Sea, accounting for 30.41 % of all larvae, followed by the Stomiidae family.

Photichthyidae, Bregmacerotidae, Myctophidae, Callionymidae, and Carangidae were the top 05 prevalent families in the upper portion of the Bay of Bengal, whereas Myctophidae, Bregmacerotidae, Photichthyidae, Gonostomatidae, and Carangidae were the top five dominating families in the western portion of the Bay of Bengal and the top 05 prominent families in the Andaman Sea were Myctophidae, Bregmacerotidae, Photichthyidae, Gonostomatidae, and Callionymidae (Lirdwitayaprasit et al., 2008). In the Pendas River estuary, southern Johor, Peninsular Malaysia, 05 dominant families (Blenniidae, Clupeidae, Gobiidae, Teraponidae, and Sillaginidae) were identified (Arshad et al., 2012). Mabahiss Bay's ten most abundant taxa were *Mulloides flavolineatus* (Mullidae), *Spratelloides delicatulus* (Clupeidae), *Gerres oyena* (Gerreidae), Tripterygiidae, *Vinciguerria mabahiss,* (Phosichthyidae), *Omobranchus puctatus,* (Blenniidae), Gobiidae, Serranidae, Gobiesocidae, and Labridae formed 82.3% of whole larvae (Abu El-Regal et al., 2014). At the rocky stations of Yenliao Bay, Northeastern Taiwan, fish from the families Pomacentridae, Apogonidae, and Tripterygiidae were dominant and more plentiful, whereas Gobiidae was abundant at the estuary. Pomacentridae (23%) was the prominent family in Yenliao Bay, followed by Carangidae (6%), *Auxis sp.* (9%), Myctophidae (4%), Apogonidae (15%), Gobiidae (6%), Ambassis sp. (9%), Tripterygiidae (3%) (Tzeng et al., 1997). In large-scale research in Thailand, Janekarn and Boonruang (1986) reported that clupeid larvae abundance was highest in February. According to Aziz 02 species of gobiid fish were discovered on the seagrass floor of Merchang Lagoon in Peninsular Malaysia (Aziz et al., 2006).

Several studies have found that the Gobiidae family is extensively dispersed in coastal locations, regardless of climate or other parameters such as seagrass area, temperature, or biological variables (Kwak and Klumpp, 2004). The Myctophidae family is the largest of the marine fish families, with 500 species found all over the world. They were an important component of many local food chains since they were prey upon by cetaceans such as whales and dolphins, as well as huge pelagic species like tuna and sharks (Nellen, 1973; Fish Base, 2004).

In southern Johor, Peninsular Malaysia, the Shannon Wiener index revealed considerable change throughout monsoon and inter monsoon seasons, with maxima in December–January and May-August, respectively, while family richness suggested two peaks each year. January–March was one high, while May-August was another. The middle estuary had the highest mean Shannon Wiener diversity index (1.48), whereas the upper estuary had the lowest (1.18). The highest evenness (0.77) had found in the middle estuary, and there was no variation in evenness between the higher and lower estuaries. The maximum family richness (1.72) was found in the middle estuary, whereas the lowest richness was found in the upper portion of the estuary (1.34) (Arshad et al., 2012). In terms of the spaito distribution of the diversity index, the open water region of Mabahiss Bay, on the Egyptian Red Sea coast, the coral reef region had the highest species diversity index of 2.48 and the seagrass area had the lowest species diversity index of 1.99 and the highest species richness of 6.08, while the seagrass area had the lowest. The species' evenness varied from 0.56 in open water to 0.69 in coral reefs (Abu El-Regal et al., 2014). The highest diversity index was found in March (2.89), July (2.83), January (2.81), and September (2.79), while the lowest diversity index was in May (2.15) in Ao Trat, Thailand. The evenness index was highest in

January and July (0.95) and lowest in March and May (0.90). The month of March had the highest species richness of 4.45, while May had the lowest species richness of 2.26 (Termvidckakorn, 2016).

The presence of fish larvae is proportional to the fish's spawning season. The planktonic stage of fish usually lasts a few weeks to several months (Brothers et al., 1983; Victor, 1986). Adults set the patterns for spawning product distribution. Still, Physical and biological elements (such as water velocity and temperature, as well as the distribution and number of prey and predators have an impact on larvae's dispersion, abundance, growth, and survival (Heath, 1992). Fish larvae seasonal patterns were linked to adult population reproductive behaviors and life cycles. They are influenced by oceanic and climatic factors (Hernandez-Miranda et al., 2003). The most important parts in determining spawning and nursery regions were the area of larvae collected. Eggs and yolk-sac larvae used in their early stages are a reliable indicator of spawning and nursery regions (El-Regal, 2013). The number of larvae may be a good index of generational success. Fish spawning sites and seasons were determined by where and when eggs and larvae were plentiful (Smith and Richardson, 1977; Fuiman and Werner, 2002), which can then be used to determine the closing seasons and closed areas (El-Regal, 2009). Most Red Sea reef fish breed during the warmer months of the year, based on the appearance of their larvae (May to August). The majority of reef fishes breed away from the reef, with only a few species spawning on the reef and establishing there, as well as mangroves and seagrasses. The summer spawners group had the most spawners in the Egyptian Red Sea, accounting for 36 species, or around 39% of all taxa. The autumn and autumn/winter spawners, on the other hand, had the fewest taxa, with only one taxon being identified (El-Regal, 2013). Mullid larvae were common in the Arabian Gulf from late spring through autumn but were few in the winter (Houde,1986). In March and April, mature females were collected in the Caribbean Sea (Munro et al., 1973).

In Yenliao Bay, Northeastern Taiwan, the number of fish species in the nearshore sites was similarly higher than in the offshore locations. According to these findings, the majority of pelagic eggs were spawned in offshore waters, and the community structure of fish larvae in nearshore waters was more diversified than in offshore areas. The abundance of fish larvae peaked in May and then began to decline. The abundance of fish larvae correlated to the seasonal fluctuation in the number of species of fish larvae, showing that most species of larvae were spawned in early spring (Tzeng et al., 1997). The breeding season for frigate tuna in the Indian Ocean, according to Yoshida (1979), spanned from January to April. Stequert and Marsac (1989) found the highest abundance of skipjack tuna larvae in the eastern Indian Ocean in February. Females of *S. gibbosa* and *S. fimbriata*, both gravid and ripe, were found in most months. Peak occurrences for *S. gibbosa* were in February-March in the southern region and March-April in the northern region, and for *S. fimbriata* May-July over the north west Bay of Bengal (Ghosh et al., 2013).

CHAPTER-3: MATERIALS AND METHODS

3.1 Study area

The study was conducted in Bangladesh's Rezukhal Estuary (N 21.2952777, E 92.035000) on the Cox's Bazar Coasts, with monthly sampling from March 2020 to February 2021. The software "Arc-GIS" (Version-10.3) was used to create the map (Figure-01).

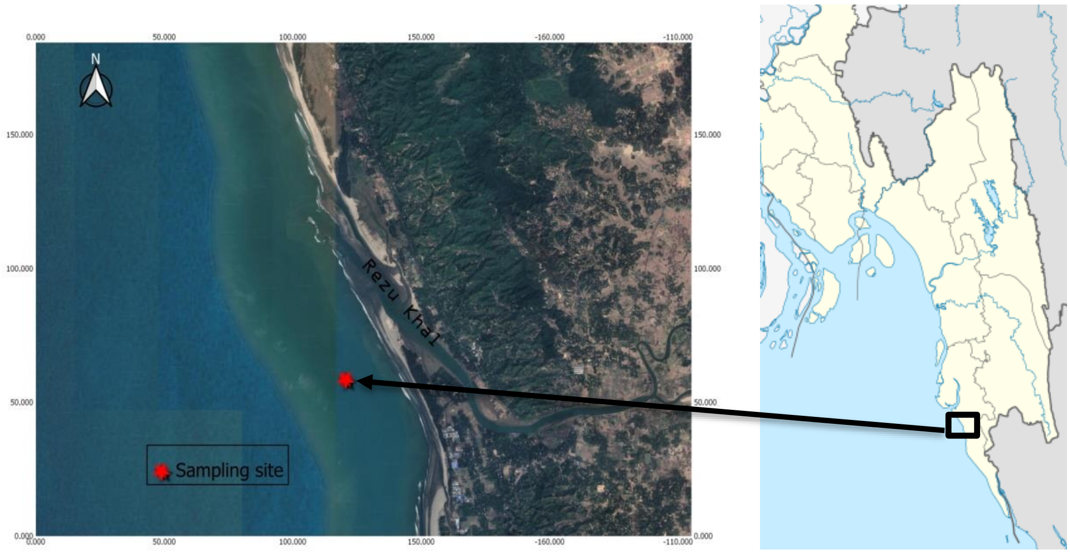

Figure-01: Study Area

3.2 Sampling procedure

Fish larvae were collected using a bongo net with a mouth diameter of 0.50 m, a length of 1.3 m, and a mesh size of 500 µm at the body. The sampling duration was 10 minutes and each tow covered about 2 km of the surface area. A flow meter (Model: KC Denmark A/S 23.090-23.091) was attached to determine the volume of seawater filtered during each tow. After each tow, samples were instantly fixed in 90% ethanol and transported to the Chattogram Veterinary and Animal Sciences University's Aquatic Ecology laboratory. During the daytime period, a total of 36 samples were taken.

3.3 Fish larvae sorting

For taxonomic identification, larvae were sorted from the whole sample. The first step of sorting was to discard ethanol from the sample. To do this, samples were thoroughly washed with distilled water so that sand particles, plastics, leaves, and other unwanted matters could easily be removed. Washed larvae were again placed into a jar with fresh ethanol and each sample was placed in a petri dish one by one to be analysed under a stereo microscope at low magnification (10x) and several pictures were taken. However, depending on the abundance of the target species, it is appropriate to analyse 25% to 50% of the sample or even less for particular research focused on larvae of more abundant species.

3.4 Morphological identifications of larval fish

Fish larvae examined under an OPTIKA ITALY C-B3 stereomicroscope at a modest magnification (10 x) to identify fish larvae. Fish larvae were identified to the highest taxonomic level possible using the available guidelines (Leis and Rennis, 1983; Leis and Carson-Ewrat, 2000; Rodriguez et al., 2017). Unidentified larvae samples had categorized as "unidentified" due to the larvae being too small to identify. Identified individuals preserved in 90% ethanol separately. Identified sample and picture was given a specific code so that it can be easily found later.

3.5 Determination of abundance of larvae

The number of total fish larvae were mapped for temporal distribution and normalized to the number collected per 1,000 m^3 of saltwater volume filtered.

The volume of water passed in each sampling=

The indicated number of revolutions× Pitch of the impeller (0.3) ×Net opening area (m^2) ×1000

Where,

Bongo net diameter, d= 0.50m

So, net radius, r = 0.25m

Net opening area= πr^2

$=3.1416\times0.25^2$

$=0.19635\times2$; as each net has two openings

$=0.3927$

Number of larvae per 1000m^3 = (Number of larvae in sample×1000) ÷Volume of water passed

3.6 The constancy of occurrence

Determination of the Constancy of Occurrence was based on the ecological index cited by Schifino et al., (2004) as given below:

- Formula: C = P/Q x100

Where C = Constancy of Occurrence of the family (%), P = number of samples where the family occurred, Q = Total number of samples

The identified families were divided into three categories based on the value of constancy of occurrence, which was the following:

- Constants (when C>50%)
- Accessories (when 25%≤C≤50%)
- Accidental (when C<25%)

3.7 Determination of the Ecological indices of the fish larvae

Ecological indices of fish larvae were determined by using larvae abundance along with diversity index (Shannon and Wiener, 1949), Richness (Margalef, 1958), and Evenness (Pielou, 1966). The following formulas were used for the calculations;

- Diversity index, H = –∑ Pi In Pi

Where Pi=S/N

(S = number of individuals of one species, N= total number of all individuals in the sample, ln = natural logarithm).

- Richness = (S – 1)/In N

Where, S=total number of species, N=the total number of individuals in the sample, and ln=natural logarithm.

- Evenness, e = H/In S

Where, H=Shannon-Wiener diversity index, S=total number of species in the sample

3.8 Determination of the spawning season

Fish spawning sites and seasons were determined by where and when eggs and larvae were plentiful (Smith and Richardson, 1977; Fuiman and Werner, 2002). The spawning season was determined by considering the month before the month in which larvae began to be found in the selected station. The spawning season of the identified families was classified as Winter, Summer, and Monsoon based on monthly larval abundance. The Winter season continues from November to February, while the Summer season lasts from March to June. Monsoon months cover July, August, September and October. Further these groups were subdivided into early, mid and late based on the availability in different months.

3.9 Analysis and visualization of collected data

All data were summarized, categorized, analyzed in Microsoft Excel (Version-2016) and SPSS (Version- 25.0).

CHAPTER-4: RESULTS

4.1 Total fish larvae

A total of 15 families of larvae were identified consisting of 2467 individuals from the Rezukhal Estuary (Table-1). The average number of fish larvae was 206/1000 m^3/month, and the highest abundance was found (1197 larvae/1000 m^3) in September and the lowest was found (0 larvae/1000 m^3) in June (Table-1). Accidently no larvae were found in June.

Table-1: Composition and abundance of fish larvae (larvae/1000 m^3)

SL	Family	Month											
		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
1	Engraulidae	0	0	0	0	4	0	1115	9	0	0	0	1
2	Clupeidae	88	206	5	0	11	603	0	0	122	16	0	9
3	Mugilidae	2	0	0	0	0	89	51	0	0	0	0	0
4	Ambassidae	0	8	9	0	2	3	2	2	6	0	0	0
5	Blenniidae	0	0	0	0	0	0	0	8	0	0	0	17
6	Sillaginidae	0	0	0	0	0	0	0	0	0	0	0	15
7	Terapontidae	0	0	0	0	0	0	0	0	0	0	11	0
8	Gobiidae	0	0	0	0	1	3	1	0	0	0	0	2
9	Myctophidae	0	0	0	0	0	0	0	0	3	2	0	0
10	Carangidae	0	0	0	0	0	0	1	0	0	0	3	0
11	Megalopidae	0	0	0	0	3	0	1	0	0	0	0	0
12	Hemiramphidae	0	2	0	0	0	0	0	0	0	0	0	1
13	Siganidae	0	0	0	0	0	0	1	0	0	0	0	0
14	Sparidae	0	0	0	0	0	0	0	0	0	0	0	2
15	Sciaenidae	0	1	0	0	0	0	0	0	0	0	0	0
16	Unidentified	0	0	0	0	1	0	25	0	0	0	0	0
	Total	90	217	14	0	22	698	1197	19	131	18	14	47

4.2 Constance of Occurrence

Among the identified 15 families, 02 families of Clupeidae, and Ambassidae were considered constant, 03 families of Engraulidae, Mugilidae, and Gobiidae were accessory and 10 accidental families of Blenniidae, Sillaginidae, Terapontidae, Myctophidae, Carangidae, Megalopidae, Hemiramphidae, Siganidae, Sparidae, Sciaenidae were recorded (Table-2). The percentages by families of constant: accessory: accidental families were 13:20:67 (Figure-2). The majority of the families were not found frequently in this region and were considered to be accidental.

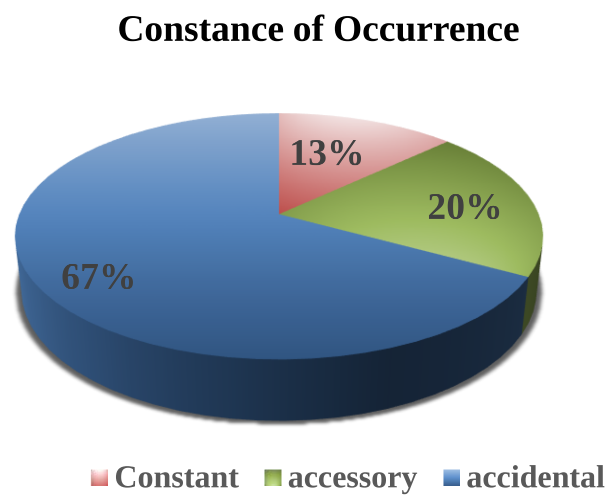

Figure -2: The percentages of Constance of occurrence

4.3 Top Five Dominant families

1. Engraulidae: Engraulidae larvae were the most abundant (45.76%) family in total identified fish larvae (Table-2 and Figure-3). They were found in July, September, and February (Table-1 and Figure-5). The mean number of Engraulidae was 94.08 larvae/ 1000m^3 (Table-2 and Figure-4). E.g: *Stolephorus indicus, Stolephorus insularis, Stolephorus waitei, Thryssa hamiltonii, Coilia ramcarati* etc.

2. Clupeidae: Clupeidae larvae were the second most abundant (42.97%) family in the total fish larvae counted and were found in all months except June, September, October, and January (Table-2, Figure-3 and Figure-5). The mean number was 88.33 larvae/1000m^3 (Table-2, and Figure-4). E.g.: *Anodontostoma chacunda, Hilsa kelee, Escualosa thoracata* etc.
3. Mugilidae**:** This is the third most abundant larval family, which comprises 5.76% of the total fish larvae in numbers (Table-2, Figure-3). Mugilidae was found in March, August, and September and the mean number was 11.83 larvae/1000m^3 (Table-2, Figure-4 and Figure-5). E.g: *Chelon parsia*
4. Ambassidae**:** Ambassidae larvae contributed 1.30% of total counted larvae, and the mean number was 2.67 larvae/1,000m^3 (Table-2, Figure- 3, Figure- 4). E.g: *Ambassis dussumieri*, etc.
5. Blenniidae**:** Blenniidae larvae ranked the 5th most abundant of the total fish larvae in numbers. They constitute 1.01% but were found in only October and February (Table-2, Figure-3 and Figure-5). The mean number of these larvae was 2.08 larvae/1,000m^3 (Table-2, and Figure-4). E.g.- *Omobranchus ferox, Omobranchus punctatus,* etc.

   The others families were Gobiidae, Sillaginidae, Terapontidae, Myctophidae, Carangidae, Megalopidae, Hemiramphidae, Siganidae, Sparidae, Sciaenidae which consists of 3.20 % (Table-2, and Figure-3).

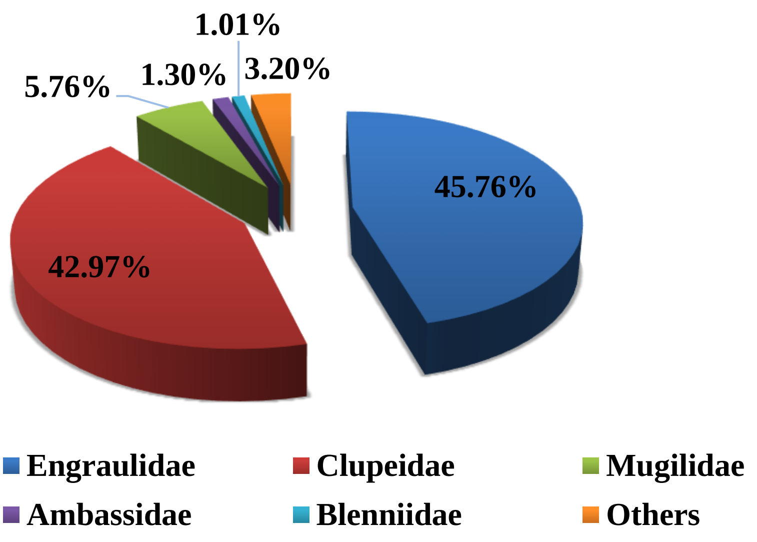

Figure-3: Top five dominant families

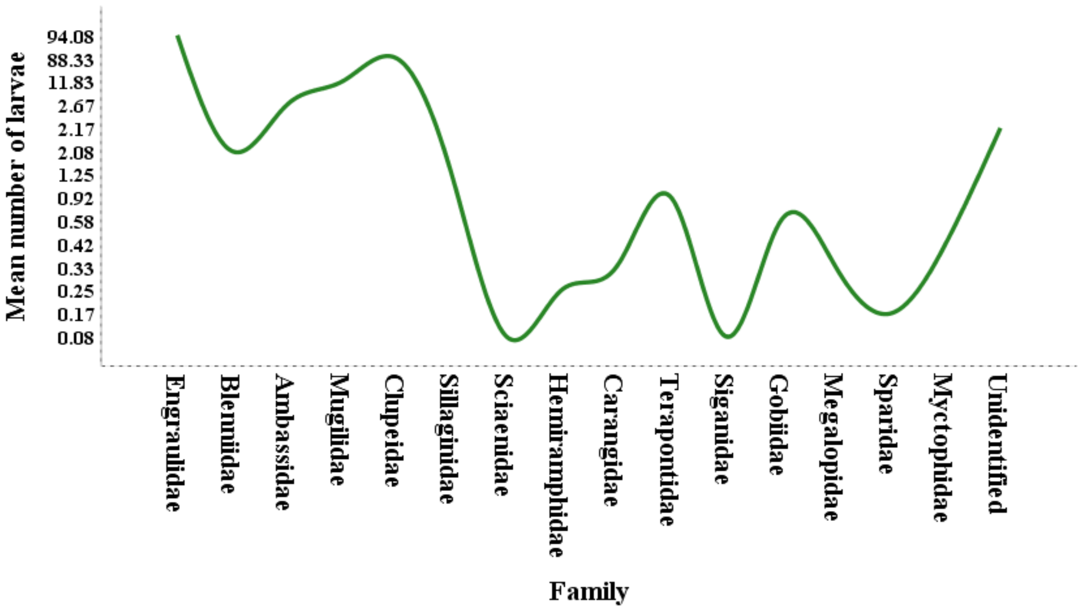

Figure-4: Mean number of larvae in each families

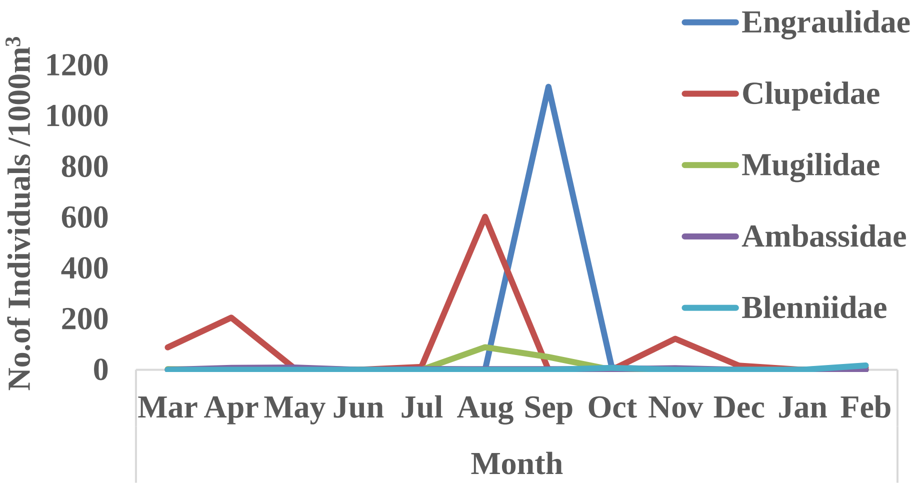

Figure-5: Temporal Variation of top five families

Table-2: Total number of fish larvae/1000 m^3 and constancy of occurrence

Family	Total number of larvae (larvae/ 1000 m^3)	Mean number of larvae	SD	SE	Percentage of the total catch	Rank	Frequency of Occurrence	Classification according to Constance of occurrence 1	2	3
Engraulidae	1129	94.08	321.52	92.81	45.76	**1**	33.33		*	
Clupeidae	1060	88.33	174.65	50.42	42.97	**2**	66.67	*		
Mugilidae	142	11.83	28.36	8.19	5.76	**3**	25.00		*	
Ambassidae	32	2.67	3.26	0.94	1.30	**4**	58.33	*		
Blenniidae	25	2.08	5.23	1.51	1.01	**5**	16.67			*
Sillaginidae	15	1.25	4.33	1.25	0.61	6	8.33			*
Terapontidae	11	0.92	3.18	0.92	0.45	7	8.33			*
Gobiidae	7	0.58	1.00	0.29	0.28	8	33.33		*	
Myctophidae	5	0.42	1.00	0.29	0.20	9	16.67			*
Carangidae	4	0.33	0.89	0.26	0.16	10	16.67			*
Megalopidae	4	0.33	0.89	0.26	0.16	11	16.67			*
Hemiramphidae	3	0.25	0.62	0.18	0.12	12	16.67			*
Siganidae	1	0.08	0.29	0.08	0.04	14	8.33			*
Sparidae	2	0.17	0.58	0.17	0.08	13	8.33			*
Sciaenidae	1	0.08	0.29	0.08	0.04	15	8.33			*
Unidentified	26	2.17	7.20	2.08	1.05					
Total	2467				100.00					

*(1) constants; (2) accessories; (3) accidental

4.4 Temporal variation of larval abundance

In the Rezukhal Estuary, September had the highest number of family members (08), while June had the lowest (0) family member (Figure-6). The maximum larval abundance was reported in September (1197larvae/1000m^3), August (698 larvae/1000m^3), April (217 larvae/1000m$^{3)}$, and November (131 larvae/1000m^3), and the minimum larval abundance in June (0 larvae/1000m^3) respectively (Figure-6).

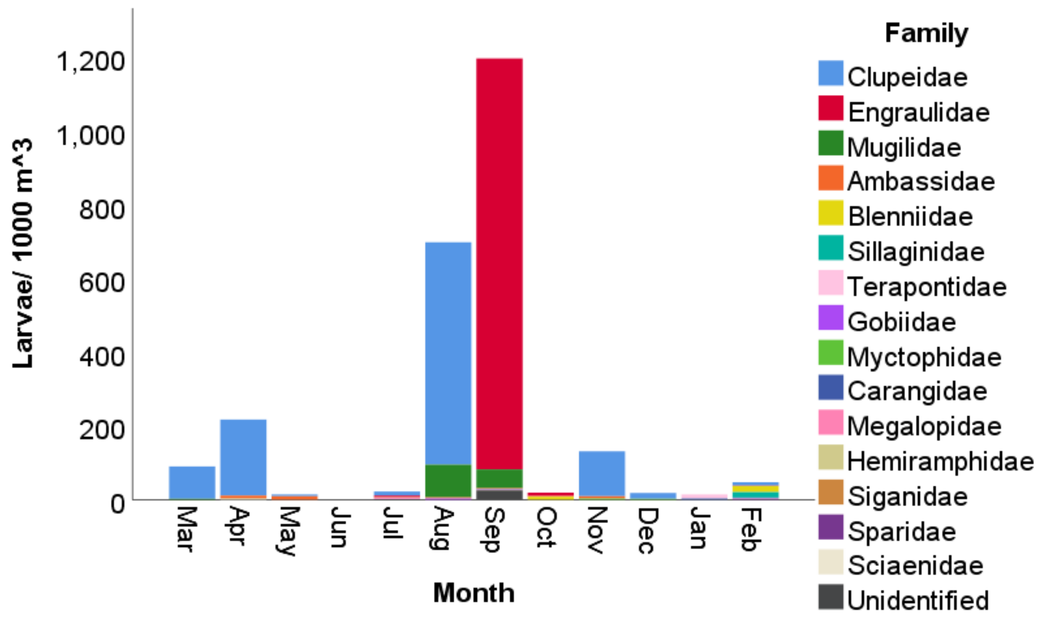

Figure-6: Temporal variation of Larvae at Rezukhal Estuary

4.5 Biodiversity indices of the fish larvae

Temporal variation of biodiversity index of identified larvae in the Cox's Bazar Coasts was determined by diversity index (Shannon-Wiener), richness (Margalef index), and evenness index (Pielou's). Month wise diversity index, richness, and evenness were described below:

4.5.1 Shannon-Wiener Diversity Index

The Highest Shannon-Wiener diversity index (1.481) was calculated in February which is in Winter season. and the lowest Shannon-Wiener diversity index (0.000) was calculated in June (Figure-7). The greater the value of H, the greater the diversity of families in a given sample. The lower the value of H, the less diverse the population. A sample with a H value of 0 has only one family.

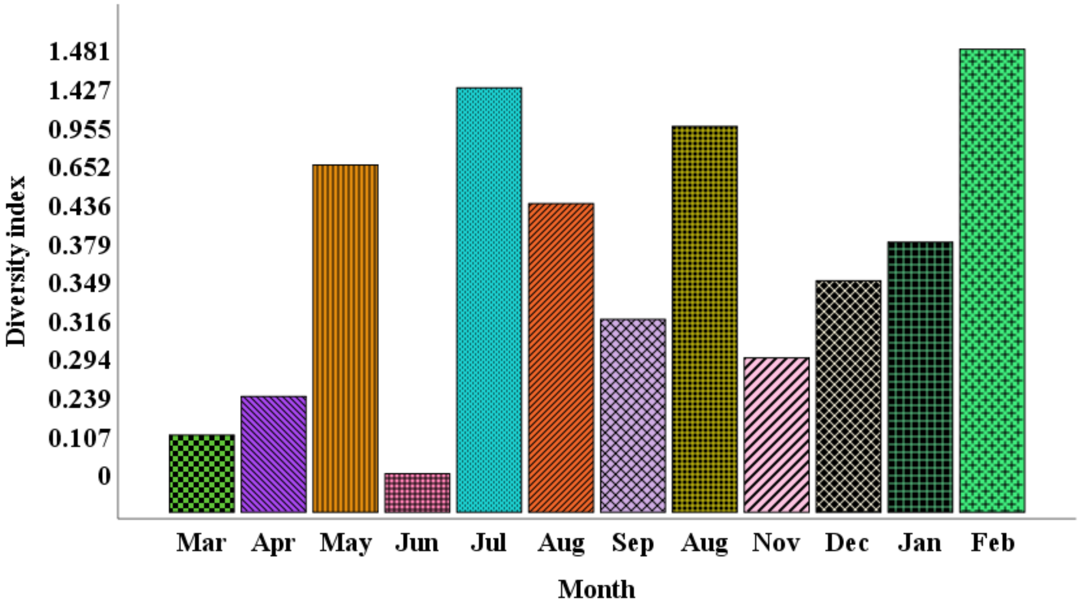

Figure-7: Diversity Index of each month in Rezukhal Estuary

4.5.2 Pielou's evenness index

The evenness refers to the number of individuals of each family present. The highest evenness (0.940) was recorded in May and the lowest evenness (0.000) was recorded in June (Figure-8). Pielou's evenness is an indicator that shows both diversity and species richness. Pielou's evenness has a predicted number ranging from 0 (no evenness) to 1 (complete evenness). Pielou's evenness is connected to the Shannon-Wiener index since it is determined by dividing the Shannon-Wiener index by the total number of families. In this study, the evenness index is 0 for June indicating that there is no evenness.

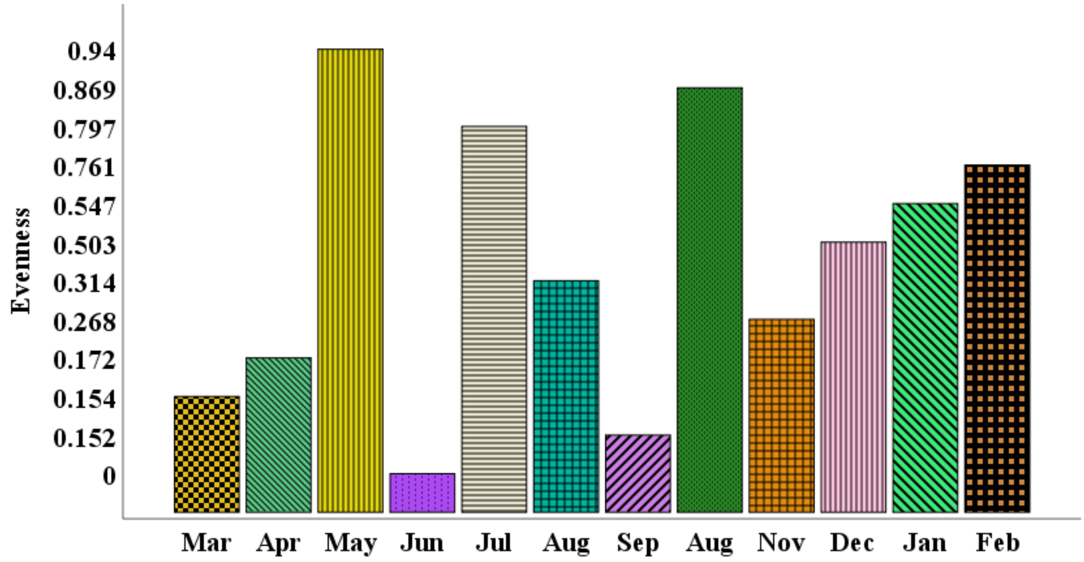

Figure-8: Evenness of each month in Rezukhal Estuary

4.5.3 Margalef Richness index

The family richness refers to the number of different family present in a particular region. Margalef's richness index has no range. The highest family richness (1.618) was found in July and the lowest family richness (0.000) was found in June. No family were found in June (Figure-9).

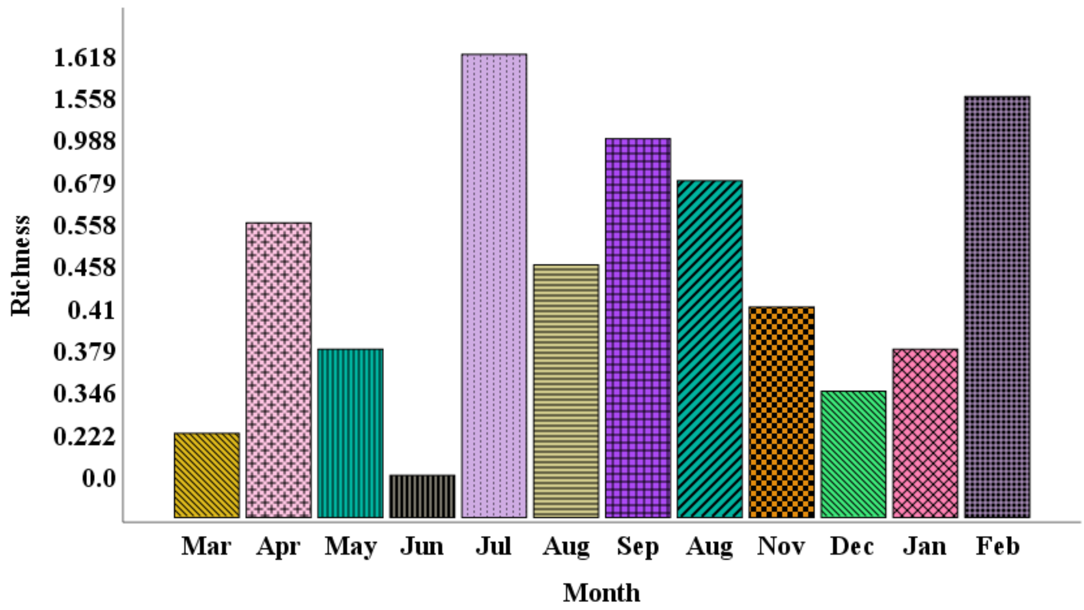

Figure-9: Richness of each month in Rezukhal Estuary

4.6 Spawning season

15 larvae families were identified and the frequency of occurrence indicated their spawning seasons. The spawning season of the identified families was classified as Winter, Summer, and Monsoon based on monthly larval abundance. The highest number 4 (Mugilidae, Blenniidae, Myctophidae and Carangidae) of Families comes from Winter, Monsoon season and involved forming about 26% of all taxa. Whereas the Summer, Winter (Hemiramphidae); Summer (Sciaenidae) included the lower number of taxa only 01 taxon was recorded (Table-3, Figure-10 and Figure-11). The larvae of Clupeidae spawning season were Mid-winter; Late Summer; Late Monsoon and the Engraulidae family spawning season was Mid-Winter; Late Summer; Middle Monsoon were recorded respectively. A family of Mugilidae spawning season was Late Winter; Early Monsoon (Table-3).

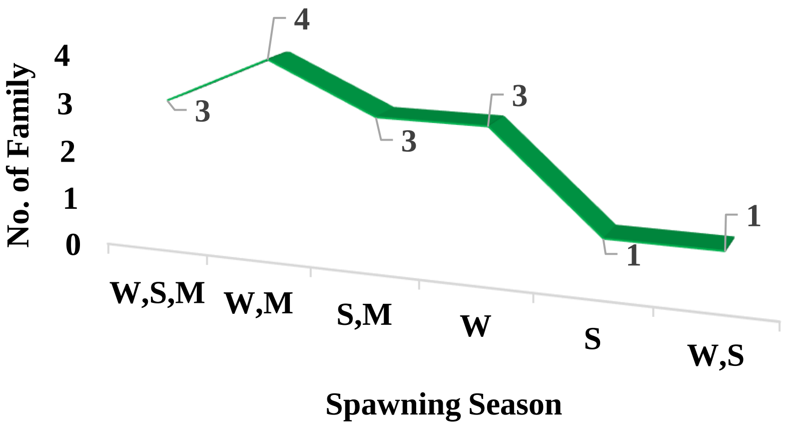

Figure-10: Number of families in each spawning season

Note: W=Winter; S=Summer; M=Monsoon

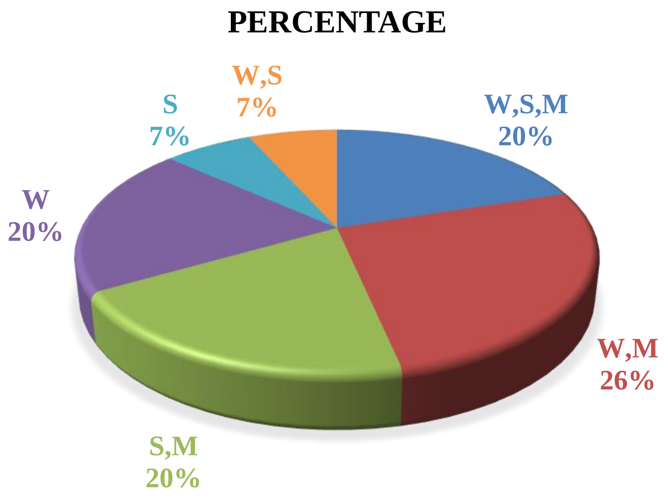

Figure-11: Percentages of spawning season for different Spawner group

Note: W=Winter; S=Summer; M=Monsoon

Table-3: Spawning Seasons of the fish larvae collected during the study

Family	Availability	Spawning month	Spawning season
Engraulidae	Feb, Jul, Sep, Oct	Jan, Jun, Aug-Sep	Mid-winter; Late summer; Mid monsoon
Clupeidae	Jan, Feb, Mar, Apr, May, Jul, Aug, Nov, Dec	Dec-Apr, Jun-Jul, Oct-Nov	Mid-winter; Late summer; Late monsoon
Mugilidae	Mar, Aug, Sep	Feb, Jul-Aug	Late winter; Early monsoon
Ambassidae	Apr, May, Jul, Aug, Sep, Oct, Nov	Mar-Apr, Jun-Oct	Early summer; Mid monsoon
Blenniidae	Feb, Oct	Jan, Sep	Mid-winter; Mid monsoon
Sillaginidae	Feb	Dec	Mid-winter
Terapontidae	Jan	Dec	Mid-winter
Gobiidae	Feb, Jul, Aug, Sep	Jan, Jun-Aug	Mid-winter; Late summer; Mid monsoon
Myctophidae	Nov, Dec	Oct-Nov	Early winter; Late monsoon
Carangidae	Jan, Sep	Dec, Aug	Mid-winter; Mid monsoon
Megalopidae	Jul, Sep	Jun, Aug	Late summer; Mid monsoon
Hemiramphidae	Feb, Apr	Jan, Mar	Mid-winter; Early summer
Siganidae	Apr, Sep	Mar, Aug	Early summer; Mid monsoon
Sparidae	Feb	Jan	Mid-winter
Sciaenidae	Apr	Mar	Early summer

CHAPTER-5: DISCUSSION

This study has revealed 15 families that appear to had less diversity than the previous work in the various parts of the Indian Ocean. Young et al., (1986) recorded 103 larvae fish families in the southeast Indian Ocean, whereas Lirdwitayaprasit et al. (2008) found 52 families in the Bay of Bengal. In the Tropical Eastern Indian Ocean, Beckley et al., (2019) found 92 neritic and 21 mesopelagic teleost families. Nellen (1973) found 102 larval families in the Indian Ocean's north-eastern region, including the Arabian Sea, Red Sea, and the Persian Gulf. In the Indian Ocean, Rathnasuriya et al., (2021) identified 80 species belonging to 69 larval families using morphological and molecular methods. Janekarn (1988) identified 62 families of fish larvae on the west coast of Thailand. Chesalina et al., (2013) found 40 larval fish families in the south-western part of the Sea of Oman, which showed the findings of the present study. Lower larval diversity could be associated with low productivity along the Cox's Bazar Coasts, as nutrients carried by rivers are assumed to be lost in deeper seas due to the narrow shelf (Qasim, 1977).

Among the identified 15 families, 02 families of Clupeidae, and Ambassidae were considered constant, 03 families of Engraulidae, Mugilidae, and Gobiidae were accessory and 10 accidental families of Blenniidae, Sillaginidae, Terapontidae, Myctophidae, Carangidae, Megalopidae, Hemiramphidae, Siganidae, Sparidae, Sciaenidae were recorded. The percentages by families of constant: accessory: accidental families were 13:20:67. The findings showed a low number of constant families in the Rezukhal Estuary, Cox's Bazar Coasts. However, Lirdwitayaprasit et al., (2008) reported several constant (28) and accessory (22) families in the Bay of Bengal, and 50 families were considered accidental. And the western part of the Bay of Bengal the percentages by families were 32:21:47 and in the Andaman Sea were 27.5:27.5:45, respectively. This result suggested that fish larvae were widely distributed between inshore and offshore waters, implying that this area was important for the habitat of adult fish and their larvae.

Based on the percentage of the catch, 05 dominant families were identified as Engraulidae, Clupeidae, Mugilidae, Ambassidae, and Blenniidae. Lirdwitayaprasit et al., (2008) recognized Photichthyidae, Myctophidae, Bregmacerotidae, Gonostomatidae, Callionymidae, and Carangidae were recognized as abundant families in the Bay of Bengal. According to Tzeng et al., (1997), Pomacentridae, Apogonidae, and Tripterygiidae were dominant families at the rocky stations, and Gobiidae was abundant at the estuarine stations of Yenliao Bay. Chesalina et al., (2013) identified the four most common families: Sparidae, Scombridae, Clupeidae, and Nemipteridae.

In this study, most of the abundant families were Engraulidae, Clupeidae, Mugilidae, Ambassidae, and Blenniidae. The most abundant families of the Bay of Bengal were Photichthyidae, Myctophidae, Bregmacerotidae, Gonostomatidae, Callionymidae, and Carangidae (Lirdwitayaprasit et al., 2008). Among the 19 families of Pendas River estuary, Clupeidae was the most prevalent family of all fish, followed by Blenniidae, Teraponidae, Gobiidae, Sillaginidae, Nemipteridae, and Mullidae (Arshad et al., 2012). In Mabahiss Bay, the Egyptian Red Sea, larvae of the families Mullidae and Clupeidae dominated the collection of all collected larvae (Abu El-Regal et al., 2014). According to Chamchang (2006), the Myctophidae family was the most prevalent in the Andaman Sea followed by the Stomiidae family.

During the time of the study, a total of 15 families of larvae were identified consisting of 2467 specimens from the Rezukhal Estuary. The Highest Shannon-Wiener diversity index (1.481) was calculated in February and the lowest Shannon-Wiener diversity index (0.000) was calculated in June. In southern Johor, Peninsular Malaysia, the Shannon Wiener index revealed considerable change throughout monsoon and inter-monsoon seasons, with maxima in December–January and May-August, respectively. The middle estuary had the highest mean Shannon Wiener diversity index (1.48), whereas the upper estuary had the lowest (1.18) (Arshad et al., 2012). In terms of the spaito distribution of diversity index, the open water region of Mabahiss Bay, on the Egyptian Red Sea coast, the coral reef region had the highest species diversity index of 2.48 and the seagrass area had the lowest species diversity index of 1.99 (Abu El-Regal et al., 2014). The highest diversity index was found in March (2.89), July (2.83), January (2.81), and September (2.79), while the lowest diversity index was in May (2.15) in Ao Trat, Thailand (Termvidckakorn, 2016). Brief research performed by Zhang et al., (2021) from September to October in 44 different stations in Eastern Indian Ocean showed quite similar result to this study. The average Shannon-Wiener index was 0.83, where highest was 1.52 and lowest was zero (0).

The highest family richness (1.618) was found in July and the lowest family richness (0.000) was found in June. No family were found in June. In southern Johor, Peninsular Malaysia, family richness suggested two peaks each year. January–March was one high, while May-August was another. The maximum family richness (1.72) was found in the middle estuary, whereas the lowest richness was found in the upper portion of the estuary (1.34) (Arshad et al., 2012). The open water region of Mabahiss Bay had the highest species richness of 6.08, while the seagrass area had the lowest (Abu El-Regal et al., 2014). In Ao Trat, Thailand, the month of March had the highest species richness of 4.45, while May had the lowest species richness of 2.26. (Termvidckakorn, 2016). This study also exhibited similarity to Brinda et al. (2010) where Margalef's richness varied from 0.71(May) to 0.91 (March). Brief research performed by Zhang et al., (2021) from September to October in 44 different stations in Eastern Indian Ocean showed quite similar result to this study. Mean richness index was 1.01 and evenness index was 0.79.

The highest evenness (0.940) was recorded in May and the lowest evenness (0.000) was recorded in June. In southern Johor, Peninsular Malaysia the highest evenness (0.77) had been found in the middle estuary, and there was no variation in evenness between the higher and lower estuaries (Arshad et al., 2012). The species' evenness varied from 0.56 in open water to 0.69 in coral reefs in the open water region of Mabahiss Bay (Abu El-Regal et al., 2014). The evenness index was highest in January and July (0.95) and lowest in March and May (0.90) in Ao Trat, Thailand (Termvidckakorn, 2016). This study also exhibited similarity to Brinda et al., (2010) where Pielou's evenness index ranged between 0.71 (May) and 0.93 (April). The study was conducted in three distinct stations at Vellar estuary, which is situated at the Southeast coast of India. Lower biodiversity (diversity, richness, evenness) could be associated with low productivity along the Rezukhal Estuary, Cox's Bazar Coasts, as nutrients carried by rivers are assumed to be lost in deeper seas due to the narrow shelf.

15 larvae families were identified and the frequency of occurrence indicated their spawning seasons. The highest number 4 (Mugilidae, Blenniidae, Myctophidae and Carangidae) of Families comes from Winter, Monsoon season and involved forming about 26% of all taxa. Whereas the Summer, Winter (Hemiramphidae); Summer (Sciaenidae) included the lower number of taxa only 01 taxon was recorded. Most Red Sea reef fish breed during the warmer months of the year, based on the appearance of

their larvae (May to August). The majority of reef fishes breed away from the reef, with only a few species spawning on the reef and establishing there, as well as mangroves and seagrasses. The summer spawners group had the most spawners in the Egyptian Red Sea, accounting for 36 species, or around 39% of all taxa. The autumn and autumn/winter spawners, on the other hand, had the fewest taxa, with only one taxon being identified (El-Regal, 2013).

In Yenliao Bay 65 species were collected in the fall-winter period, with dominant species differing from those of the spring-summer period. *S. marmoratus* (28.6%), *Encrasicholina punctifer* (9.8%), *Trichiurus lepturus* (8.3%), and *Ambassis gymnocephalus* (8.3%) were the top four dominant species in fall-winter (Tzeng et al., 1997).

The larvae of Clupeidae spawning season were Mid-winter; Late summer; Late monsoon and the Engraulidae family spawning season was Mid-winter; Late summer; Mid monsoon was recorded respectively. A family of Mugilidae spawning season was Late winter; Early rainy monsoon. Mullid larvae were common in the Arabian Gulf from late spring through autumn but were few in the winter (Houde et al., 1986). In March and April, mature females were collected in the Caribbean Sea (Munro et al., 1973). In Peninsular Malaysia the Clupeid larvae spawning season was February-March (Arshad et al., 2012). Clupeoids grow quicker in tropical waters and have a shorter life cycle than in temperate environments (Araújo et al., 2008).

CHAPTER-6: CONCLUSION

Identification of the marine fish larvae is very important to determine the abundance and evaluate spawning seasons, and the stock-recruitment process of marine fishes. The present study successfully identified important marine fish larvae and their spawning seasons and biodiversity index in the Rezukhal Estuary, Cox's Bazar Coasts of the Bay of Bengal, which will help in the decision-making regarding marine fisheries management in the Cox's Bazar Coasts of the Bay of Bengal. A Total 15 families of fish larvae were identified at the Rezukhal estuary, Cox's Bazar Coasts. Engraulidae was the most dominant family in the study area. It was observed that a few families distributed in the Rezukhal estuary, Cox's Bazar Coasts. Understanding the abundance and distribution of fish larvae in relation to environmental circumstances could fill a gap in the study of fish life cycle and provide useful information for fishery management. The larval stage is generally the most vulnerable to environmental changes. Any change in the quality or quantity of ecological factors would be detrimental to larval survival and could suggest future recruitment potential.

CHAPTER-7: RECOMMENDATIONS AND FUTURE PERSPECTIVES

According to the findings of the present study, the following recommendations may be done in the study area:

1. It will be possible to determine the hydro-biological parameters of spawning grounds along the coasts and feeding habits of commercially important larval fishes.
2. In future it will establish the ecological relation model of larval fishes for conservation and sustainability.
3. Identify and validate the larval fishes through DNA Barcoding and EDNA methods.

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Appendix-1

Operation of fish larvae sampling in the Rezukhal Estuary, Cox's Bazar Coasts

Month	Date	Time Start	Time Finish	Flowmeter reading	Interval between flowmeter reading	Volume of water passed (m^3)
Mar,20	09/03/2020	11.31	11.41	R1 (75395-77383)	1988	234
		11.45	11.56	R2 (77384-78829)	1445	170
		12.01	12.11	R3 (78830-79708)	878	103
Apr,20	13/04/2020	12.15	12.27	R1 (16390-19026)	2636	311
		12.35	12.46	R2 (19027-22361)	3334	393
		12.52	1.03	R3 (22361-24952)	2591	305
May,20	11/05/2020	10.42	10.55	R1 (43575-46255)	2680	316
		10.59	11.1	R2 (46255-51358)	5103	601
		11.15	11.27	R3 (51358-54901)	3543	417
Jun,20	10/06/2020	11.05	11.14	R1 (71210-73113)	1903	224
		11.21	11.32	R2 (73113-75617)	2504	295
		11.43	11.54	R3 (75617-77659)	2042	241
Jul,20	09/07/2020	11.25	11.34	R1 (06546-08957)	2411	284
		11.41	11.52	R2 (08957-11677)	2720	320
		11.56	12.08	R3 (11677-14058)	2381	281
Aug,20	12/08/2020	10.45	10.56	R1 (29198-30311)	1113	131
		11.02	11.15	R2 (30311-31145)	834	98
		11.21	11.32	R3 (31145-33790)	2645	312
Sep,20	11/09/2020	11.04	11.14	R1 (51283-52395)	112	13
		11.21	11.32	R2 (52395-55132)	2737	322
		11.37	11.48	R3 (55132-58265)	3133	369

Oct,20	16/10/2020	12.15	12.29	R1 (93827-96094)	2267	267
		12.35	12.47	R2 (96094-98765)	2671	315
		12.55	1.09	R3 (98765-102954)	4189	494
Nov,20	12/11/2020	11.18	11.32	R1 (12621-15461)	2840	335
		11.41	11.52	R2 (15463-16865)	1402	165
		11.55	12.08	R3 (16865-19104)	2239	264
Dec,20	09/12/2020	10.31	10.45	R1 (19231-22436)	3205	378
		10.55	11.05	R2 (22439-27266)	4827	569
		11.11	11.22	R3 (25120-27266)	2146	253
Jan,21	10/01/2021	11.17	11.31	R1 (68632-71172)	2540	299
		11.35	11.46	R2 (71173-73968)	2795	329
		11.55	12.09	R3 (73968-76989)	3021	356
Feb,21	19/02/2021	12.05	12.16	R1 (92831-97766)	4935	581
		12.21	12.32	R2(97769-101690)	3921	462
		12.4	12.55	R3(101690-103657)	1967	232

Appendix-2

Monthly Abundance of fish larvae and biodiversity index

Month	Family	Number of individuals (per 1000m^3)	Diversity index	Richness	Evenness
Mar,20	Clupeidae	88	0.022	0.222	0.032
Mar,20	Mugilidae	2	0.085		0.122
Apr,20	Hemiramphidae	2	0.043	0.558	0.031
Apr,20	Sciaenidae	1	0.025		0.018
Apr,20	Clupeidae	206	0.049		0.036
Apr,20	Ambassidae	8	0.122		0.088
May,20	Ambassidae	9	0.284	0.379	0.410
May,20	Clupeidae	5	0.368		0.531
Jun,20		0	0.000	0.000	0.000
Jul,20	Clupeidae	11	0.347	1.618	0.193
Jul,20	Megalopidae	3	0.272		0.152
Jul,20	Gobiidae	1	0.141		0.078
Jul,20	Ambassidae	2	0.218		0.122
Jul,20	Engraulidae	4	0.310		0.173
Jul,20	Unidentified	1	0.141		0.078
Aug,20	Ambassidae	3	0.023	0.458	0.017
Aug,20	Clupeidae	603	0.126		0.091
Aug,20	Mugilidae	89	0.263		0.189
Aug,20	Gobiidae	3	0.023		0.017
Sep,20	Engraulidae	1115	0.066	0.988	0.032
Sep,20	Mugilidae	51	0.134		0.065
Sep,20	Gobiidae	1	0.006		0.003

Sep,20	Ambassidae	2	0.011		0.005
Sep,20	Siganidae	1	0.006		0.003
Sep,20	Megalopidae	1	0.006		0.003
Sep,20	Carangidae	1	0.006		0.003
Sep,20	Unidentified	25	0.081		0.039
Oct,20	Engraulidae	9	0.354	0.679	0.322
Oct,20	Ambassidae	2	0.237		0.216
Oct,20	Blenniidae	8	0.364		0.332
Nov,20	Ambassidae	6	0.141	0.410	0.129
Nov,20	Clupeidae	122	0.066		0.060
Nov,20	Myctophidae	3	0.086		0.079
Dec,20	Clupeidae	16	0.105	0.346	0.151
Dec,20	Myctophidae	2	0.244		0.352
Jan,21	Carangidae	3	0.189	0.379	0.273
Jan,21	Terapontidae	11	0.189		0.273
Feb,21	Sparidae	2	0.134	1.558	0.069
Feb,21	Clupeidae	9	0.317		0.163
Feb,21	Blenniidae	17	0.368		0.189
Feb,21	Sillaginidae	15	0.364		0.187
Feb,21	Gobiidae	2	0.134		0.069
Feb,21	Hemiramphidae	1	0.082		0.042
Feb,21	Engraulidae	1	0.082		0.042

Appendix-3 Temporal variation of biodiversity index at Rezukhal Estuary

Month	Diversity index	Richness	Evenness
Mar,20	0.107	0.222	0.154
Apr,20	0.239	0.558	0.172
May,20	0.652	0.379	0.940
Jun,20	0.000	0.000	0.000
Jul,20	1.427	1.618	0.797
Aug,20	0.436	0.458	0.314
Sept,20	0.316	0.988	0.152
Oct,20	0.955	0.679	0.869
Nov,20	0.294	0.410	0.268
Dec,20	0.349	0.346	0.503
Jan,21	0.379	0.379	0.547
Feb,21	1.481	1.558	0.761

<u>**PHOTO GALLERY**</u>

Plate-01: Bongo Net

Plate-02: Flow meter

Plate-03: Sample Collection

Plate-04: Larval sample

Plate-05: Materials

Plate-06: Larvae sorting rest of zooplankton

Plate 07: Larvae

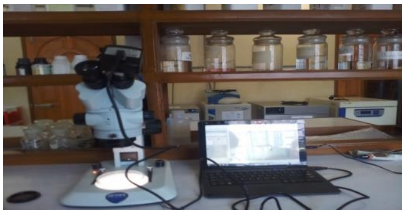

Plate 08: Stereomicroscope

Plate 09: Larvae identified through stereomicroscope

Plate-10: Engraulidae

Plate-11: Clupeidae

Plate-12: Mugilidae

Plate-13: Ambassidae

Plate-14: Blenniidae

Plate-15: Sillaginidae

Plate-16: Terapontidae

Plate-17: Gobiidae

Plate-18: Myctophidae

Plate-19: Carangidae

Plate-20: Hemiramphidae

Plate- 21: Megalopidae

Plate-22: Siganidae

Plate-23: Sparidae

Plate-24: Sciaenidae

Plate-25: Unidentified

Plate-26: Unidentified

Plate-27: Larvae Preservation

BRIEF BIOGRAPHY OF THE AUTHOR

Nargis Sultana, daughter of Sirajul Islam Chowdhury and Rehena Akter, was born on May 25, 1996, at Chandanaish, Chattogram in Bangladesh. She passed the Secondary School Certificate Examination in 2012 and Higher Secondary Certificate Examination in 2014. She graduated in 2019 from the Faculty of Fisheries, Chattogram Veterinary & Animal Sciences University (CVASU) Khulshi-4225, Chattogram, Bangladesh. Now, she doing her MS in Fisheries Resource Management, Faculty of Fisheries, CVASU. She is looking forward to carrying out research in her area of interest and has enormous enthusiasm to develop her skills and expertise in the area of sustainable management of different aquatic bodies. She is also keen to deliver her intense observation for drawing the outline of different new-based aquaculture management systems in the near future.