CHAPTER ONE

INTRODUCTION

1.1 Background

A diversity of freshwater and marine species, as well as juveniles, coexist in estuaries, which are a transitional area between the sea and rivers. Many different marine and freshwater animals that travel there at various stages of their life cycles can find refuge in these environments (Rashed-Un-Nabi et al., 2011). Particularly among juveniles, estuarine fish assemblages are renowned for their remarkable diversity and richness (Whitfield, 1999).Fish play a crucial role in these ecosystems as permanent and ephemeral ecological elements and rely on estuaries for food, reproduction, development, and protection (Rez-Guzaman and Huidobro, 2002). Although the larval stages are unknown, it is hypothesized that marine fish larvae and juveniles migrate to estuaries to benefit from the plentiful food supply and predator protection to increase their chances of surviving (Van der Veer et al., 2001).Therefore, accurate predictions about the function of estuary nurseries would be supported by a thorough understanding of fish larvae dynamics in estuaries. Estuarine larval fish assemblages are heterogeneous in terms of species composition and movement patterns (Harris et al., 1995). Depending on ecological conditions and the reproductive seasons of the species, these assemblages change across time and space (Arshad et al., 2012).During their transition, which can take a few days to several months, marine larval fish grow from 2.5 to 3.0 mm in size at hatching to 10 to 30 mm. The larvae float like plankton in the water after hatching. Pelagic larvae must maintain their position on the water's surface in order to reach planktonic food sources (Webb, 1999). The vast majority of marine fish species lay pelagic eggs that float with the currents. Using common morphometric measurements, closely related species are found.

For a number of reasons, studying larval fish is crucial. Important fish species' spawning seasons and locations can be learned through information on the distribution and availability of fish eggs and larvae, for instance, as well as from the environmental requirements of various fish species.

Fish larvae provide important data on the diversity of species and reproductive processes, as well as help identify areas that serve as larval nurseries.Larval samples have more commonly been selected based on morphometric, meristic, and color characteristics (Rathnasuriya et al., 2021). Additionally, one of the key components of the pelagic food web is the knowledge of larval fish (Raymond, 1983), which can act as a vital link between smaller planktonic and larger nektonic species. The larval stage is typically the most vulnerable to environmental changes; any change in the quality or quantity of ecological elements will be harmful to larval life and may indicate the likelihood of future recruitment (Leis and Rennis, 1983).Fish eggs and larvae have made major contributions to fisheries management and are anticipated to continue doing so in the future as fish stocks are augmented and conserved. The amount of knowledge about the development of fish has increased dramatically during the past 40 years (Rutherford, 2002; Pattira et al., 2012). It is now clear that information gleaned from fish eggs and larvae makes a number of unique contributions to fishery sciences that are essential for proper fish population estimation and monitoring (Fuiman and Werner, 2002).A warm tropical climate, copious rainfall, and nutrients from the land are all present in Bangladesh's coastal and marine regions, creating one of the planet's most prolific ecosystems (Hossain, 2001; Islam, 2003). Bangladesh's economy may benefit from research, excavation, and management of the Bay of Bengal's living and non-living resources.Particularly in light of recent decisions by the International Tribunal for the Law of the Sea (ITLOS) on the maritime boundary between Bangladesh and Myanmar in 2012 and the UNCLOS Arbitral Tribunal on the maritime boundary between Bangladesh and India in 2014, which established Bangladesh's sovereign rights over more than 118,813 km2 of territorial waters and 200 NM of the Exclusive Economic Zone (EEZ), as well as all types of living and non-living resources within the continental shelf (MoFA, 2014).The coastal and marine ecosystems of the Bay of Bengal are home to a wide variety of biodiversity, including fish, crabs, mollusks, mammals, seaweed, and other species. There are about 511 marine species, including shrimp, in the seas off Bangladesh (Murshed-E-Jahan et al., 2014). Just 16.28% of the total amount of fish produced comes from marine fisheries. The potential of the coastal fishing industry has not been fully realized. Instead, the resources were overused, which led to a decrease in fish stocks (Shamsuzzaman et al., 2017).

Ichthyoplankton studies in Maheshkhali para could be used to 3 establish production and management strategies by detecting seasonal and geographical differences in the abundance and composition of larvae across the regions. Fish eggs and larvae require complex taxonomic identification, which is a challenging task. Identifying fish in their juvenile and adult phases is more difficult. This is because of a variety of factors. Firstly, due to their small size, features that could be used to identify fish eggs and larvae can only be seen using a stereoscopic microscope. The key problem with fish larvae is that they go through constant and, in some cases, significant structural, morphometric, and pigmentary changes throughout their development.

The Maheshalipara region is situated at Teknaf in Cox's Bazar district, the northern part of Cox's Bazar. It is a maritime area that runs parallel to the coastline. Maheshkhalipara is one of Bangladesh's important marine zones. The Rezukhal estuary, the Bakkhaliriver, and the Shaplapur region all are notable areas near Maheshkhalipara. Many studies have been conducted in these areas to determine their importance in fisheries, but none have been carried out Maheshkhalipara. As no research has been done in Maheshkhalipara, there are a variety of possibilities to explore this location. Some study has been done in areas besides Maheshkhalipara, such as the Naf Estuary, Bakkhali Estuary, RezuKhal Estuary, and Shaplapur, thus the research in Maheshkhalipara is unique and new. Despite the significance of young fish in the management of fisheries, limited research has been done. However, extensive scientific research is necessary to ensure the long-term viability of this fisheries resource. This study concentrated on the annual seasonal abundance of fish larvae in the Maheshkhalipara. It provides an estimate of the total number of families present in coastal areas throughout the year and categorizes them based on their spawning season and temporal assemblages.

1.2 Significance of the study

Several studies on the abundance and distribution of marine fishes, their life cycles, and spawning seasons were conducted in Cox's Bazar and the Bay of Bengal. Yet, no research on fish larval assemblages has been done in this region. So far advancements in the identification of the fish larvae that live in Maheshkhalipara will enable a more extensive assessment of the ichthyoplankton in terms of species diversity, geographic distribution, species combinations, and how fish larvae are influenced by climatic modifications, leading to an improved perception of the ecosystem. This study provides a comprehensive review of the abundance of larval groups present in the Moheshkhaliapara on the Cox's Bazar coast. This research intends to gather additional scientific information for the sustainable management of Bangladesh's marine fisheries resources by identifying the spawning periods, spawning areas, and nursery grounds of various fishes in the specified area using the early stages of fish.

1.3 Objectives

- To identify the larval fishes and determine their abundance in the Maheshkhalipara,Teknaf Coast,Cox’s Bazar.
- To compare fish larvae assemblages of different seasons and detect major spawning season of some important fishes in the Maheshkhalipara,Teknaf Coast,Cox’s Bazar.

CHAPTER TWO

REVIEW OF LITERATURE

Identification of larval fish has been a key morphological challenge in marine biology due to the enormous transformations that most species endure from early larval stages to adulthood.Ichthyoplankton, or fish larvae, are often pelagic, drifting in the water and interacting with predators and zooplankton.Most fish larvae are predominantly carnivorous during their larval stages, preying on small planktonic organisms, even in species that become herbivores as adolescents or adults.Larger nektonic and planktonic creatures, in turn, eat larval fish. Larvae go through growth and ontogeny to get out of this vulnerable stage.Larger nektonic and planktonic creatures, in turn, eat larval fish. Larvae go through growth and ontogeny to get out of this vulnerable stage.To retrieve eggs and larvae of marine fishes, fine-mesh plankton nets or specially designed traps are used.The locations, abundance, richness, and structure of 'Ichthyoplankton' communities, as well as the connections between larvae and their rivals and prey, are all investigated at sea.These surveys are commonly used in fisheries management as part of stock assessments (Steele et al., 2001).Studying the first stage of the fish life cycle provides substantial information on breeding periods, spawning sites, nurseries, and development, as well as determining population dynamics, in addition to specifying essential features of life history.It also enables the evaluation of migratory patterns, the potential for renewal (effective recruitment), the assessment of the species' conservation status, and the support of fishing stock maintenance (Cruz et al., 2016), all of which can be used to guide management and conservation efforts.

2.1 Coastal areas as nursing ground

The ability of larvae to reach coastal nursery grounds that provide protection and nourishment for their survival and growth is critical to the development of marine fish larvae (Bailey et al., 2008).Major fish larval and juvenile habitats are typically referred to as estuaries and other nearshore coastal environments (Amara, 2003; Baptista et al., 2019).As a result, larval dispersal from breeding grounds to nursery sites is an important part of fish population dynamics and life history.With larval growth, the capacity to regulate migration towards nursery regions improves, and larvae must respond to inputs that signal their proximity (e.g., geomagnetic, olfactory, auditory, visually and chemical cues, river plumes) (Teod'osio et al., 2016).Many biological and environmental factors influence larval survival and dispersal during dispersion, making this a particularly susceptible stage of the fish life cycle, with mortality rates ranging from 5% to 40% every day (Bailey et al., 2008; Houde, 2008).Estuaries and adjacent wetlands serve as nurseries and refuges for fish, particularly marine species (McLusky et al., 2004).Depending on the fish species, spawning takes place in the river, the estuary, or offshore (Elliott et al., 2007b). Pelagic eggs are released by some fish species, and these eggs, as well as the larvae that will hatch, will float around for days or weeks at sea. Other fish species deposit demersal eggs, which are bigger and heavier eggs that land on the substratum, possibly as a defense against being swept out of the estuary (Wolanski, 2015).

2.2 Fish larvae and its importance

The management of fisheries has benefited greatly from the use of fish eggs and larvae, and it is anticipated that they will continue to play a vital role in enhancing and conserving fish supplies in the long term. Researchers determine where key fish species spawn and what their environmental requirements by using information on the distribution and richness of fish eggs and larvae. Furthermore, it is essential to know ichthyoplankton because, as a part of the oceanic food web, it can act as a connecting link between tiny planktonic and larger nektonic species (Raymond, 1983). Finally, the survival of fish larvae may have a direct impact on the number of adult fish stocks in the future. Fish stocks undergo considerable inter - annual variations in biomass because the majority of activities governing recruiting intensity and geographic distribution of fish populations occur during the planktonic phase of fishes. Additionally, they are used to assess the spawning population, spawning regions, spawning times, and nursery areas of the commercial fishes. Over the last 40 years, research on fish early life has grown at an incredible rate (Rutherford, 2002; Pattira et al., 2012). However, ichthyoplankton research can give a depth of knowledge on the ecosystems and structure of fish populations at economical rates in a quite concise way than data drawn from juvenile or adult populations. Because of this, one capture of plankton hauls could give details on the majority of pelagic and demersal fish species that spawn in a certain area, while adult samples would demand large vessels and a variety of research equipment and procedures.

2.3 Abundance and distribution

Seasonal variations of fish larval abundance are related to adult population reproductive habits and life cycles, which are often influenced by marine and climatic conditions (Hernandez-Miranda et al., 2003).Food availability is linked to biotic factors, and zooplankton density is occasionally linked to larval fish abundance; for example, the seasonality of larval fish abundance can be considerably linked to copepod nauplii abundance (Mateo et al. 2006).Arshad et al. (2012) collected 2687 larvae from the Pendas River estuary in Malaysia, averaging 28.29 larvae per $100m^3$.Peninsular Malaysia's larval fish composition consisted of 19 families, with 17 found in the middle estuary, 16 in the lower estuary, and 14 in the upper estuary.According to the distribution pattern of total fish larvae, the number of fish families and densities in the estuary decreased noticeably from the lower to the upper estuary.This shows that the fish larvae in the estuary came from the sea. Between January–March (Northeast monsoon) and June–August (Southern monsoon), the dominant families (Clupeidae, Blenniidae, Gobiidae, and Teraponidae) relocated to the estuary (Southwest monsoon).The effect of the monsoon on the quantity of fish larvae in the Pendas River estuary is a unique feature of the larval community. A research from the Bay of Bengal gathered 6170 larval specimens from 18 different groups. 07 households were economically significant among them. Hemirhamphidae, Carangidae, Sphyraenidae, Gempylidae, Scombridae, Bothidae, and Cynoglossidae were the families involved. They all contributed roughly 5.64 percent of the total number of fish larvae. Carangidae was the most prominent family in the area, followed by Scombridae and Gempylidae (Lirdwitayaprasit et al., 2008).Nellen (1973) discovered 102 fish larval groups in the northwest Indian Ocean (Red Sea, Arabian Sea, and Persian Gulf). There were 44 oceanic plus deep benthic families and 58 shelf fish larvae among them. Another study was undertaken in the southeast Indian Ocean (Australia's NW continental shelf), where 103 larval groups were discovered (Young et al., 1986). He discovered 36 families of marine larvae and 67 families of shelf fish larvae. In 1982 and 1983, Janekarn (1988) described the discovery of 55 and 62 larval fish groups along

Thailand's west coast. He calculated the total number of 123 fish larval families on Thailand's west coast based on his and other research (Janekarn, 1992). Chamchang (2006) found a low number of stable families in terms of fish larvae composition and number, indicating that the system was unreliable. 62 families of fish larvae were discovered in the Andaman Sea between the Thai and Myanmar coastlines between 6°44.47'N and 12°40.80'N, and 95°51.20'E to 96°45.30'E, based on this reference. Azhagar et al. (2009) discovered that the monthly distribution of finfish larval density in Kodikkarai coast ranged from 8 larvae/10m3 to 76 larvae/10m3, but at Arkattuthurai it ranged from 10 larvae/10m3 to 65 larvae/10m3. During the summer season, both localities had the highest larval density. The larvae density was at its lowest during the monsoon. Melville-Smith and Baird (1980) discovered 15 families and 17 species of larval fish at the Swartkops Estuary in South Africa. They did another survey in the Kromme River Estuary the following year, with a somewhat lower total of 12 groups and 15 species discovered (Melville and Baird, 1981). Beckley (1985) found 17 species in the mouth of the Swartkops Estuary. Strydom (1998) discovered 15 fish families with 28 species and nine undetermined species in the Gamtoos Estuary. Strydom et al. (2003) found 23 fish families with 63 species in warm-temperate estuaries in the Eastern Cape, including four unknown species, whereas Montoya-Maya and Strydom (2009) found 17 families with 33 species in cool-temperate habitats. In subtropical estuaries along South Africa's eastern coastlines, the number of families and species increases dramatically. Strydom (2015) investigated patterns in larval fish variety, abundance, and distribution in 25 South African estuaries, discovering 29 larvae families and 89 species in total. The cool-temperate estuaries had 24 families and 46 species, the warm temperate estuaries had 23 families and 68 species, and the boundary estuaries had 18 families and 40 species.

2.4 Larval family

Clupeidae was the most common family in a study at the Pandas River estuary in Peninsular Malaysia, accounting for 41.07 percent of all families. Blenniidae (24.45 percent), Teraponidae (8.80 percent), Gobiidae (5.40 percent), Sillaginidae (3.22 percent), Nemipteridae (1.72 percent), and Mullidae (1.72 percent) were the next families on the list (1.28 percent). Clumpeid larvae were the most prevalent family, with the maximum numbers in February–March, which coincided with Peninsular Malaysia's northeast monsoon season.During the monsoon season (February–March), the clupeid population rose, indicating seasonal spawning. Teraponidae, the second most common family, was found throughout the year, with a surge in February, indicating the family's reproductive season. These larvae were also far more prevalent in other months. Gobiidae larvae were observed all year, with the highest densities in the northeast monsoon in January–March (Arshad et al., 2012).In the Western Peninsular of Thailand, Janekarn and Boonruang (1986) reported that the density of clupeid larvae was highest in February. According to Aziz et al.,(2006) two species of gobiid fish were discovered on the seagrass bed of Merchang Lagoon in Peninsular Malaysia. Regardless of climate or other parameters such as seagrass diversity, temperature, or biological factors, many studies have indicated that the Gobiidae family is widely distributed in coastal areas (Blaber et al., 1997, Kwak and David, 2003,).The Gobiidae family's high predominance can be traced back to clumps of unusually diverse recruitment in schooling species, which appear to have resulted through aggregative settlement (Anand and Pillai, 2005). Much more information about fish larvae was discovered in a large-scale study conducted by Lirdwitayaprasit et al. (2008) in three separate regions of the Bay of Bengal.Photichthyidae, Myctophidae, Bregmacerotidae, Carangidae, and Callionymidae were consistent families in the upper portion, Gonostomatidae, Photichthyidae, Myctophidae, Bregmacerotidae, and Callionymidae were constant families in the western section, and 14 families were constant in the Andaman sea region The Myctophidae family was the most abundant, accounting for over 30.41 percent of larvae, according to Chamchang (2007), followed by the Stomiidae family.During the investigation in the Andaman Sea, the percentage of fish families such as Scombridae, Mugilidae, Clupeidae, Carangidae, Engraulidae, Leiognathidae, Tetradontidae, Lutjanidae, Pomacentridae, Sciaenidae, and Chirocentridae was analyzed. However, the proximate makeup of larvae at both sites differed. The Scombridae family was the most common (10.12% and 10.14%), while the Chirocentridae family was the least common (2.61 percent and 2.72 percent) (Azhagar et al., 2009).The clupeidae fish family was the most frequently captured fish family in all three biogeographical regions of temperate South Africa. A single species (G. aestuaria) from this family accounted for an average of 77.00 percent of cold temperate estuaries, 63.38 percent of warm temperate estuaries, and 73.60 percent of border estuaries. The second and third highest contributions to the overall catch came from the families Gobiidae and Blenniidae. Less than 1% of the total catch came from the remaining fish groups.

2.5 Diversity indices

The Euhaline salinity zones, which indicate the accumulating impact of marine and estuarine species, showed the highest alpha diversity, which shows intra-estuary trends, in a large-scale research at temperate South African estuaries by Strydom (2015). The most diverse estuary at the Beta diversity level is the warm-temperate, permanently open Kromme Estuary in the Eastern Cape (diversity score: 1.77), followed by the cold-temperate, permanently open Olifants Estuary in the Western Cape (diversity score: 1.66).

The Western Cape's narrow, closed Diep Estuary, which is chilly and only seldom accessible, has the least diversity (0.15). At the Gamma diversity level, warm temperate estuaries (1.67) had a higher mean diversity of fish larvae than cold temperate (1.50) or boundary estuaries (0.96) did. On the other hand, there weren't much variations between the regions.. The mean diversity of the permanently open estuaries (1.11) was higher than that of the seasonally open-closed estuaries (0.68) and estuarine lake (0.83) systems, despite the fact that there was no statistically significant difference in species diversity between the estuaries.

In the Malaysian estuary of the Pendas river, there were no significant differences in the densities of fish larvae between the stations ($p>0.05$).In comparison to the upper estuary, the middle estuary had the highest average Shannon Winner diversity index (1.48). (1.18). The middle estuary had the highest evenness (0.77), whereas the upper and lower estuaries were equal in evenness. The highest family wealth was found in the middle estuary (1.72), while the lowest wealth was found in the upper estuary (1.34). Between months, there were significant differences in the overall fish larval density (p 0.05).The Shannon Wiener index demonstrated significant variation between monsoon and intermonsoon seasons, with peaks in December to January and May to August. Additionally, throughout the course of a year, family wealth displayed two unique peaks. January through March had one high, and May through August saw the other (Arshad et al., 2012).

2.6 Spawning season

The majority of Red sea species used for commerce spawn between May and August. Of all commercially accessible species, they produced around 61 percent. Of the 13 summer spawners, 44 percent came from the commercial species. Six and five species, or 19 and 16 percent of commercial species, were contributed by the winter and spring, respectively. Clupeidae and Engraulidae, two specieshave been found to reproduce throughout the year and without any obvious pattern (El-Regal, 2013). Azhagar et al. (2009) showed that, over all four seasons, larvae belonging to the Teraponide family were most plentiful (26.09 percent) in the post-monsoon season, whereas Tetrodentridae were the least common (in a descriptive study at the Bay of Bengal of South East coast of India) (1.30 percent).However, during the summer, Teraponidae was the least prevalent family while Clupeidae was the most numerous (17.22%). (0.99 percent). Leiognathidae held the majority during the premonsoon season (25.58%) whereas Latidae had the lowest percentage (1.16 percent). Pomadasydae (35.26 percent) was the most abundant family and Carrangidae (less numerous) during the monsoon season (1.55 percent).The most bony fishes of all taxa were present during the post-monsoon season, followed by the summer. Rainfall data show negative relationships with the distribution and abundance of finfish larvae, according to Rajaseker et al. (2005). In the Tuticorin region, Marichamy and Siraimeetan (1984) found two peaks in the dispersion of fish larvae. The first peak occurred in January–February, while the second peak occurred in June–July.According to Yoshida (1979), the frigate tuna reproductive season in the Indian Ocean lasted from January to April. The eastern Indian Ocean's quantity of skipjack tuna larvae peaked in February, according to Stequert and Marsac (1989). Most months saw females of S. gibbosa and S. fimbriata that were both ripe and pregnant. Peak occurrences of S. gibbosa occurred in the southern region from February to March, in the northern region from March to April, and across the northwestern Bay of Bengal from May to July (Ghosh et al., 2013).Most of the 330 Anchoa tricolor ovaries were researched by Araujo et al. (2008) in a tropical bay in southeast Brazil. The Fulton fish condition peaked in September and reached its lowest point in June and August.These variations show that Stolephoruscommersonnii can modify its reproductive cycle in response to environmental influences, with temperature, nutrition availability, and photoperiod being the most crucial variables influencing engraulid reproduction in coastal areas (Silva et al., 2003; Araujo et al., 2008). Anchovies (engraulidae) have different spawning seasons in tropical and subtropical waters, according to several studies, most notably Kim et al. (2013) and Andamari et al. (2002).

CHAPTER THREE

METHODOLOGY

3.1 Study area

The study was carried out in the Maheshkhalipara (N 21°04'18.0", E 92°08'05.7") with monthly sampling from March 2020 to February 2021. It was situated in the northern portion of Teknaf, in the Cox's Bazar district. The study area was chosen because of its ecological significance to coastal fisheries. The coordinates were taken using a GPS meter, and the map was created using the software QGIS (version 3.4.5) (Fig-1).

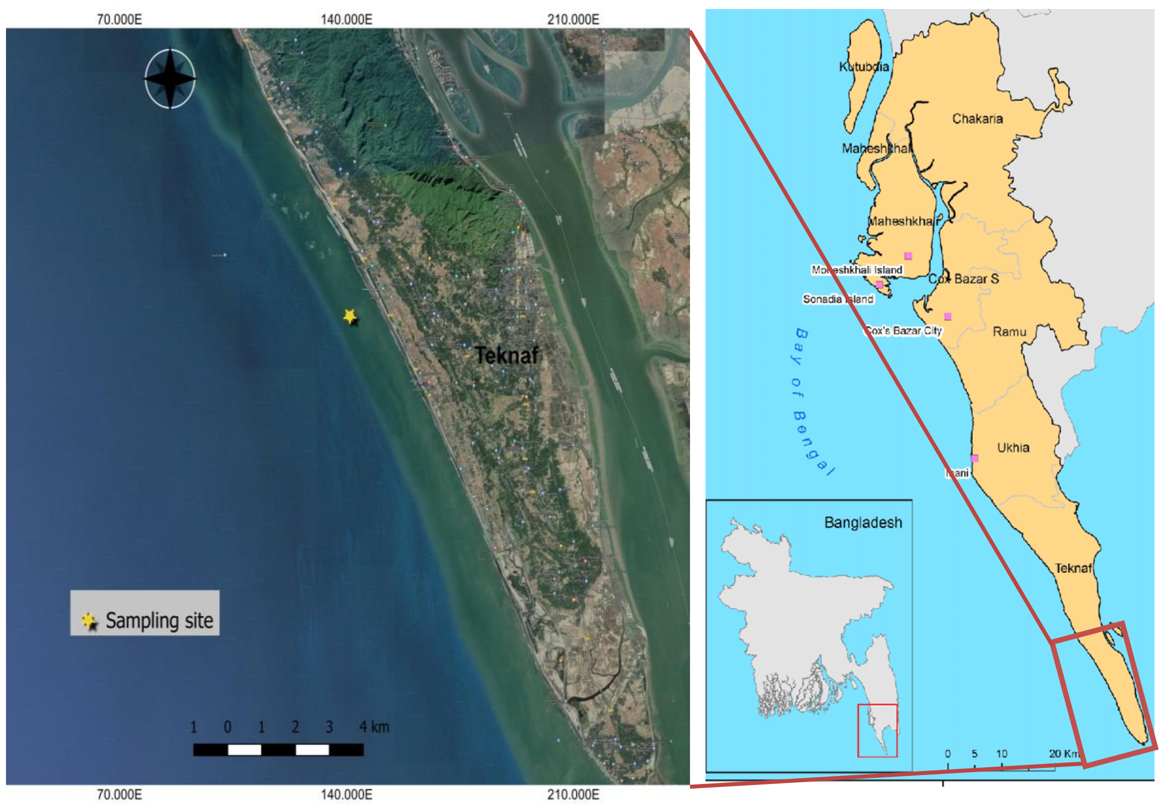

Fig .(1): Map of Study Area

3.2 Sampling Procedure

Fish larvae were collected from the selected spot by Bongo Net (0.50 m mouth diameter, 1.3m long, and 500µm mesh at the body). A flow meter (Model: KC Denmark A/S 23.090-23.091) was attached to the mouth of the net to determine the volume of seawater filtered during each tow. The sampling period was about 10 minute's surface tow-in daylight. The collected specimen was preserved in 90% ethanol and transported to the Chattogram Veterinary and Animal Sciences University's Aquatic Ecology laboratory for sorting out based on morphology and other attributes.

3.3 Fish larvae sorting

Usually, 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 sieved through meshes of 0.1 mm and 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 (90%) and each sample was placed in a petri dish one by one to be analysed under an OPTIKA ITALY C-B3 stereo microscope at low magnification (10x) and several pictures were taken. Each picture was given a specific code so that it can be easily found later.

3.4 Morphological identification of fish larvae

Fish larvae were identified under the stereo microscope up to family level using the descriptions of related taxa given in Leis and Rennis (1983), Leis and Carson-Edwart (2000) and Rodriguez et al (2017). The body structure, coloring pattern, and meristic and morphometric traits are the most significant charactrstics to identify larval fish. The larvae's body structure allows them to be divided into numerous major categories (Russell, 1976). For instance, larvae with slender, narrow bodies,larvae with laterally flattened bodies, typical fish shaped larvae, bodies with aberrant shapes or showing specialized larval characters for the plankton life, cranial armatures, extended fin rays, stalked eyes, or large and early formed fins. The different measures of a larva are referred to as morphmetric characteristics.

3.5 Determination of abundance of larvae

Number of fish larvae according to specific family were counted through naked eye. This number was simplified into per $1000m^3$ for further analysis. Temporal variation of fish larvae were determined by number of larvae along with diversity indices. Diversity of the larval fish assemblage was measured by the Shannon-Wiener index (Shannon, 1949) and equitability or evenness was expressed by Pielou's evenness index (Pielou, 1966). Family richness was calculated following Margalef (1958). At its most basic level, diversity refers to the number of different species that exist. The number of species (richness) and relative abundance of these species (evenness) differ among biological communities (Anon, 2021). Species richness (S) and evenness (E) are two independent components of species diversity, which is a vital factor in ecology.

3.5.1 Measurement of diversity

The type of diversity used here the diversity of species within a community or habitat. The diversity index was calculated by using the Shannon – Wiener diversity index (1949).

Diversity index = H = – H Pi In Pi

where Pi = S / N

S = number of individuals of one species

N = total number of all individuals in the sample

In = logarithm to base e

The higher the value of *H*, the higher the diversity of species in a particular community. The lower the value of *H*, the lower the diversity. A value of $H = 0$ indicates a community that only has one species.

3.5.2 Measurement of species richness

Margalef's index was used as a simple measure of species richness (Margalef, 1958).

Margalef's index = (S – 1) / In N

Here, S = total number of species

N = total number of individuals in the sample

3.5.3 Measurement of evenness

For calculating the evenness of species, the Pielou's Evenness Index (e) was used (Pielou, 1966).

e = H / In S

Here, H = Shannon – Wiener diversity index

S = total number of species in the sample

3.6 Determination of the spawning season

The spawning season was determined by considering the month before the month in which larvae began to be found in the selected station. Based on the monthly larval abundance, the spawning season of the identified families was categorized as the summer, winter, pre-monsoon, monsoon, and post-monsoon. The winter season lasts from December to February, while the summer season lasts from March to May. Pre-monsoon months were June and July, monsoon months cover August and September, and post-monsoon months include October and November.

3.7 StatisticalAnalysis

All the data were being entered into Microsoft Office Excel (version 2010, USA). Data management and data analysis done by SPSS (version 25).SPSS is a software packageused for logical batched and non-batched statisticalanalysis.

CHAPTER FOUR

RESULTS

4.1 Total Fish Larvae

A total of 14 families of larvae were identified consisting of 1223 individuals from the Maheshkhalipara(Fig-2 and Table-1). The average number of fish larvae was 102/1000 m^3 /month (Table-1).

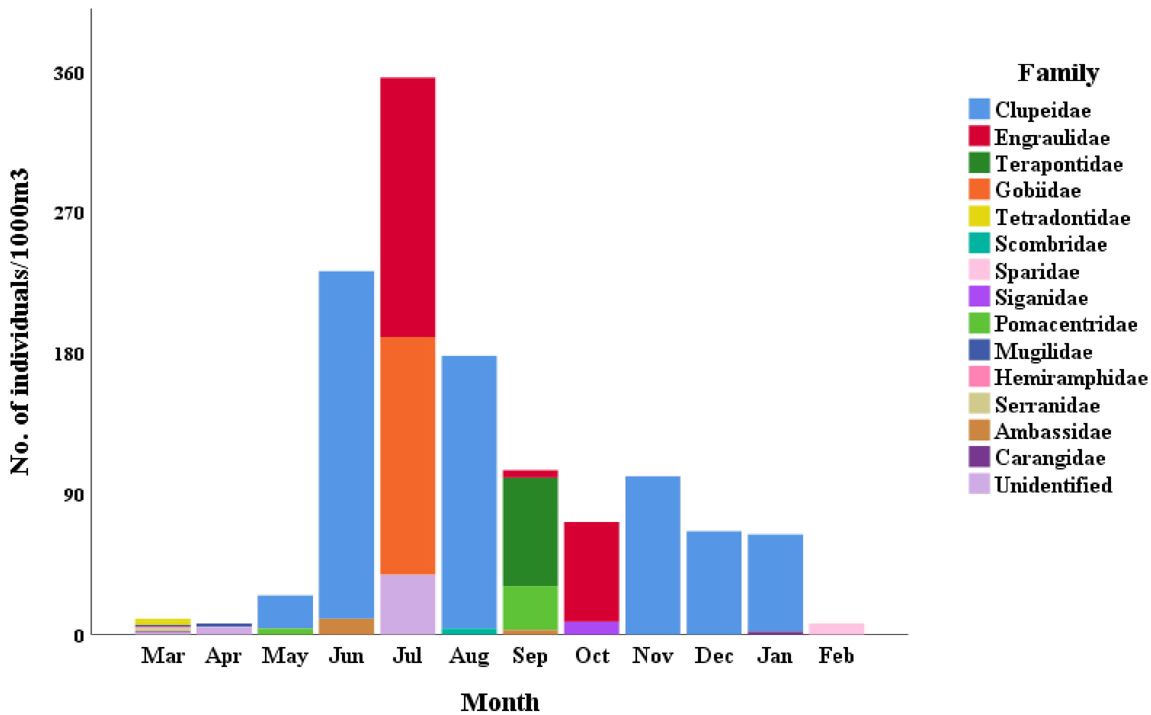

Fig. (2): Temporal variation of larval families at Maheshkhalipara

4.2 Constance of Occurrence

Depending on the frequency of occurrence, among the 14 families, the percentages by families of constant: accessory: accidental families were 7:7:86. It suggests that just 7% of families were discovered at a constant rate throughout the year in the Maheshkhalipara and they commonly use it as a nursing ground. The majority of the families were not found frequently in this region and were considered to be accidental (Table- 1).

Table-1: Total number of fish larvae/1000 m^3 and constancy of occurrence

Family	Total number of larvae (larvae/ $1000m^3$)	Mean number of larvae	SD	SE	Percentage of total catch	Rank	Frequency of Occurrence	Classification according to Constance of occurrence		
								1	2	3
Clupeidae	646	53.83	76.05	21.95	52.82	1	50.00	*		
Engraulidae	235	19.58	49.61	14.32	19.22	2	25.00		*	
Pomacentridae	32	2.67	8.06	2.33	2.62	5	16.67			*
Gobiidae	154	12.83	43.83	12.65	12.59	3	16.67			*
Tertradontidae	2	0.17	0.58	0.17	0.16	12	8.33			*
Mugilidae	3	0.25	0.62	0.18	0.25	11	16.67			*
Ambassidae	13	1.08	2.94	0.85	1.06	6	16.67			*
Carangidae	3	0.25	0.62	0.18	0.25	10	16.67			*
Scombridae	4	0.33	1.15	0.33	0.33	9	8.33			*
Sparidae	7	0.58	2.02	0.58	0.57	8	8.33			*
Siganidae	8	0.67	2.31	0.67	0.65	7	8.33			*
Hemiramphidae	1	0.08	0.29	0.08	0.08	14	8.33			*
Serranidae	2	0.17	0.58	0.17	0.16	13	8.33			*
Terapontidae	69	5.75	19.92	5.75	5.64	4	8.33			*
Unidentified	44	3.67	10.91	3.15	3.60					
Total	1223				100					

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

4.3 Composition of larval families

Fourteen larvae i.e - Clupeidae, Engraulidae, Terapontidae, Gobiidae, Tetradontidae, Scombridae, Sparidae, Siganidae, Pomacentridae, Mugilidae, Hemiramphidae, Serranidae, Ambassidae, Carangidae.The top three families were- Clupeidae, Engraulidae, Gobiidae. Among them, Clupeidae was the most abundant family, which contributes about 52.82% followed by Engraulidae (19.22%), Gobiidae (12.59%). The other families were about Terapontidae (5.64%), Pomacentridae (2.62%), Ambassidae (1.06%) and others (6.02%) (Table-1& Fig.3).

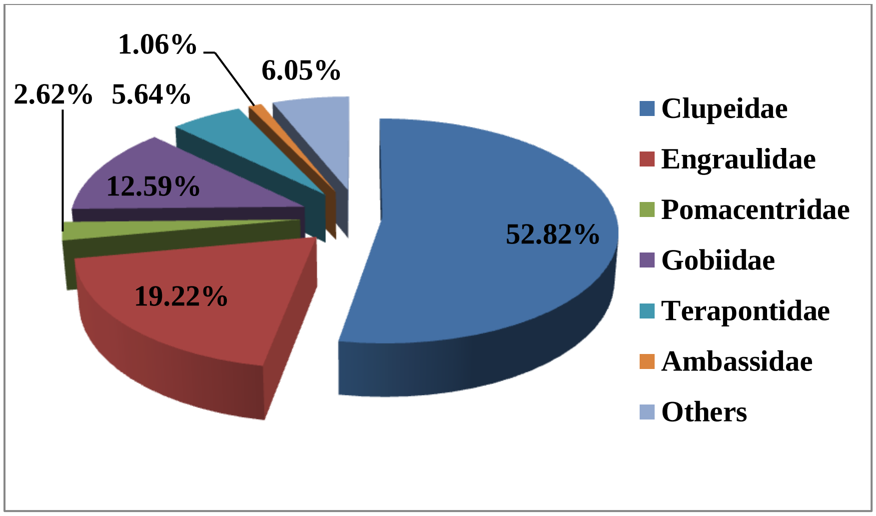

Fig. (3): Larval composition of fish families of Maheshkhalipara

4.4 Top three larval families are:

4.4.1 Clupeidae

Clupeidae were the most abundant larvae and contributed more than half of the total abundance (52.82%) at study area (Table-1 & Fig. 3). This family was found in six months of a year-from May to June, August, November and December (Fig. 4). The mean density of this family was 53.83±76.05(Table-1).

4.4.2 Engraulidae

Engraulidae family was the second abundant family, which contributed 19.22% of the total abundance (Table-1 & Fig. 3). This family was found in three consecutive months from July, September to October (Fig. 4). The mean density of the larvae was 19.58±49.61(Table-1).

4.4.3 Gobiidae

Gobiidae family comprised 12.59% of the total abundance (Table-1 & Fig. 3).This family was found in two months of the sampling year- March, July (Fig. 4). The mean density of the larvae was 12.83± 43.83 (Table-1).

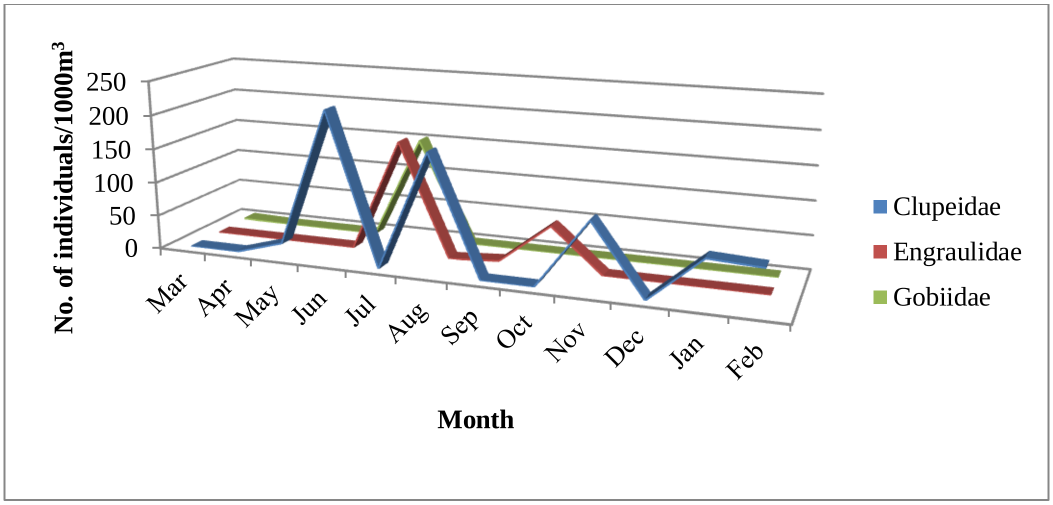

Fig. (4): Temporal abundance of top three families of Maheshkhalipara

4.5 Temporal variation of larval abundance

In the Maheshkhaliapara, March had the highest number of family members (07), while November, December and February had the lowest (1) family member. The maximum larval abundance was reported in June (222 larvae/1000m^3) and minimum larval abundance was reported in March (1 larvae/1000m^3). The highest mean total density of larvae was 118.67±70.2 that was observed in the month of July, while in March lowest was found which was 1.43±0.54 (Table-2).

Table-2: Temporal variation of larval abundance at Maheshkhalipara

Month	Mean number of larvae	Number of family	Std. Deviation	Std. Error	Minimum	Maximum
Mar	1.43	7	0.54	0.2	1	2
Apr	3.5	2	2.12	1.5	2	5
May	12.5	2	12.02	8.5	4	21
Jun	116	2	149.9	106	10	222
Jul	118.67	3	70.2	40.53	38	166
Aug	89	2	120.2	85	4	174
Sep	26.25	4	30.67	15.3	3	69
Oct	36	2	39.59	28	8	64
Nov	101	1			101	101
Dec	66	1			66	66
Jan	32	2	42.43	30	2	62
Feb	7	1			7	7

4.6 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:

Diversity indices showed significant variation within months. The highest Shannon-Wiener index was found in March (1.916) and July (0.958) respectively (Fig.5). Margalef's richness index also clearly showed one significant peak in March (2.606) and the next one in September (0.645) (Fig. 6). In terms of Pieulo's evenness, the highest was March (0.985) and the second highest was July (0.872) (Fig. 7).

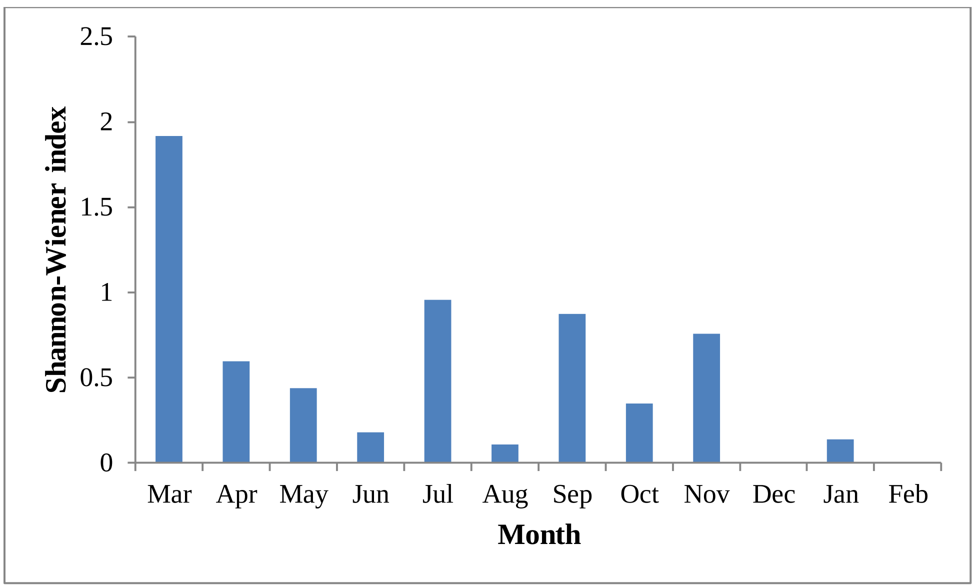

Fig. (5): Shannon-Wiener index of larval family diversity of each month, Maheshkhalipara.

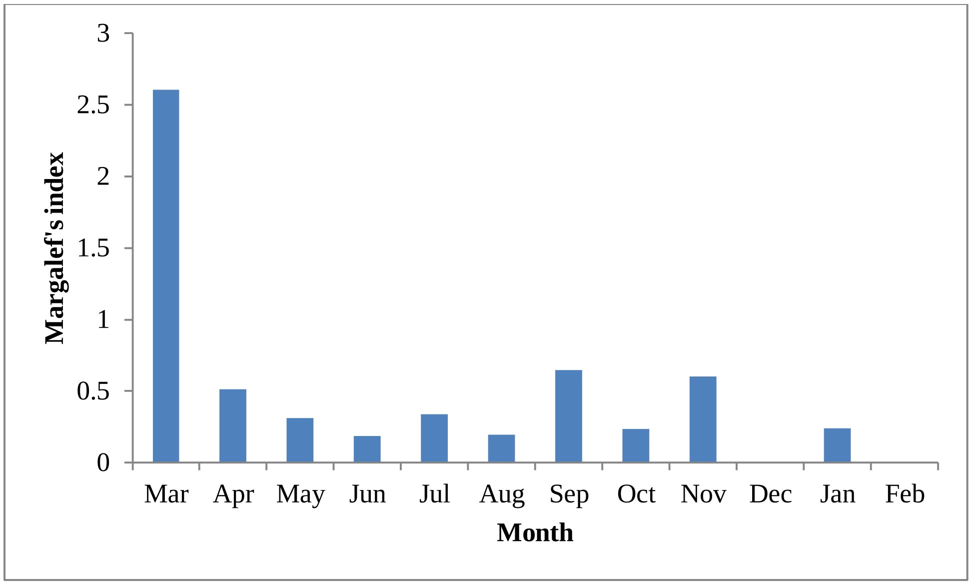

Fig .(6) :Margalef's richness index of larval family of each month, Maheshkhalipara.

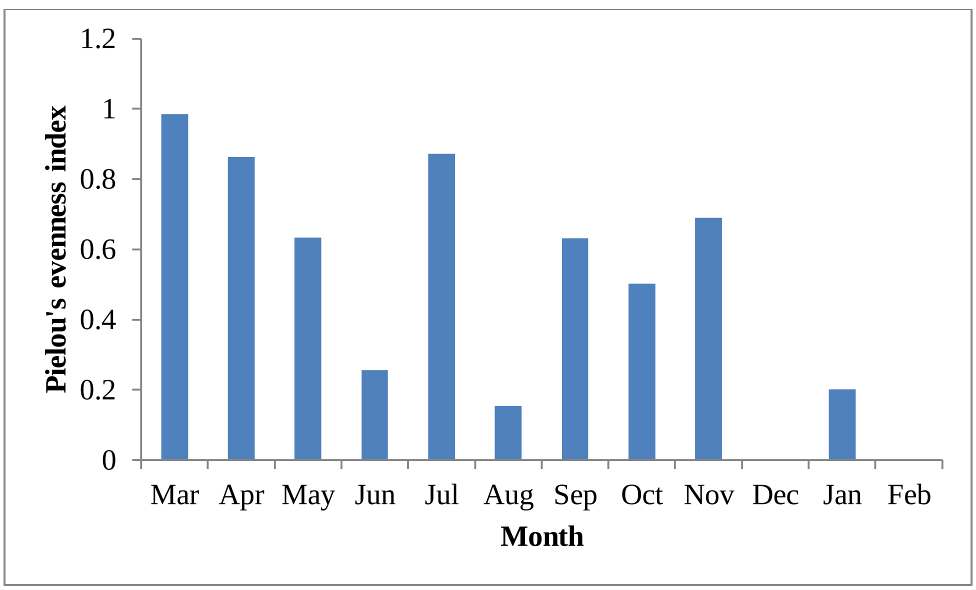

Fig. (7): Pieulo's evenness index of larval family of each month, Maheshkhalipara

4.7 Spawning season:

Larvae of 14 fish families were collected and their time of occurrence was used as indication of their spawning season. The spawning seasons of the families were classified as summer, winter and monsoon. Most of the families spawn in the cooler months of the year (November to February) based on the availability of their larvae (Fig. 8). Among the families, Clupeidae and Engraulidae were confirmed as spawner of summer, monsoon and winter, as their larvae were found in eight months of the year. Gobiidae family were recorded to spawn in mid winter and late winter, Terapontidae were documented to reproduce in mid monsoon and Pomacentridae as mid summer and mid monsoon, Ambassidae as mid summer and monsoon. Six (6) families are classified as single spawners since they reproduce once a year (Table- 3).

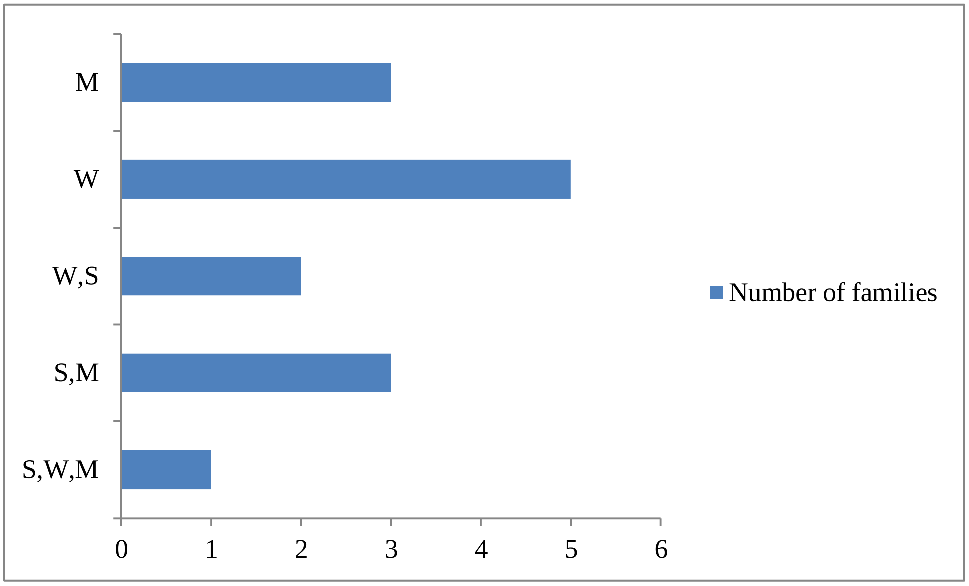

Fig.(8): Number of families in different spawning season of larval families, Maheshkhalipara.

Table- 3: Spawning season of identified fish larvae with their frequency of occurrence and spawning month

Family	**Spawning month**	**Spawning season**
Clupeidae	Apr, May, Jul, Oct, Nov, Dec	Mid S, Early M, Late M, Early W
Engraulidae	Jun, Aug, Sep	Late S, Mid M
Pomacentridae	Apr, Aug	Mid S, Mid M
Gobiidae	Feb, Jun	Late W, Late S
Tertradontidae	Feb	Late W
Mugilidae	Feb, Mar	Late W, Early S
Ambassidae	May, Aug	Mid S, Mid M
Carangidae	Feb, Dec	Late W
Scombridae	Jul	Early M
Sparidae	Jan	Mid W
Siganidae	Sep	Mid M
Hemiramphidae	Feb	Late W
Serranidae	Feb	Late W
Terapontidae	Aug	Mid M

(S = Summer, M = Monsoon, W = Winter)

CHAPTER FIVE

DISCUSSION

5.1 Fish larval composition and abundance

Because most fish larvae were tiny, they were readily neglected, and they had been classified as a big subcategory of zooplankton. However, because ichthyoplankton play a significant role in fish life cycles, they were crucial in assessing environmental effects, fisheries resources, and climate change reactions. Ichthyoplankton were also an essential food supply and link in marine food cycles, thus their assessment was necessary in fisheries resource management. This study identified 1223 individuals and 14 families. Based on the morphological analysis of larvae, the families' were- Clupeidae, Ambassidae, Engraulidae, Gobiidae, Mugilidae, Megalopidae, Sillaginidae, Blenniidae, Terapontidae, Sparidae and Gerreidae (Fig. 2). This area appears to had less diversity than the previous work in the various parts of the Bay of Bengal and Indian Ocean. Nellen (1973) found 102 larval families in the Indian Ocean's north-eastern region, including the Arabian Sea, Red Sea, and the Persian Gulf. Youngs et al. (1986) identified 103 larvae fish families in the southeast Indian Ocean, whereas Lirdwitayaprasit et al. (2008) found 52 families in the Bay of Bengal. Janekarn (1988) identified 62 families of fish larvae on the west coast of Thailand. In the Indian Ocean, Rathnasuriya et al. (2021) identified 80 species belonging to 69 larval families using morphological and molecular methods.Lower larval diversity could be associated with low productivity along the Cox's Bazar-Teknaf coasts, as nutrients carried by rivers are assumed to be lost in deeper seas due to the narrow shelf (Qasim, 1977). Rashed-Un-Nabi et al. (2011) reported to have 49 fish and shrimp species by char jal in Bakkhali river estuary. Hossain et al. (2007), on the contrary, reported collecting 161 species using various types of nets from the Naaf river estuary, which is about 50 kilometers south from the current research site. Reason behind this fluctuation is that the rubber dam has created a controlled environment in the Bakkhali estuary, reducing the number of species. Changes in water properties caused by the dam might also have a big impact on the river's species population. (McAllister et al., 2001).Based on the percentage of the larvae, two (02) dominant families were identified as Clupeidae and Ambassidae. Lirdwitayaprasit et al. (2008) recognized Photichthyidae, Myctophidae, Bregmacerotidae, Gonostomatidae, Callionymidae, and Carangidae as abundant families in the Bay of Bengal. Another research by Tzeng et al. (1997) at the estuarine stations of Yenliao Bay confirmed Pomacentridae, Apogonidae, and Tripterygiidae as dominant families at the rocky stations, and Gobiidae was abundant. Chesalina et al. (2013) identified the four most common families: Sparidae, Scombridae, Clupeidae, and Nemipteridae. Arshad et al. (2012) studied Clupeidae as the most abundant followed by Blenniidae, Teraponidae, Gobiidae, Sillaginidae, Nemipteridae, and Mullidae in Pendas river estuary, Peninsular Malaysia.

5.2 Constance of Occurrence

Based on the constancy of occurrence among the 14 families, the percentages of constant: accessory: accidental families were 7:7:86. Only Clupeidaefamily were found throughout the year in the Maheshkhalipara, and they commonly used it as a nursing ground, which made them constant families. Engraulidae were considered accessory family. The majority of the families were not found frequently in this region and were considered to be accidental (Table -1). The result of the study showed a low number of constant families in the Bay of Bengal. This was consistent with the findings of Lirdwitayaprasit et al. (2008), who observed a low number of constant (28) and accessory (22) families in the Bay of Bengal, with 50 families classified as accidental.

5.3 Temporal density and diversity indices

The abundance of fish larvae was greatest in July, during the monsoon season. However, the majority of the fish families were recorded in March, indicating that summer is the most prolific month. The highest Shannon-Wiener index (H) was observed 1.91 in March, which is in Summer season. The lowest value, zero (0), was found in December and February. 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. In terms of richness and evenness, both were highest in March. The highest Margalef's richness was 2.60 and Pielou's evenness index was 0.98. Margalef's richness index has no range. Pielou's evenness is an indicator that shows both diversity and species richness. While family richness refers to the number of different family present in a particular region, evenness refers to the number of individuals of each family present. 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 zero (0) for December, February indicating that there is no evenness.

The obtained Shannon-Wiener index in this study matched with Arshad et al. (2012) that indicated significant variation within monsoon and intermonsoon season at Pendas river estuary. However, family richness peaked in January-March at this estuary.

Brinda et al. (2010) described that Margalef's richness varied from 0.71(May) to 0.91 (March). 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.

Again, a brief research performed by Zhang et al. (2021) from September to October in 44 different stations in Eastern Indian Ocean. The average Shannon-Wiener index was 0.83, where highest was 1.52 and lowest was zero (0). Mean richness index was 1.01 and evenness index was 0.79.

5.4 Spawning season

Fish spawning season is responsible for the presence of fish larvae. Fish planktonic phases often extend a few weeks to a few months (Victor, 1986; Brothers et al., 1983). The study of temporal and geographical patterns, as well as the availability of fish larvae in connection to oceanographic circumstances, can give insight into the adaptability and influence of spawning patterns on yearly strength for the entire physical and biological processes. (Somarakis et al., 2002). However, the majority of studies on fish spawning season focused on histological analysis. In this study, the spawning seasons were classified into three (03) distinct groups: summer, winter, and monsoon. Further these groups were subdivided into early, mid and late based on the availability in different months. Majority of the families (08) spawn in winter season, which means they reproduce from November to February and their larvae were found from December to March in this estuary. Clupeidae was confirmed as spawner of all three seasons.

Engraulidae, Pomacentridae and Ambassidae families spawn in summer and monsoon. Gobiidae, Mugilidae spawn in winter and summer. Tetradontidae, Carangidae, Sparidae, Hemiramphidae, Serranidae were reported to spawn in winter. Scombridae, Siganidae, Terapontidae families spawn in monsoon.

El-Regal (2013) reported that Clupeidae and Engraulidae tended to reproduce at irregular intervals throughout the year with no apparent pattern. Most of the commercially available species were summer spawners in Red Sea, which matched this study. Clupeidae grow quicker in tropical waters and have a shorter life cycle than in temperate environments (Araújo et al. 2008). Rajaseker et al. (2005) demonstrated that rainfall data shows significant negative relationship with the distribution and frequency of finfish larvae.

CHAPTER SIX

CONCLUSION

In the Maheshkhalipara, diversity of larval family was distinct in relation to month. A total of 1223 larvae were collected and 14 families were identified based on their morpho-meristic characterstics. The month of July had the highest number of larvae, whereas the month of March had the most families. The highest Shannon-Wiener index,family richness and evenness were highest in Summer (March).It was revealed that this site did not have as many families as anticipated in comparison to other sites. Clupeidae was the most frequent family followed by Engraulidae and Gobiidae. These three families comprise of some commercially important fish species such as *Tenualosailisha*, *T. toli*, *Ambassisdussumieri*,*Stolephorusindicus*, *Stolephorusinsularis*, *Glossogobiusgiuris.*These fish families may spawn because of suitable environmental conditions, particularly salinity. As a result, many families use the Maheshkhalipara coastal area as a nursing ground. In addition, spawning season was also identified based on the larval frequency. Clupeidae larvae have been recorded in seven distinct months indicating that their spawning season is summer, monsoon, winter , Engraulidae larvae have been recorded in three distinct months indicating that their spawning season is summer, monsoon. Gobiidae larvae have been recorded in two distinct months indicating that their spawning season is summer, winter. Overall, eight (08) families were identified as winter spawners. This research will lay the foundation for improvement of fisheries resource management strategies in the Cox's Bazar region.

CHAPTER SEVEN

RECOMMENDATIONS

This study contains yearlong valuable data of larval fish abundance, diversity indices and their spawning season at MaheshkhaliparaTeknaf coast of Cox's bazar, Bangladesh. According to this research work, the following recommendations maybe done:

- It will be possible to determine which fish larvae are using this estuary as nursing ground from this research.
- In addition, the breeding season of identified fishes in that region might be stated, as well as their ban period, in order to achieve sustainable fisheries management.
- It will serve as a foundation for future decisions about the management and conservation of the fishes of the Maheshkhalipara.
- Responsible authority should monitor physical, chemical and biological characteristics of this region to serve as nursing ground for freshwater and marine fish larvae.

REFERENCES

Amara R. 2003. Seasonal ichthyodiversity and growth patterns of juvenile flatfish on a nursery ground in the Southern Bight of the North Sea (France).Environmental Biology of Fishes. 67: 191–201.

Anand PEV, Pillai NGK. 2005. Occurrence of juveniles fishes on the seagrass beds of Kavaratti Atoll, Lakshadweep, India. Indian Journal of Fisheries. 52: 459–467.

Andamari R, Milton D, Zubaidi T. 2002. Reproductive biology of five species of anchovy (Engraulidae) from Bima Bay, Sumbawa, Nusa Tenggara. Indonesia. Journal of Agriculture Science 3: 37-42.

Anon, 2021.Introduction, Simpson's Index and Shannon-Weiner Index.

Araújo FG, Silva MA, Azevedo MCC, Santos JNS. 2008. Spawning season, recruitment and early life distribution of *Anchoa tricolor* (Spix and Agassiz, 1829) in a tropical bay in southeastern Brazil. Brazilian Journal of Biology. 68(4): 823-829.

Araújo FG, Silva MA, Santos JNS, Vasconcellos RM. 2008. Habitat selection by anchovies (Clupeiformes:Engraulidae) in a tropical bay at Southeastern Brazil. Neotropical Ichthyology 6: 583-590.

Arshad AB, Ara R, Amin SN, Daud SK, Ghaffar MA. 2012. Larval fish composition and spatio-temporal variation in the estuary of Pendas River, southwestern Johor, Peninsular Malaysia. Coastal marine science. 35(1): 96-102.

Arzamani K, Vatandoost H, Rassi Y, Akhavan AA, Abai MR, Alavinia M, Akbarzadeh K, Mohebali M, Rafizadeh S. 2018. Richness and Diversity of Phlebotomine Sand Flies (Diptera: Psychodidae) in North Khorasan Province, Northeast of Iran. Journal of Arthropod-borne diseases. 12(3): 232–239.

Azhagar S, Anbalagan T, Veerappan N. 2009. Distribution and abundance of finfish larvae along Bay of Bengal (South East Coast of India). Current Research Journal of Biological Sciences. 1(1): 14-17.

Aziz A, Bujang JS, Zakaria MH, Suryana Y, Ghaffar MA. 2006. Fish communities from seagrass bed of Merchang Lagoon, Terengganu, peninsular Malaysia. Coastal Marine Science. 30(1): 268–275.

Bailey KM, Abookire AA, Duffy-Anderson JT. 2008. Ocean transport paths for the early life history stages of offshore-spawning flatfishes: a case study in the Gulf of Alaska. Fish Fisheries. 9: 44–66.

Baptista J, Martinho F, Martins R, Carneiro M, Azevedo M, Vieira AR, Gomes P, Pardal MA. 2019. Water temperature gradient shapes the structure and composition of nearshore marine fish communities in southern Europe. Journal of Sea Research. 154.

Beckley LE. 1985. Tidal exchange of ichthyoplankton in the Swartkops Estuary mouth, South Africa. South African Journal of Zoology 20: 15–20.

Brinda S, Srinivasan M, Balakrishnan S. 2010. Studies on diversity of fin fish larvae in Vellar estuary, southeast coast of India. World Journal of Fish and Marine Sciences, 2(1): 44-50.

Brothers EB, Williams DM, Sale PF. 1983.Length of larval life in twelve families of fishes at "One Tree Lagoon", Great Barrier Reef, Australia. Marine Biology. 76(3):319-324.

Chamchang C. 2006. Composition, abundance and distribution of Ichthyoplankton in the Andaman Sea. In: Preliminary Results on the Large Pelagic Fisheries Resources Survey in the Andaman Sea. TD/RES/99 SEAFDEC. 66-100.

Chesalina T, Al-Kharusi L, Al-Aisry A, Al-Abri N, Al-Mukhaini E, Al-Maawali A. and Al-Hasani L. 2013. Study of diversity and abundance of fish larvae in the South-western Part of the Sea of Oman in 2011-2012. Journal of Biology, Agriculture and Healthcare. 3(1):30-43.

Chowdhury ZA, Sanaullah M. 1991. A check list of the shrimps/ prawns of the Moheshkhali Channel, Cox's Bazar. Bangladesh. Journal of Zoology. 19: 147-50.

Cruz PR, Affonso IP. Gomes LC. 2016. Ecologiadoictioplâncton: umaabordagemcienciométrica. OecologiaAustralis. 20(4): 436-450.

Elliott M, Whitfield AK, Potter IC, Blaber SJM, Cyrus DP, Nordlie FG, Harrison TD, 2007. The guild approach to categorizing estuarine fish assemblages: a global review. Fish Fish. 8:241–268.

El-Regal MA. 2013. Spawning seasons, spawning grounds and nursery grounds of some Red Sea fishes. The Global Journal of Fisheries and Aquaculture. 6(6): 105-125.

Fuiman LA, Werner RG. 2002. Special considerations of fish eggs and larvae. In: Fuiman LA, Werner, RG. (Eds.), Fishery Science. The Unique Contributions of Early Life Stages.Fishery Blackwell Publishing.206-221.

Ghosh S, Rao MV, Sumithrudu S, Rohit P, Maheswarudu G. 2013. Reproductive biology and population characteristics of Sardinellagibbosa and Sardinellafimbriata from north west Bay of Bengal.

Gillanders BM, Able KW, Brown JA, Eggleston DB, Sheridan PF, 2003. Evidence of connectivity between juvenile and adult habitats for mobile marine fauna: an important component of nurseries. Marine Ecology Progress Series. 247:281-295.

Harris SA, Cyrus DP, Forbes AT. 1995. The larval fish assemblage at the mouth of the Kosi Estuary, KwaZulu- Natal, South Africa. South African Journal of Marine Science. 16: 351–364.

Harris SA, Cyrus DP. 1995. Occurrence of larval fishes in the St. Lucia estuary, KwaZulu-Natal, South Africa. South African Journal of Marine Sciences. 16: 333–350.

Helfman GS, Collette BB, Facey DE, Bowen BW. 2009. Early life history. In: The Diversity of Fishes: Biology, Evolution, and Ecology. Blackwell, Chichester, UK.129–147.

Hernandez-Miranda E, Palma AT, Ojeda FP. 2003. Larval fish assemblages in near shore coastal waters off central Chile: temporal and spatial patterns. Estuarine, Coastal and Shelf Science. 56: 1075–1092.

Hossain MM. 1971. The commercial fishes of the Bay of Bengal (survey for the development of fisheries, East Pakistan, Chittagong). UNDP Project publication.No. 1 PAK. 22:1-6.

Hossain MS, Das NG, Chowdhury MSN. 2007. Fisheries management of the Naaf River. Coastal and Ocean Research Group of Bangladesh, Institute of Marine Sciences and Fisheries, University of Chittagong. 267.

Hossain MS. 2001. Biological aspects of the coastal and marine environment of Bangladesh. Ocean & Coastal Management, 44(3e4): 261-282.

Houde ED. 2008. Emerging from Hjort’s shadow. Journal of Northwest Atlantic Fisheries Science 41: 53–70.

Islam MS. 2003.Perspectives of the coastal and marine fisheries of the Bay of Bengal, Bangladesh.Ocean & Coastal Management. 46(8):763-796.

Janekarn V, Boonruang P. 1986. Composition and occurrence of fish larvae in mangrove areas along the east coast of Phuket Island, Western Peninsula, Thailand. Research Bulletin. 44.

Janekarn V. 1988.Biogeography and environmental biology of fish larvae along the West coast of Thailand.A master degree dissertation.The University of Newcastle. 107.

Janekarn V. 1992.Fish larvae in the vicinity of shelf front in the Andaman Sea.In:Proceeding: The Seminar on Fisheries, 16-18 September 1992, Department of Fisheries, Bangkok, Thailand. 343-353.

Kim JY, Lee KS, Kim SS, Choi SM. 2013. Environmental factors affecting anchovy reproductive potential in the southern coastal waters of Korea. Animal Cells and Systems 17: 133-140.

Kwak SN, David WK. 2003. Temporal variation in species composition and abundance of fish and decapods of a tropical seagrass bed in Cockle Bay, North Queensland, Australia.Aquatic Botany. 78: 119–134.

Leis JM and Carson-Ewart BM. 2000. The Larvae of Indo-Pacific Coastal Fishes: An Identification Guide to Marine Fish Larvae. Leiden, The Netherlands: Brill Publisher. ISBN 13: 9789004115774.

Leis JM, Rennis DS. 1983. The larvae of Indo- Pacific Coral Reef Fishes. New South Wales University Press. New South Wales, Australia. 269.

Lirdwitayaprasit P, Nuangsang C, Puewkhao P, Rahman MJ, Sein AW. 2008. Composition, abundance and distribution of fish larvae in the Bay of Bengal. SEAFDEC, Thailand. 93-124.

Magurran A. 2004. Measuring biological diversity.Blackwells; Oxford, UK.

Margalef R. 1958. Information theory in ecology. General Systems. 3: 36–71.

Marichamy R, Siraimeetan P. 1984. Hydrobiological studies in the coastal waters of Tuticorin, Gulf of mannar. Journal of Marine Biological Association of India. 21(1,2): 67-76

Mateo MA, Cebrián J, Dunton KH, Mutchler T. 2006. Carbon Flux in Seagrass Ecosystems.*In:* Larkum D., Robert J. Orth., Carlos M. D.uarte (editors) Seagrasses: Biology, Ecology and Conservation. The Netherlands: Springer.

McAllister DE, John F, Craig, Davidson N, Delany S, Seddon M. 2001. Biodiversity Impacts of Large Dams Background Paper No. 1 prepared for IUCN/UNEP/WCD International Union for Conservation of Nature and Natural Resources and the United Nations Environmental Programme. 49.

McLusky DS and Elliott M. 2004. The estuarine ecosystem: ecology, threats and management. OUP Oxford.

Melville-Smith R, Baird D. 1980.Abundance, distribution and species composition of fish larvae in the Swartkops Estuary.South African Journal of Zoology. 15: 72–78.

Melville-Smith R. 1981. The ichthyoplankton of the Kromme River Estuary.South African Journal of Zoology. 16: 71–72.

MoFA. 2014. Ministry of foreign affairs, press Release: Press statement of the Honorable foreign minister on the verdict of the arbitral tribunal/PCA. Dhaka, 08 July 2014.

Montoya-Maya P, Strydom NA. 2009. A description of larval fish composition, abundance and distribution in nine south and west coast estuaries of South Africa. African Zoology 44(1): 75–92.

Murshed-E-Jahan K, Belton B, Viswanathan KK. 2014. Communication strategies for managing coastal fisheries conflicts in Bangladesh. Ocean & Coastal Management, 92: 65-73.

Nellen W. 1973.Kinds and abundance of fish larvae in the Arabian Sea and the Persian Gulf. In: Zeitzschel, B. (ed.). The Biology of the Indian Ocean Springer-Verlag, New York.415-430.

Pattira LN, Chirat P, Paitoon R, Jalilur UH, Aung UW. 2012. Composition, Abundance and Distribution of Fish Larvae in the Bay of Bengal. The Ecosystem-Based Fishery Management in the Bay of Bengal

Pielou EC. 1966. The measurement of diversity in different types of biological collections. Journal of theoretical biology, 13: 131-144.

Pothoff T.1984. Clearing and Staining Techniques.*In* H.G. Moser, W.J. Richards, D.M.

Qasim SZ. 1977. Biological productivity of the Indian Ocean.

Rajaseker MS, Bragadeeswaran R, Senthilkumar. 2005. Distribution and abundance of fish eggs and larvae in Arasalar estuary, Karaikal, South east coast of Indian Journal of Environmental Biology. 26(2): 273-276

Rashed-Un-Nabi M, Al-Mamun M.A, Ullah MH, Mustafa MG. 2011.Temporal and spatial distribution of fish and shrimp assemblage in the Bakkhali river estuary of Bangladesh in relation to some water quality parameters. Marine Biology Research, 7(5): 436-452.

Rathnasuriya MIG, Mateos-Rivera A, Skern-Mauritzen R, Wimalasiri HBU, Jayasinghe RPPK, Krakstad JO, Dalpadado P. 2021. Composition and diversity of larval fish in the Indian Ocean using morphological and molecular methods. Marine Biodiversity, 51(2):1-15.

Raymond JEG. 1983. Plankton and productivity in the oceans. Vol. 2.Zooplankton.

Rez-Guzman A, Huidobro L. 2002. Fish communities in two environmentally different estuarine systems of Maxico Journal of Fish Biology. 61: 182–195.

Rodriguez JM, Alemany F, Garcia A. 2017. A guide to the eggs and larvae of 100 common Western Mediterranean Sea bony fish species.FAO, Rome, Italy. 256.

Russell FS.1976. The eggs and planktonic stages of British marine fishes. Academic Press, London.

Rutherford ES. 2002. Fishery management. In: Fuiman, L.A., Werner, R.G. (Eds.), Fishery Science. The Unique Contributions of Early Life Stages.Fishery Blackwell Publishing.206-221.

Shamsuzzaman MM, Islam MM, Tania JN, Mamun AAM, Barman PP, Xu X. 2017. Fisheries resources of Bangladesh: Present status and future direction, Aquaculture and Fisheries.

Shannon C, Weaver W. 1949. The mathematical theory of communication. Urbana: University Illinois Press. 117.

Silva MA, Araújo FG, Azevedo MCC, Mendonça P. 2003. Distribuiçãoespacial e temporal de *Cetengraulisedentulus*(Cuvier, 1829) (Actinopterygii, Engraulidae) naBaía de Sepetiba, Rio de Janeiro, Brasil. RevistaBrasileira de Zoologia 20: 577-581.

Somarakis S, Drakopoulos P, Filippou V. 2002. Distribution and abundance of larval fish in the northern Aegean Sea—eastern Mediterranean—in relation to early summer oceanographic conditions. Journal of Plankton Research. 24(4):339-358.

Steele J, Thorpe S, Turekian K. 2001. Encyclopedia of ocean sciences.

Stequert B, Marsac F. 1989. Tropical tuna surface fisheries in the Indian Ocean. FAO Fisheries Technical Paper no. 282: 238.

Strydom NA. 1998. Fish larval dynamics in the mouth region of the Gamtoos Estuary. M.Sc. thesis, University of Port Elizabeth, Port Elizabeth. 104.

Strydom NA. 2003. An assessment of habitat use by larval fishes in a warm temperate estuarine creek using light traps. Estuaries 26(5): 1310–1318.

Strydom NA. 2015. Patterns in larval fish diversity, abundance, and distribution in temperate South African estuaries. Estuaries and Coasts, 38(1): 268-284.

Teod´osio MA, Paris CB, Wolanski E, Morais P. 2016. Biophysical processes leading to the ingress of temperate fish larvae into estuarine nursery areas: a review. Estuarine, Coastal and Shelf Science. 183: 187–202.

Tzeng WN, Wang YT and Chern YT. 1997. Species composition and distribution of fish larvae in Yenliao Bay, northeastern Taiwan. Zoological studies-taipei-. 36:146-158.

Van der Veer HW, Dapper R, Whitte JIJ. 2001. The nursery function of the intertidal areas in the western Wadden Sea for 0-group sole *Soleasolea*(L.). Journal of Sea Resources. 45: 271–279.

Victor BC. 1986. Duration of the planktonic larval stage of one hundred species of Pacific and Atlantic wrasses (family Labridae). Marine Biology. 90(3):317-326.

Webb JF, 1999. Larvae in fish development and evolution.In The origin and evolution of larval forms.109-158.

Whitfield AK. 1999. Ichthyofaunal assemblages in estuaries: A South African case study. Review of Fish Biology and Fisheries 9:151-86.

Wolanski E, Elliott M. 2015. Estuarine ecohydrology: an introduction. Elsevier.

Yoshida HO. 1979. Synopsis of biological data on tunas of the genus Euthynnus.NOAA Technical Report NMFS Circle.429:57.

Young PC, Leis JM, Hausfeld HF. 1986. Seasonal and spatial distribution of fish larvae in waters over the North West Continental Shelf of Western Australia. Marine Ecology Progress Series.209-222.

Zhang L, Zhang J, Liu S, Wang R, Xiang J, Miao X, Zhang R, Song P and Lin L. 2021. Characteristics of Ichthyoplankton Communities and Their Relationship With Environmental Factors Above the Ninety East Ridge, Eastern Indian Ocean. Frontiers in Marine Science 8:764859.

Appendix-1 Operation of fish larvae sampling in the Maheshkhalipara

Month	Date	Month		Flowmeter reading	Interval between flowmeter reading	Volume of water passed (m^3)
		Start	Finish			
Mar,20	3/9/2020	11.31	11.41	R1(87261-88264)	1003	118
		11.45	11.56	R2(88266-89524)	1258	148
		12.01	12.11	R3(89526-92405)	2879	339
Apr,20	4/13/2020	12.15	12.27	R1(99030-101313)	2283	269
		12.35	12.46	R2(102341-103573)	1232	145
		12.52	1.03	R3(103578-105899)	2321	273
May,20	5/11/2020	10.42	10.55	R1(60302-62027)	1725	203
		10.59	11.1	R2(62027- 63547)	1520	179
		11.15	11.27	R3(63547- 65279)	1732	204
Jun,20	6/10/2020	11.05	11.14	R1(99822-101824)	2002	236
		11.21	11.32	R2 (101824-102848)	1024	121
		11.43	11.54	R3 (102848-103482)	634	75
Jul,20	7/9/2020	11.25	11.34	R1 (102848-102998)	150	18
		11.41	11.52	R2 (102998-103189)	191	23
		11.56	12.08	R3 (103189-103505)	316	37
Aug,20	8/12/2020	10.45	10.56	R1 (33792-36414)	2622	309
		11.02	11.15	R2 (36414-38542)	2128	251
		11.21	11.32	R3 (38542-40159)	1617	190
Sep,20	9/11/2020	11.04	11.14	R1 (58275-59589)	1314	155
		11.21	11.32	R2 (59597-60966)	1369	161
		11.37	11.48	R3 (60969-62613)	1644	194
Oct,20	10/16/2020	12.15	12.29	R1 (62615-63693)	1078	127
		12.35	12.47	R2 (63693-64668)	975	115
		12.55	1.09	R3 (64671-65678)	1007	119
Nov,20	11/12/2020	11.18	11.32	R1 (15659-17232)	1573	185

		11.41	11.52	R2 (17232-18774)	1451	171
		11.55	12.08	R3 (18774-20876)	2102	248
Dec,20	12/9/2020	10.31	10.45	R1 (33792-36414)	2622	309
		10.55	11.05	R2 (36414-38542)	2128	251
		11.11	11.22	R3 (38542-40159)	1617	190
Jan,21	1/10/2021	11.17	11.31	R1 (83745-85454)	1709	201
		11.35	11.46	R2 (85454-86620)	1166	137
		11.55	12.09	R3 (86620-88006)	1386	163
Feb,21	2/19/2021	12.05	12.16	R1 (15659-17232)	1573	185
		12.21	12.32	R2 (17232-18774)	1542	182
		12.4	12.55	R3 (18774-20876)	2102	248

Appendix-2 Temporal variation of biodiversity index at Maheshkhalipara

Month	Diversity index	Richness	Evenness
Mar	1.916	2.606	0.985
Apr	0.598	0.514	0.863
May	0.44	0.311	0.634
Jun	0.178	0.184	0.256
Jul	0.958	0.34	0.872
Aug	0.108	0.193	0.155
Sep	0.875	0.645	0.631
Oct	0.349	0.234	0.503
Nov	0.759	0.6	0.691
Dec	0	0	0
Jan	0.139	0.24	0.201
Feb	0	0	0

PHOTO GALLERY

Plate 1. Sampling by bongo net

Plate 2. Sample collection

Plate 3. Sample collection

Plate 4. Fish larvae sorting from sample

Plate 5. Larvae identification under stereo microscope

Plate 6. Larvae labeling and storage

Plate 6. Clupeidae larvae

Plate 7. Ambassidae larvae

Plate 8. Engraulidae larvae

Plate 9. Gobiidae larvae

Plate 10. Hemiramphidae larvae

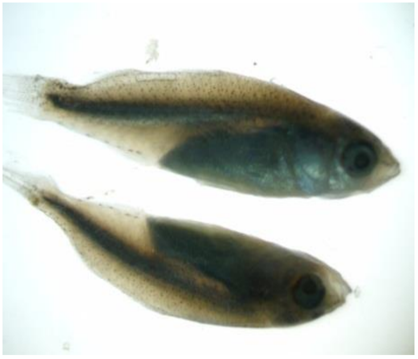

Plate 11. Mugilidae larvae

Plate 12. Siganidae larvae

Plate 13. Pomacentridae larvae

Plate 14. Terapontidae larvae

Plate 15. Sparidae larvae

Plate 16. Gerreidae larvae

Plate 17. Carangidae larvae

Plate 17. Tetradontidae

Plate 18. Serranidae

Plate 19. Unidentified

Plate 20. Larvae preservation