# CHAPTER-1

# INTRODUCTION

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The larval stage of most marine fish is a brief phase within their overall life cycle, beginning at hatching and ending when they transform into juveniles. During this stage, teleost fish are typically in a planktonic state (Bailey and Houde, 1989; Houde, 1997). The abundance of larval fish is influenced by meteorological, environmental, oceanographic, and seasonal factors (Hernández-Miranda et al., 2003). Researchers have devoted significant attention to study the number, dispersion, distribution, and recognition of fish larvae (Nagel et al., 2021). Several factors, including water temperature, flow, turbidity, depth, physical and chemical indicators, and waterbody dynamics, affect the composition of larval fish or ichthyoplankton assemblages (Song et al., 2019). Understanding these factors is crucial in fish ecology research, as they provide insights into the prediction of early life stage survival and its impact on economically and ecologically significant fish populations (Llopiz et al., 2014; Wu et al., 2019). Understanding the effects of rising temperatures, ocean acidification, and rising $CO_2$ concentrations, as well as the temporal, spatial, and magnitude variations in secondary production and reproduction, and the synergistic effects of fishing and climate change, have been the primary areas of focus in recent years for the study of fish early life histories (Medeiros et al., 2018). It is crucial to look at the spatial and temporal distribution of fish larvae and how they react to environmental variables in order to better understand the recruitment process and supplement adult fish populations (Saunders et al., 2002). The dynamics of fish populations during the early life stages significantly impact the adult fish population (Amarullah, 2008).

Oceans are essential parts of earth's metabolism and play a significant influence in socioeconomic and environmental changes on a global scale. They sustain productive economies, contain a major amount of earth's biodiversity, provide essential life-supporting ecosystems, and contribute to global food security (Gattuso et al., 2018). Understanding the status of fish larvae and juveniles is essential for assessing the impact of climate change and the environment on marine ecology (Yen et al., 2022). The population dynamics of fish larvae are influenced by migration and movement patterns (Amarullah, 2008). The occurrence and settlement of fish larvae in specific areas can serve as a key indicator of increasing fish populations (Levin, 1994). Additionally, the size of fish larvae and the mixture of different growth stages provide insights into spawning locations and timing (Tarimo et al., 2022), while abundance patterns reflect the populations of spawning stocks (Koslow and Wright, 2016). The proportion of different developmental phases in fish larvae indicates survival rates and future fish recruitment (Bergenius et al., 2002). Comparing the distribution, density, and habitat characteristics of fish species enables the evaluation of specific relationships between environmental conditions and larval survival (Gonzalo et al., 2023). The larval phase is a critical stage in fish development and plays a significant role in determining the sustainability of biological resources in both marine and freshwater fisheries. Fish larval stocks are crucial for the conservation of fish resources, as disruptions in the early stages of fish life can negatively impact adult fish populations (Purnomo et al., 2020). The recruitment of fish larvae has direct implications for both fish populations and human welfare (Whitney et al., 2021). The production of larval fish and their dispersal capacity are major factors in generating sustainable fish stocks and acting as a buffer against fishery collapse (Caley et al., 1996; Ramesh et al., 2019).

Inland fisheries and marine fisheries are two of the many types of fisheries resources in Bangladesh. Bangladesh obtained approximately 118,813 $km^2$ of sea area as a result of an International Arbitration Court (IAC) decision in a dispute involving Myanmar and India. This contains a 350 nautical mile continental shelf, a 200 nautical mile exclusive economic zone, and 12 nautical miles of state-owned marine area (Islam and Shamsuddoha, 2018). Bangladesh's coastal and marine zone is one of the largest in the world with a huge ecosystem and considerable mangrove areas. Marine fisheries resource contributes to roughly 14.83% of total fisheries production, playing a significant role in the economy of the nation (DoF, 2022). In total, there are 740 species of marine fish belonging to 389 genera and 145 families in Bangladesh (Habib and Islam, 2020). While Bangladesh's coastal zone contains numerous estuaries and complex ecosystems within natural and planted mangrove forests, there is limited knowledge regarding the diversity of fisheries and the factors influencing their distribution and abundance (Ahammad, 2004). Although some studies have explored various biological aspects of the coastal estuarine system, few have specifically investigated the composition of species assemblages (Hossain et al., 2007; Nabi et al., 2011).

Short-term assessments of larval abundance will not accurately represent changes over time (Ratcliffe et al., 2021). Therefore, it is necessary to conduct yearlong larval abundance assessment programs to understand the patterns and trends of marine fish larval abundance in coastal areas. This information will aid in identifying key habitats and spawning areas for fish, thereby enhancing understanding of the relationship between fish larval abundance and physiochemical parameters. Additionally, there are scopes of research in the taxonomic identification of marine fish larvae in Bangladesh. There is necessity of more comprehensive investigations to identify various types of fish larvae and determine their spawning, nursing, and potential drifting areas. Considering these research scopes and opportunities, the present study aims to investigate fish larval abundance and diversity in five distinct areas along the Cox's Bazar coast, considering spatial and temporal scales. The study will also examine the relationship between fish larval abundance and oceanographic conditions, particularly temperature, pH, alkalinity, and salinity. The hypothesis of this study was to determine whether there are significant differences in the diversity and abundance of fish larvae across different locations and time periods, and how oceanographic conditions affect their diversity and abundance. The findings of this research will provide valuable insights into the early life stages of commercially important fish species, potential spawning and nursing grounds, and habitat conditions in the coastal areas of Cox's Bazar. Such studies are critical for bridging existing knowledge gaps and obtaining essential information for fisheries management and conservation purposes. Ultimately, this research can contribute to the development of effective ecosystem-based fisheries management in Bangladesh's maritime areas.

### 1.1 Objectives of this study

- To observe the abundance and diversity of fish larvae in five distinct areas along the Cox's Bazar coast, considering both spatial and temporal scales.
- To investigate how fish larvae abundance and diversity are influenced by environmental variables in the natural environment of the study areas.

## 1.2 Scopes of this study

The exploration of the marine fisheries of Bangladesh is at the beginning till now. The enormous marine fisheries resource, stocks, spawning grounds, nursing grounds, fishing grounds, migratory routes, etc. are yet to be explored and managed. Such studies on fish larvae diversity and abundance pave the way for deeper investigation and management of the marine fisheries resource of Bangladesh. Expected findings and subsequent information of this research may facilitate current and future researchers of the fisheries sector.

# CHAPTER: 02

# REVIEW OF LITERATURE

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## 2.1 Larval stage of fish

The life cycle of fish encompasses distinct stages, including the embryonic, larval, and juvenile stages. The abundance of fish populations is closely tied to the quantity and survival rate of early life stages (Ellis and Nash, 2010). Among these stages, the larval phase stands out as a critical but precarious period, marked by significant transformations in the morphological, physiological, and ecological traits. The survival and abundance of larvae serve as the foundation for replenishing fish stocks and ensuring their sustainable exploitation (Wan and Sun, 2006). Understanding the life cycle of fish necessitates the identification and study of their early larval stage (King, 2010). During this phase, the organs of fish are not fully developed, and the larvae exhibit limited mobility, relying heavily on water currents for movement (Jatmiko et al., 2018). The larval stage of fish, situated between hatching and scale development, morphologically resembles adult fish (Leis and Carson-Ewart, 2000). The stage of fish larval metamorphosis or recruitment is that in which pelagic-stage fish larvae transform into settling or prerecruit juvenile phase (Eble et al., 2011). Oviparous fish species, which constitute over 97% of all fish, lay eggs from which the offspring emerge and develop separately from the mother's body (Dulvy and Reynolds, 1997). Following hatching, fish larvae progress through various developmental stages, including the egg yolk stage, preflexion, flexion, and postflexion, before moving on to the recruitment or transformation phases (Leis and Carson-Ewart, 2000). Before transferring into suitable environments, the majority of tropical fish larvae of coastal species remain for 35 to 70 days as planktonic larvae. Mass mortalities of fish occur during the yolk sac stage and immediately after yolk sac depletion, when larvae begin feeding on prey (Garrido et al., 2015).

The upper 200 meters of the water column is the habitat of the bulk of marine fish larvae (North and Murray, 1992; Koslow and Wright, 2016). Fish larvae's presence and settling in particular places can be important indications of population expansion (Levin, 1994). The dynamics of fish populations during the early stages of life significantly influence the dynamics of adult fish populations (Amarullah, 2008). The larval stage has been identified as a crucial time for the success of marine fish reproduction. Primary determinants of recruitment and adult population size are the survival of individuals during this early stage and their subsequent transportation to nursery regions favorable to survival and growth (Bailey and Houde, 1989; Houde, 1997). Research on fish larval diversity and abundance is therefore essential for comprehending the initiation of the fish species' life cycle.

## 2.2 Importance of fish larval abundance and diversity in fisheries

The larval phase of fish holds immense significance within the life cycle and plays a crucial role in determining the sustainability of both marine and freshwater fisheries. The presence and survival of fish larvae greatly contribute to the conservation of fish resources and the overall stock dynamics. While much attention has been given to studying fish populations in the adult stage, it is essential to consider the success of early life history in stock enhancement efforts. The viability of various fishery commodities relies heavily on the survival of fish during their larval phase. Any disruptions during these initial stages can have detrimental effects on adult stock abundance (Purnomo et al., 2020). The recruitment of early life stages is closely related to effective fish stock management (Somarakis et al., 2019). The ability of larval fish to produce and disperse considerably aids in the development of sustainable fish stocks and serves as a safety net against the collapse of fisheries (Caley et al., 1996; Ramesh et al., 2019). Only a tiny percentage of fish (1:100,000) survive to adulthood, with substantial mortality rates during the early phases of their lives (Houde, 2008). In order to sustain healthy fish stocks, it is crucial to ensure the survival and welfare of fish larvae (Le Pape and Bonhommeau, 2015). Therefore, human welfare and the dynamics of fish populations are directly impacted by the recruitment of fish larvae (Whitney et al., 2021).

The availability of their prey, zooplankton, and the surrounding environment has a significant impact on fish larvae's ability to survive (De Figueiredo et al., 2005). Therefore, for efficient management of fisheries, an understanding of fish distribution trends and the factors controlling larval production is essential (Hare, 2014). Since the turn of the 20$^{th}$ century, a lot of attention has been paid to the study of fish larvae and how they affect adult stock growth (Govoni, 2005; Houde, 2008). Long acknowledged as being essential in controlling fish stock size, the processes and mechanisms determining recruitment patterns and variability in fish larvae populations (Brosset et al., 2020). Understanding the components that influence the composition of larval fish communities requires an understanding of the distribution and composition of fish larvae (Galacatos et al., 2004). Insights for production and management methods can be gained from the detection of geographical and temporal fluctuations in larval abundance and composition over a wide area by conducting ichthyoplankton surveys (Gullstrom and Dahlberg, 2004). In addition to being crucial for fisheries management, fish or ichthyoplankton in specific waterways can be observed to help monitor aquatic habitats. Studying larval diversity and survival rates of economically important species continues to be a crucial field of research in fisheries science because of the susceptibility of fishes during the egg and larval stages (Kawaguchi, 2003).

Understanding areas with high levels of biological diversity and richness, as well as the oceanographic variables that promote such biodiversity is crucial. Species-rich ecosystems are regarded to be more stable and less prone to collapse than ecosystems with few species (Bakun, 2006). Increased biodiversity has a positive effect on ecological stability, enhanced fisheries yield, nitrogen cycling, and resource use efficiency (Rocha et al., 2015). The early stages of life for the majority of marine fishes, including the egg and larval phases, are extremely short but vital. Rapid development and high mortality are characteristics of these stages (Bailey and Houde, 1989). These phases are usually the only times in the upper ocean layer that fish species with various life histories and adult habitats can coexist to form multispecies assemblages (Moser and Smith, 1993). Quantifying the extent and composition of these ichthyoplankton assemblages can provide information on reproductive biomass, reproduction effort, and potential recruitment success of significant species (Govoni, 2005; Auth et al., 2011). Studies on the distribution and availability of ichthyoplankton give essential knowledge on the places and periods where different fish species spawn (Selvam et al., 2013). Information on fish eggs and larvae aids in the identification of vital spawning locations that require conservation for the long-term survival of fragile fish populations (Sala et al., 2002). Additionally, fisheries-independent indices of ecosystem health and ichthyoplankton surveys can be used to calculate species-specific spawning biomass and overall reproductive strategies (Auth et al., 2018). For the management and oversight of these resources, research on the early stages of fish growth is also crucial (Zacardi et al., 2017).

### 2.3 Water quality, environment and fisheries biodiversity

Early life history of fish is a key factor in resource study before resources being recruited to the fishery (Watson et al., 2018). Environmental changes during this period can have significant impacts on the fluctuations in fishery resources (Houde, 2001), potentially affecting future additions to fish stocks (Lo et al., 2014). Numerous environmental factors, including temperature, salinity, the amount of prey, competition, and ocean currents, are known to have an impact on the abundance and dispersion of fish larvae and juveniles (Leis, 2006). Studying fish larvae in the local waterways is essential for managing fishing resources properly (Yen et al., 2022). The natural and predation mortality of larvae is significantly influenced by the marine environment (Li et al., 2009). Successful larval recruitment depends on the sensory acuity of temperate fish larvae and their behavioral response to estuarine cues in coastal areas (Teodósio et al., 2016) which may be able to control the larvae's dispersal depending on their developmental stage (Baptista et al., 2019).

Current understanding indicates that the interplay of active larval behavior and passive drift caused by physical factors likely affects the geographic distribution of larval fish. Several physical and biological processes operate at different scales and influence larval distributions; at larger dimensions, physical activities have a bigger influence on structuring biological patterns, whereas, at smaller scales, biological processes take the lead (Daly and Smith, 1993). Additionally, differences in larval mortality from predation and starvation may have an impact on the spatial distribution of larval abundance (Frank et al., 1993; Bradbury et al., 2003). The early life stages of fish represent a highly vulnerable phase, with fish larvae experiencing substantial mortality, often exceeding 90% (Houde, 1994). Both abiotic and biotic factors can influence the survival and abundance of fish larvae, leading them to seek suitable habitats that maximize their chances of survival (Roseman et al., 2005). Among the abiotic factors, temperature is of particular concern, as elevated environmental temperatures can result in increased metabolic rates, higher growth rates, and lower mortality (Rankin and Sponaugle, 2011). Biotic factors, including predation and competition for resources, both between species and within species, play a crucial role in shaping the complexity of fish larval assemblages (Hindell et al., 2000). Consequently, spatial distributions of fish larvae are non-random (Prchalova et al., 2009). In addition to temperature, physical conditions such as salinity, turbidity, and freshwater input can influence the abundance of larvae and juvenile fish, with variations occurring over time due to seasonal changes (Barletta et al., 2000). However, in tropical estuaries characterized by relatively stable annual temperature patterns, factors other than temperature, such as salinity and freshwater input, become important determinants of larval fish occurrence (Barletta-Bergan et al., 2002). The availability of nutrients and sufficient feed concentration is crucial for the survival and distribution of fish larvae (Lampert et al., 2003). The level of larval movement plays a significant role in their survival and distribution patterns (Hare and Govoni, 2005).

The relationship between temperature and recruitment in fish populations is complex and species-specific, making it difficult to establish robust connections (Sponaugle et al., 2006). Furthermore, recruitment, which occurs at different points in the early life stages of different species, is often determined differently (Leggett and Deblois, 1994). While the spawning patterns can be predicted based on temperature relationships, recruitment is not easily predictable (Llopiz et al., 2014). In tropical estuaries, annual patterns are rather stable, therefore other factors besides temperature affect the predominance of larvae. According to research, salinity and freshwater imports have a considerable impact on the relative abundance of larval fish species in tropical estuaries (Morais and Morais, 1994). Similar findings have been reached about how freshwater imports affect the communities of ichthyofauna in tropical estuaries by Albaret and Ecoutin (1990). Salinity and turbidity are important variables that determine the quantities of larval fish (Whitfield, 1994). Through a variety of tidal flux-related characteristics, certain places may serve as cues for fish larvae (Boehlert and Mundy, 1988). But each species reacts differently to environmental factors (Tzeng and Wang, 1992). Researchers can gain insight into the dynamics of fish larval and planktonic populations, ultimately assisting in effective management and conservation efforts in coastal ecosystems, by comprehending the intricate interactions between environmental changes, biophysical conditions, and oceanographic processes.

## 2.4 Relation of fish larval abundance with season and area

Fish larval community structure is significantly influenced by seasonality (Sabates, 1990). The seasonal patterns of fish larvae abundance are directly related to adult population reproductive methods and the various stages of their life cycles. These factors are frequently linked to oceanographic and meteorological aspects (Hernandez-Miranda et al., 2003). The "match/mismatch hypothesis" (Cushing, 1990) is a coupling mechanism between life strategies that are reflected in these seasonal patterns. Depending on latitude and spatiotemporal scales, oceanographic conditions have different effects on fish larval and planktonic populations (Guan et al., 2018). Seasonality has a significant impact on shallow-water coastal habitats in high-latitude oceans, especially during the winter and summer, but has little impact in tropical locations due to the small seasonal temperature fluctuations and heat influx (Shi et al., 2020). Monsoon seasons, which are brought on by prevailing monsoon winds, have a significant impact on tropical shallow-water coastal ecosystems (McClanahan, 1988). The onset of the reproductive phase in spring and summer spawners affects the number and diversity of fish larvae during warm, high-salinity months (Palomera and Olivar, 1996). These winds affect both abiotic elements such as nutrients, salinity, pH, and dissolved oxygen in coastal waters as well as oceanographic variables such as sea surface temperature, precipitation, tides, and currents (Subina et al., 2012).

The abundance of fish larvae of estuarine species tends to peak in the spring, summer, and the beginning of fall and is at its lowest in the winter in temperate and subtropical estuaries (Neira and Potter, 1994). The utilization of shallow-water coastal habitats by fish larvae plays a crucial role in their development and subsequent recruitment to adult populations (Polte and Asmus, 2006). Many fish species spawn in these coastal areas, and their offspring actively migrate or drift to nursery habitats shortly after the planktonic phase (Teodósio and Garel, 2015). Mangrove and seagrass habitats are particularly important as nursery grounds in tropical waters, providing favorable conditions for the early stages of fish larvae development and settlement (Ogden et al., 2014; Whitfield, 2017). Limited investigation has been done on how fish larvae exploit mangroves and seagrass meadows, despite the significance of these coastal seascapes. The distribution and composition of fish larvae in these habitats are influenced by the abundance of prey, the complexity of the habitat, and changing physical and biogeochemical water properties, which in turn affect their survival, growth, and subsequent mature reproduction (Ara et al., 2016; Costa et al., 2020). Therefore, studying fish larvae dynamics in coastal seascapes is essential but complex, requiring information on spatial and temporal scales.

### 2.5 Bangladesh perspective

Bangladesh is situated in the northeastern region of South Asia and shares borders with India, Myanmar, and the Bay of Bengal. Her land area spans 147,570 square kilometers (Siwakoti et al., 2021). The country experiences distinct seasons, namely winter, summer, and monsoon. Winter, occurring from November to February, is characterized by minimum temperatures reaching 7ºC, while summer temperatures can soar up to 37 ºC. This season accounts for 80% of the annual rainfall, which typically ranges from 1429 to 4338 mm (Siwakoti et al., 2021). Bangladesh boasts a coastal belt extending 710 kilometers. The fisheries sector plays a significant role in the nation's economy, contributing 2.08% to the national GDP, 21.83% to the agricultural GDP, and over 1.05% to total export earnings. In the 2021-2022 period, the total fish production amounted to 47.59 lakh metric tons. This sector plays a vital role in ensuring food security by providing safe and high-quality animal protein, with fish fulfilling approximately 60% (62.58 g/day/capita) of the daily dietary requirement for animal protein (DoF, 2022). The fisheries sector in Bangladesh confronts various challenges arising from natural and human-induced factors, including climate change, environmental pollution, industrialization, overexploitation, and the use of harmful fishing equipment, pesticides, and agrochemicals. These factors have led to the extinction of commercially important species, with 09 as critically endangered (CR), 30 as endangered (EN), 25 as vulnerable (VU), 27 as not threatened (NT), 122 as least concern (LC), and 40 as data deficient (DD) in terms of their biodiversity status (IUCN, 2015). To address these challenges and promote biodiversity conservation, several measures have been recommended. These include the improvement of the Fish Regulation Act of 1950, the development of Hilsa fishery management technology, beel nurseries, fingerling stocking, fish habitat rehabilitation, breeding ground conservation, pen culture, and improved biological management techniques for fish sanctuaries. These actions have the goal of reducing the use of resources, increasing production, and promoting population expansion (Chakraborty, 2021). Bangladesh is blessed with a large coastline and marine area, as well as some of the world's most notable mangrove forests. About 14.83 percent of the overall fisheries production of the country comes from marine fisheries (DoF, 2022). However, there has been a noticeable decline in marine fisheries production over the previous 19 years, with species including Indian salmon, sharks, sea catfish, jewfish, and other marine fish being particularly affected.

Among these species, Bombay duck (*Harpadon neherius*) has exhibited the highest yield from marine fish harvest, surpassing Indian salmon (*Eleutheronematetra dactylum*), pomfret (*Pampus argenteus*), catfish, and jewfish (Shamsuzzaman et al., 2020). While inland culture fish output is increasing, the production of marine fish increased by a mere 1.7% between 2005 and 2020, In 1984, the total marine capture was 0.164 million metric tonnes, which rose to 0.671 million metric tonnes by 2020 (DoF, 2022).

The marine fish species directory for Bangladesh possesses 740 distinct marine fish species, which are categorized into 145 families, 30 orders, and 389 genera. Among these, 53.38% are solely found in marine environments and 46.62% are found in both brackish and marine waters. On Saint Martin's Island, 204 of the 296 species linked to reefs have also been discovered. Additionally, 271 species of marine and/or brackishwater fish are supported by the Sundarbans mangrove environment and the neighboring sea area (Habib and Islam, 2020). According to the IUCN Red List, 7% of Bangladesh's total marine fish species have been classified as threatened. However, the IUCN has not yet evaluated the local conservation status of marine fish species in Bangladesh, which is a critical issue that needs to be addressed (DoF, 2022). The Bay of Bengal (BOB) holds significance as a marine ecosystem within the global ocean, characterized by moderate productivity due to the absence of large-scale seasonal upwelling (Madhupratap et al., 2003). It is a land-locked ocean in the north and experiences influences from seasonally reversing monsoon winds. The northern region of the BOB exhibits low sea surface salinity, primarily attributed to heavy monsoonal precipitation (Shankar et al., 2002). Major rivers such as the Ganga, Brahmaputra, and Irrawaddy contribute substantial freshwater inflow to the BOB (UNESCO, 1988). These riverine outflows create stable stratification in the upper layers of the northern BOB, forming a distinct "barrier layer" during the summer monsoon and post-summer periods, which hinders nutrient replenishment from deeper waters. The presence of this barrier layer, along with hydrographic characteristics, significantly influences biological productivity (Vinayachandran et al., 2002). In general, the BOB is considered to have lower biological productivity compared to the Arabian Sea, its western counterpart. While the rivers transport nutrients, it is believed that these nutrients become depleted in deeper waters due to the narrow shelf (Qasim, 1977). Previous studies in the BOB have primarily focused on seasonal variations in primary production, as well as the composition and abundance of mesozooplankton (Madhupratap et al., 2003). However, little is understood about the variety and number of fish larvae in this region. Understanding ecosystem dynamics and fisheries management in the BOB is crucial for promoting sustainable fishing practices. More research is necessary to determine the abundance and composition of fish larvae in the BOB in order to develop effective ecosystem-based fishery management approaches. This will enable us to comprehend the early life stages of commercially important fish species. Conducting studies on fish larvae abundance and distribution in the BOB is critical for bridging the existing knowledge gap and obtaining valuable information for fishery management purposes. Additionally, comprehending the ecological conditions and their impact on fish larvae can provide insights into the early stages of fish species, facilitating the formulation of effective ecosystem-based fishery management strategies.

## 2.6 Challenges and research need in fisheries biodiversity assessment and management

Temporal variations in fish populations and the composition of fish assemblages occur at different scales, influenced by both external forcing and internal biological processes (Collie et al., 2008). These variations are driven by anthropogenic exploitation, environmental fluctuations, and climate change, which pose significant threats to fish populations and their ecosystems (Guan, 2015). It is crucial to understand these external perturbations and their impacts on fish populations for effective management and conservation strategies. Due to the dynamic nature of mesoscale characteristics and accompanying conditions in pelagic environments, it might be difficult to demarcate places with significant biodiversity (Marchese, 2015). Ecology and oceanography must be integrated into management strategies for pelagic habitat management (Lewison et al., 2015). Knowledge of biological communities in pelagic habitats is still inadequate, despite the growing appreciation for the value of biodiversity (Mittermeier et al., 2011).

The detrimental effects of habitat degradation on fisheries serve as a reminder of the necessity for coastal conservation efforts (Khamis et al., 2019). Increasing the survival rate of fish larvae is an important conservation objective due to its direct impact on fish production (Silva et al., 2017). Understanding the link between spawning and nursery environments in fish larval dispersal is crucial for conservation and restoration efforts in coastal seascapes (Carlson et al., 2021).

When establishing marine reserves, habitat connectivity, and fish larval dispersal patterns are usually taken into consideration (Balbar and Metaxas, 2019). Through coastal marine reserves, fish populations are controlled and biodiversity is safeguarded (Gaines et al., 2010). They contribute to habitat preservation and improved larval fish production by aiding larvae spread to non-protected areas and encouraging suitable larval settlement locations (Baskett and Barnett, 2015).

Emphasizing the importance of physical water features in larval retention, settling, and distribution across habitats, especially for the design of marine protected areas (MPAs), it is important to comprehend the distribution and dispersal patterns of fish larvae (Green et al., 2015). To gain insights into the distribution and conservation of fish larvae in pelagic ecosystems, it is essential to consider external forcing factors, ecological processes, and habitat connectivity. Integrating disciplines such as ecology, oceanography, and conservation biology is crucial for the effective management of fish populations, biodiversity protection, and sustainable fisheries in these interconnected ecosystems. The identification of larval fishes at the species level requires taxonomic expertise, making collected data highly valuable. Larval fish assemblages in a region are measured using data on larval identification, which includes current monitoring efforts at coastal oceanographic reference stations. This type of database serves as a clearinghouse for surveys of larval fish and can help with the investigation of changes in marine fish spawning patterns brought on by the changing environment (Smith et al., 2018), The larval and egg stages of marine organisms, including fish, are referred to as ichthyoplankton because of their significance in population recovery and individual connection (Lefevre and Bellwood, 2015).

Ichthyoplankton, as part of the zooplankton community, is subject to ongoing research as it provides valuable insights into the biology, ecology, and distribution patterns of fish species in their adult stages. Furthermore, ichthyoplankton contributes to energy flow processes and overall ecosystem stability (Montagnes et al., 2010; Zhou et al., 2011). Despite their importance, knowledge gaps exist regarding the taxonomy and ecology of ichthyoplankton in various regions worldwide, including tropical coastal zones, primarily due to taxonomic complexities (Neira et al., 1998). The investigation of fish's early life history, particularly the larval stage, has been a focus of research for many years, leading to significant progress in understanding factors that influence larval survival. However, recent studies have shifted towards examining the consequences of climate change and other human-induced stressors on fish's early life stages (Llopiz et al., 2014). It is crucial to understand these effects to produce baseline estimates of biodiversity and assemblage structure and to assess how changing environmental conditions affect larval fish assemblages in maritime habitats. The study of ichthyoplankton, which includes the number, spreading, distribution, and recognition of fish larvae, continues to be crucial to understand fish ecology (Nagel et al., 2021). The regional distribution of larval fish assemblages is influenced by several factors, including water temperature, turbidity, depth, velocity, physical and chemical indicators, and river dynamics (Song et al., 2019). The geographical and temporal patterns of fish species distribution alter as a result of habitat variability at regional and larger global scales (Stacy-Duffy et al., 2021). Understanding the number and distribution of fish larvae is crucial for studying the life history of fish and putting effective fishery management practices into action. While there is some understanding of fish larvae in the Indian Ocean's coastal sections, there is little data on their distribution and abundance in the BOB's offshore areas. Therefore, research on fish larvae distribution and abundance in the eastern, northern, and western portions of the BOB is necessary.

This study is important because it investigates how marine fish larval abundance changes seasonally and spatially in response to physicochemical factors along Bangladesh's Cox's Bazar Coast. By examining the quantity and dispersion patterns of fish larvae in the Cox's Bazar coastal region, this study fills a significant information gap. The study offers important insights into the ecological dynamics of marine fish populations in this region by studying the impact of physicochemical parameters on larval abundance. This study's usefulness to conservation and management activities is one of its most important attributes. In Cox's Bazar Coast, developing effective conservation plans and sustainable fisheries management practices can be aided by an understanding of the variables that influence fish larval abundance.

The research gives information on the potential impacts of climate change on fish populations in Cox's Bazar Coast by examining the response of fish larvae to several environmental factors. This study's implications for ecosystem health indicators are another important component. Indicators of the overall productivity and well-being of marine ecosystems include fish larvae. The study offers insights into the current condition of the Cox's Bazar Coast ecosystem by examining their abundance and dispersion patterns. These results help us understand how ecosystems function and can be used to monitor and evaluate the condition of the local marine environments. Finally, the results of this study have applications for fisheries management plans. Stakeholders may determine the best periods and locations for fishing by looking at the seasonal and spatial dynamics of fish larval abundance. This knowledge can be used to improve fishing methods, avoid overfishing, and save vital spawning and nursery areas. The research results give the Cox's Bazar Coast sustainable fisheries management a scientific foundation, enhancing local populations' quality of life and ensuring the fisheries sector's long-term survival.

# CHAPTER: 03

# MATERIALS AND METHODS

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## 3.1 Study area

The probability of fish larvae occurrence remains high in the estuarine and nearshore areas because of shelter and nutrient availability (Arevalo et al., 2023). Therefore, 05 sampling areas were selected based on their location in the nearshore and estuarine regions of the Cox's Bazar coast. The sampling stations were Moheshkhali Para, Naf River Estuary, Bakkhali River Estuary, Rezukhal Estuary, and St. Martin respectively (Figure-01).

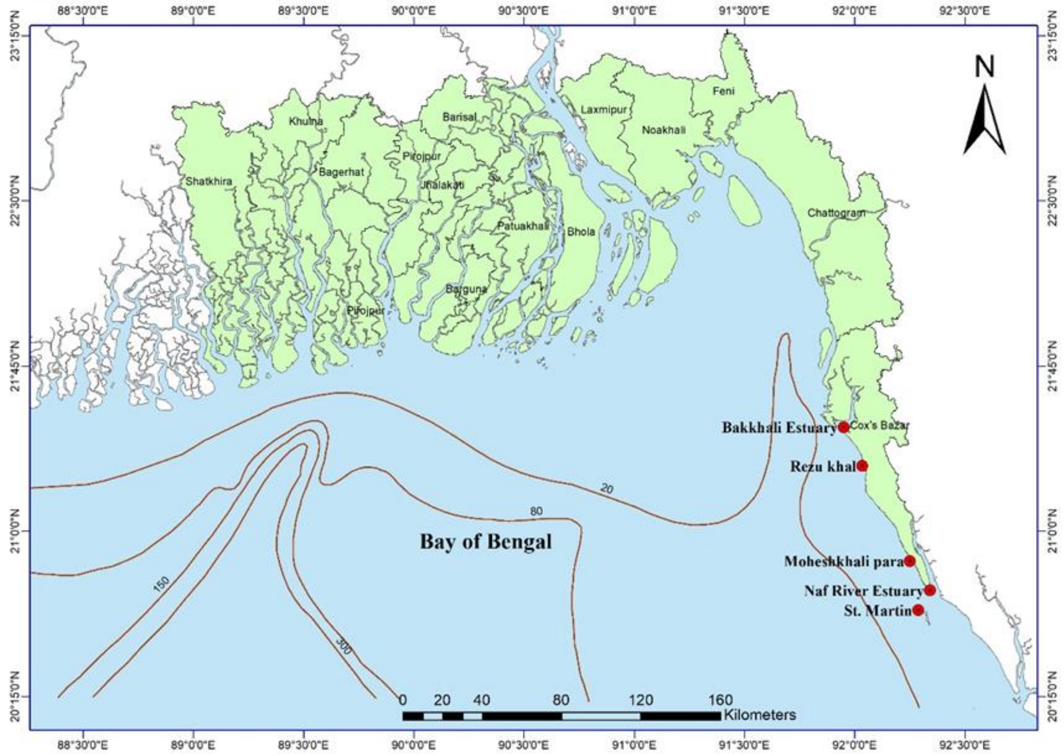


**Figure-01:** Five sampling stations of the study area

### 3.2 Sampling of fish larva

The sampling was done once a month after full moon for 3 seasons (Summer: March–June, Monsoon: July–October, and Winter: November–February) over 12 months in 2022. A bongo net with a 0.50 m mouth diameter, 1.3 m length, and 500 µm mesh at the body was used for collecting larval fish. To measure the volume of water flowing through the net, a flow meter (Model: KC Denmark A/S 23.090-23.091) was fastened within the opening of the net. A traditional fishing boat at a speed of about 2 km/h was used for sampling purposes. A typical fishing boat traveling at a speed of roughly 2 km/h was employed for sampling, The net towing period was set at roughly 10 minutes per location. Samples were taken in triplicates from each site. The larval samples were collected in sample jars, kept in 90% ethanol, and then brought to the lab for additional classification and identification (Plate-02).

### 3.3 Water quality measurement

During each sampling in the five sites, information on the water quality variables: Temperature ($^{0}$C), pH, Alkalinity (mg/L), and Salinity (ppt) were collected in addition to the larvae samples (Pate-02). The parameters were measured using a digital thermometer (APC), a pH meter (YSI pH100A), an alkalinity kit (APC), and a refractometer (ATC) respectively.

### 3.4 Larval identification

#### 3.4.1 Sorting and grouping

Fish larvae from the collected samples were separated to taxonomically identify them. The sample jars' ethanol was first removed. To get rid of plastic, leaves, sand, and other undesired things, the larvae samples were thoroughly rinsed with distilled water. The cleaned larval samples were then sorted according to their external appearance, and they were then put back into sample jars with 90% ethanol for further examination (Plate-03).

### 3.4.2 Morphological identification

The collected fish larvae were classified in the laboratory to the family level through morphological investigations. A stereo-microscope (OPTIKA ITALY C-B3) was used to morphologically identify the collected larval fish. The identification was based on descriptions of related taxa provided by Leis and Rennis (1983), Ozawa (1986), Leis and Carson-Edwart (2000), and Rodriguez et al. (2017). Samples that were too difficult to identify morphologically were categorized as "unidentified" (Plate-03).

### 3.5 Determination of larval abundance

The number of total fish larvae found in each sample was normalized to the number of larvae collected per 1,000 $m^3$ water (Equation-01). Total abundance (%) and relative abundance (%) of larvae family was determined (Equation-02 and Equation-03).

**Equation 1: Volume of water passed in each sampling ($m^3$)** = Indicated number of revolutions in flowmeter × Pitch of the impeller (0.3) × Net opening area ($m^2$) × 1000

**Where,**

Diameter of Bongo net, d= 0.50 m

So, net radius, r = 0.25 m

Net opening area = $\pi r^2 = 3.1416 \times (0.25)^2 = 0.19635 \times 2 = 0.3927$; as each net has two openings

Number of fish larva per 1000 $m^3$ = $\frac{\text{Number of larvae in each sample} \times 1000}{\text{Volume of water passed } (m^3)}$

**Equation 2: Total abundance (%) of family =** $\frac{n}{N} \times 100$

**Where,**

n = number of individuals in each fish family

N = number of total individuals

**Equation 3: Relative abundance (%) of family** = $\frac{N_a}{N_s} \times 100$

$N_a$ = Number of individuals of a family in a particular area

$N_s$ = Number of total individuals of that family

**3.6 Determination of the ecological indices**

Different ecological indices were used to determine the diversity, richness, and evenness of fish larvae in the targeted areas. The indices include Margalef's richness index (Margalef, 1958), Shannon-Weiner diversity index (Shannon and Wiener, 1949), Simpson's Index (Simpson, 1949), and Pielou's evenness index (Pielou, 1966) (Equation- 04, Equation-05, Equation-06 and Equation-07).

**Equation 4: Margalef's richness index,** $D_{Mg} = \frac{S-1}{\ln N}$

**Where,**

N = Total number of individuals in the sample

S = Number of family or species recorded

**N.B:** Values of the Margalef's index range from 0 to 8 and higher values indicate a higher diversity of species. A value of 0 indicates a very low diversity of species, while a value of 8 or greater indicates a very high diversity of species.

**Equation 5: Shannon-Weiner diversity index,** $H = -\sum Pi \times \ln Pi$

Where, Pi=S/N

S = Number of individuals of one species,

N= Total number of all individuals in the sample

ln = Natural logarithm

**N.B:** The diversity of species in a given community increases with increasing H value. The diversity decreases as the H value decreases.

**Equation 6: Simpson's Index,** $D = \sum(\frac{n_i}{N})^2$

**Where,**

$n_i$ = Total number of individuals in a family/species

N = Total number of individuals of all families/species

**N.B:** The value of Simpson's index ranges from 0 to 1, with 0 representing infinite diversity and 1 representing no diversity, so the larger the value of D, the lower the diversity. For this reason, Simpson's index is often as its complement (1-D) which represents the opposite.

**Equation 07: Pielou's evenness index,** $J = \frac{H}{\ln S}$

**Where,** H= Shannon-Weiner diversity index, S=total number of species/families in the sample.

**N.B:** Pielou's evenness index (J) has a value between 0 and 1. Higher values denote greater levels of evenness. J = 1 when evenness is maximum.

### 3.7 Statistical analysis and interpretation

Collected data were summarized, categorized, and analyzed in Programming Language R (Version- 3.6.3), SPSS (Version-22.0), XLSTAT (Version-2016) and Microsoft Excel (Version-2019). The obtained data were presented with mean + SD and with appropriate visualizations. Statistical tests: one-way analysis of variance (ANOVA), Post-hoc Test and Tukey's Honestly Significant Difference (HSD) was conducted ($p = 0.05$, $df = 4$, CI = 95%) to determine the significance of spatial and temporal variation of fish larvae abundance, diversity, richness, and evenness.

**N.B:** The research methodology was shown in a flow diagram (Plate-01).

# PHOTO GALLERY

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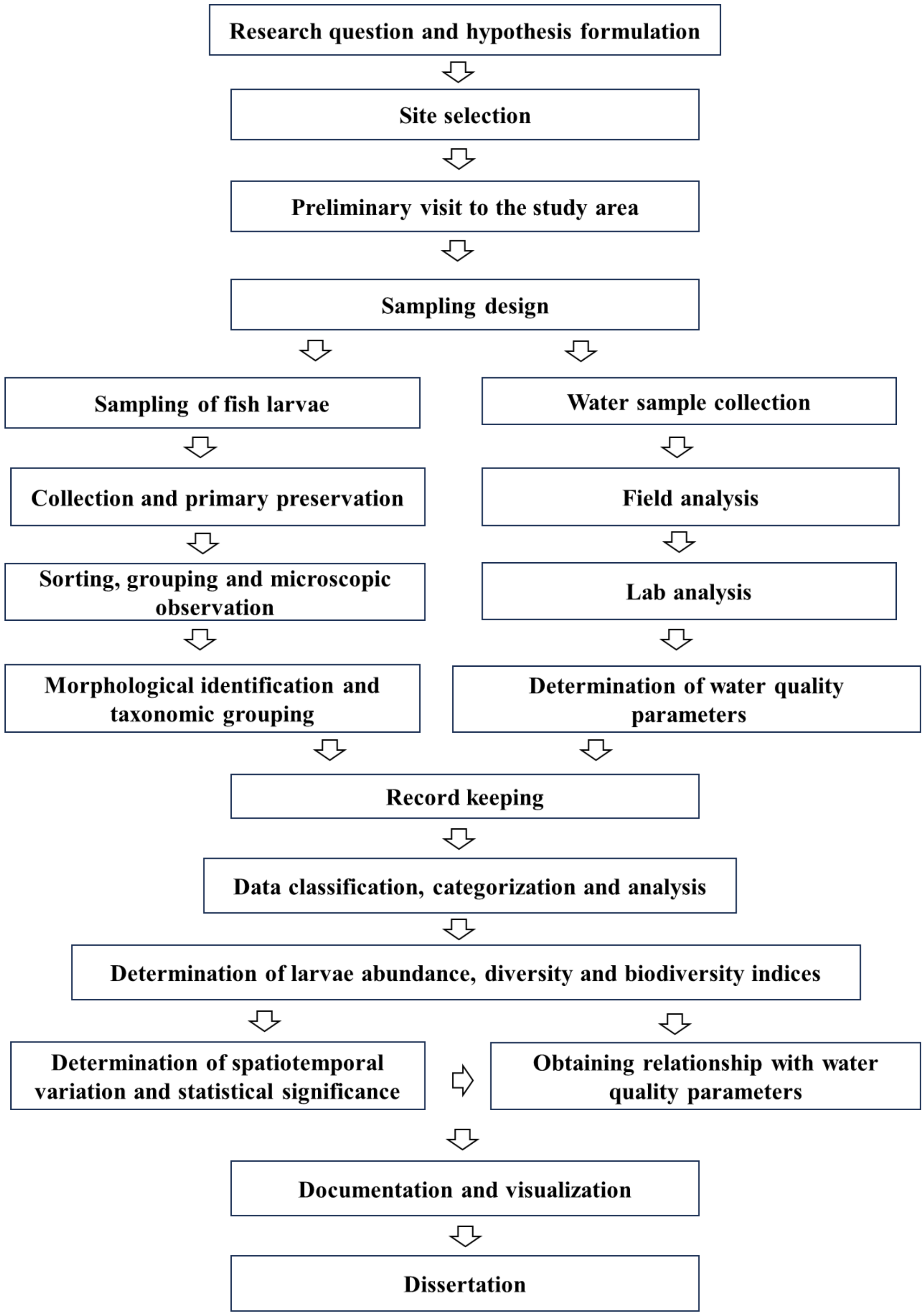


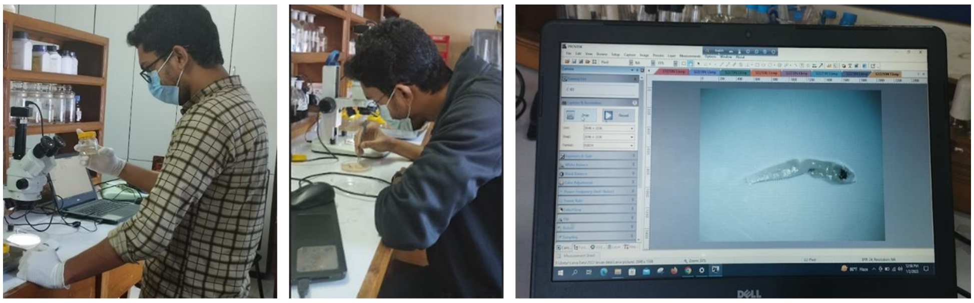

**Plate-01:** Flow diagram of the research methodology

Larval sample collection with the Bongo net

Water sample collection from the sampling areas

Preservation and labeling of larval samples

**Plate-02:** Larvae and water **s**ample collection and preservation



Larval sample observation and identification

Determination of hydrological parameters

**Plate-03:** Lab analysis, water quality assessment and larvae identification

# CHAPTER: 04

# RESULT

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## 4.1 Larval abundance and occurrence

### 4.1.1 Station

A total of 32 families and 3082 individuals of fish larvae were found in all stations and seasons (Plate-04). Among the stations, the highest number of families (24) were found in Naf River Estuary and the lowest number of families (16) were found in St. Martin (Figure-02: Appendix 01). The larval count (mean ± SD) was highest in the Bakkhali River estuary (40.11 ± 71.08), followed by St. Martin, Rezukhal Estuary, and Naf River estuary where the larval count (mean ± SD) in Moheshkhali para (17.44 ± 22.17) was lowest (Figure-02). According to one-way ANOVA ($p = 0.05$, df =4, CI = 95%), there was no significant difference ($p > 0.05$) in the larval count among the stations. A Post-hoc Test (Tukey's Honestly Significant Difference: HSD) was also conducted to determine the inter-variation of fish larval abundance among the stations but no significant variation in the mean abundance of fish larvae was found.

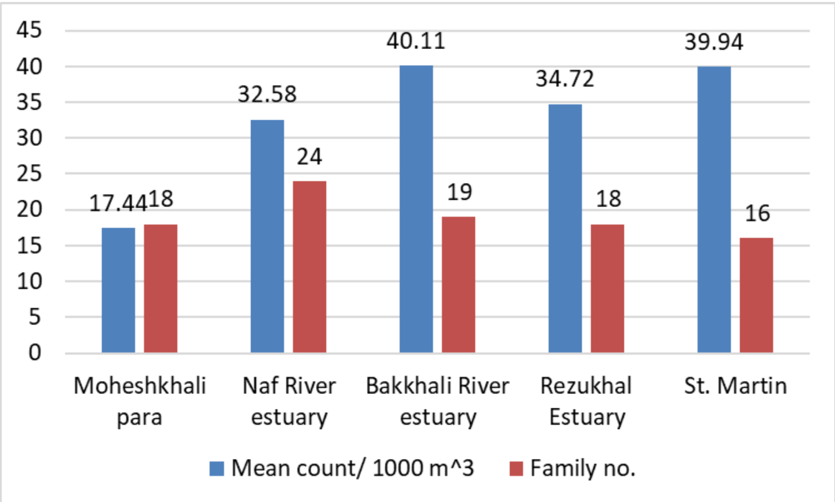


**Figure-02:** Mean count of larva per 1000 $m^3$ and number of families found in each sampling station

### 4.1.2 Season

The mean larval count per 1000 $m^3$ (Mean ± SD) was highest in monsoon (28.42 ± 51.60) followed by summer (22.45 ± 34.11) and lowest in winter (13.63 ± 21.44) (Table-01).

Among the sampling areas, the larval count was highest in summer (137/1000 $m^3$) and lowest in monsoon (84/1000 $m^3$) in the Moheshkhali Para. In the Naf River, the larval count was highest during monsoon (372/1000 $m^3$) and lowest in winter (175/1000 $m^3$). The larval count was highest during winter (324/1000 $m^3$) and lowest during summer (184/1000 $m^3$) in the Bakkhali River Estuary. The larval count was highest in summer (445/1000 $m^3$) and lowest in monsoon (88/1000 $m^3$) in the Rezukhal Estuary. In the St. Martin, the larval count was highest during monsoon (511/1000 $m^3$) and lowest in winter (54/1000 $m^3$) (Figure-03, Appendix 01).

According to one-way ANOVA (F = 2.053, p = 0.05, df =4), there was no significant variation in the mean abundance of fish larvae among the seasons (p> 0.05). Post-hoc Test (Tukey's Honestly Significant Difference: HSD) revealed no significant inter-variation in the mean abundance of fish larvae as well.

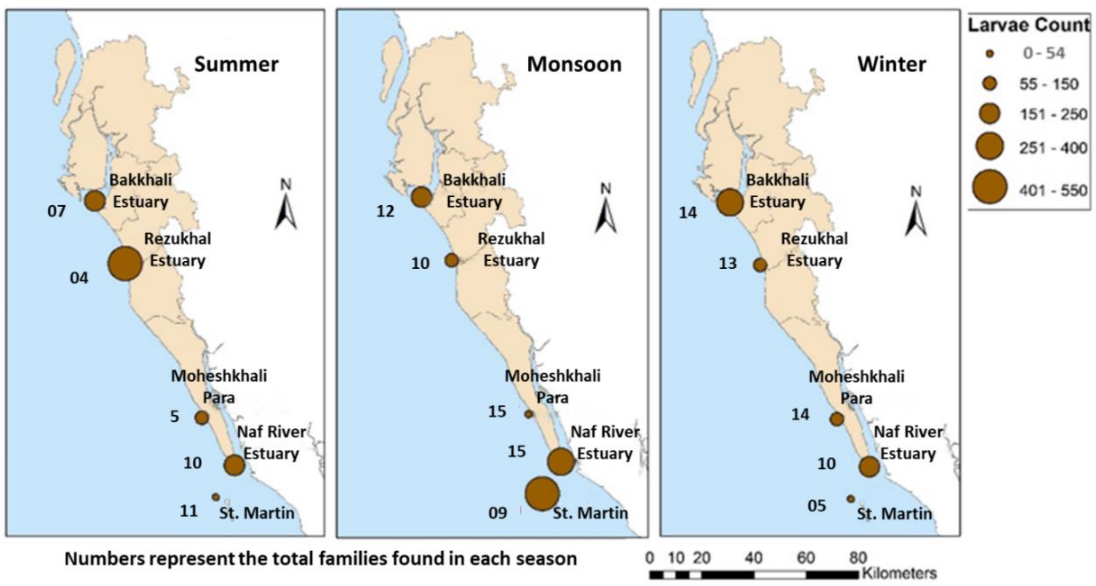


**Figure-03:** Season-wise comparison of total count of larvae per 1000 $m^3$ and number of families in each sampling station

**Table-01:** Seasonal variation in the mean count of fish larvae

| Station | Mean ± SD |
|---|---|
| **Summer** | 22.45 ± 34.11 |
| **Monsoon** | 28.42 ± 51.60 |
| **Winter** | 13.63 ± 21.44 |

### 4.2 Relative abundance

Ten (10) families were selected based on their occurrence in all five stations to determine their relative abundance. Among the selected families, Ambassidae displayed the highest relative abundance in Moheshkhali Para, comprising 53% of the larvae. Conversely, it had the lowest relative abundance in the Naf River Estuary, accounting for only 5.63% of the larvae. Blenniidae exhibited the highest relative abundance in the Naf River Estuary, representing 65.55% of the larvae, while it showed the lowest relative abundance in St. Martin, with a mere 0.84% of the larvae. Carangidae showed the highest relative abundance in the Bakkhali River Estuary, constituting a significant proportion of 94.90% of the larvae, whereas it had the lowest relative abundance in Moheshkhali Para, accounting for only 1% of the larvae. Clupeidae reached its highest relative abundance in the Naf River Estuary, with a percentage of 32.85%, and the lowest relative abundance in Moheshkhali Para, at 3%. Engraulidae had its highest relative abundance in the Rezukhal Estuary, comprising 39.54% of the larvae, while the lowest relative abundance was observed in Moheshkhali Para, accounting for 7% of the larvae. Mugilidae exhibited the highest relative abundance in the Naf River Estuary, representing 48.98% of the larvae, and the lowest relative abundance in the Bakkhali River Estuary, at 4.08%. Myctophidae displayed its highest relative abundance in the Naf River Estuary, with a percentage of 32.69%, while it had the lowest relative abundance in St. Martin, at 3.85%. Pomacentridae reached its highest relative abundance in St. Martin, accounting for 52.46% of the larvae, whereas it had the lowest relative abundance in Moheshkhali Para, comprising 2% of the larvae. Siganidae exhibited the highest relative abundance in the Naf River Estuary, comprising 41.82% of the larvae, while it had the lowest relative abundance in the Rezukhal Estuary, with 7.27% of the larvae. Lastly, Sillaginidae displayed its highest relative abundance in the Bakkhali River Estuary, representing 46.21% of the larvae, and the lowest relative abundance in St. Martin, at 5.30% (Figure-04; Appendix 04).

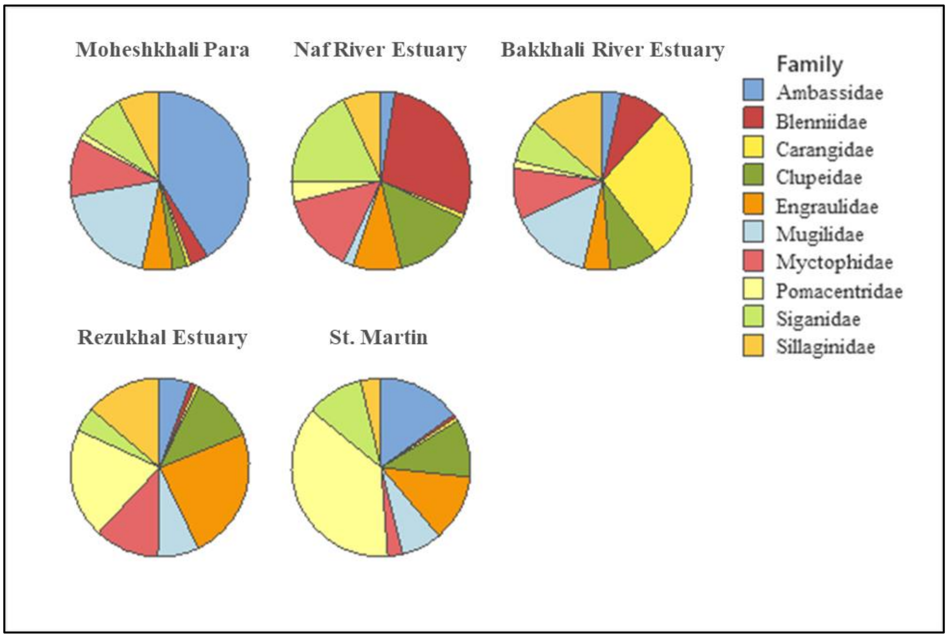


**Figure-04:** Relative abundance of fish larvae families in all sampling stations of the study area

## 4.3 Family composition

### 4.3.1 Station

The top 05 families regarding total count (larva/ 1000 m$^3$) and abundance (%) were Clupeidae (974, 31.60%), Engraulidae (789, 25.60%), Gobiidae (162, 5.26%), Ambassidae (142, 4.61%) and Sillaginidae (132, 4.28%) respectively among the stations and within the total sampling period (Table-02). **(a)** In Moheshkhali Para, Ambassidae was most abundant (75, 23.89%), while Carangidae, Gobidae, and Pamacentridae were least abundant (1, 0.32%). **(b)** In the Naf River estuary, Clupeidae had the highest abundance (320, 40.92%), while Megalopidae, Microdesmidae, and Sparidae had the lowest (1, 0.13%). **(c)** In the Bakkhali River Estuary, Clupeidae had the highest abundance (288, 39.89%), while Hemiramphidae, Microdesmidae, and Terapontidae had the lowest (1, 0.14%). **(d)** Engraulidae had the highest total count (312, 49.92%), while Carangidae and Pristigasteridae had the lowest count (1, 0.16%) in the Rezukhal Estuary. **(e)** In the St. Martin, Gobiidae was highly abundant (154, 24.10%), while Blenniidae, Carangidae, and Hemiramphidae was least abundant (1, 0.16%) (Table-02).

**Table-02:** Total larvae count (Larvae/1000m$^3$), abundance and family composition in the sampling stations

| | Moheshkhali para | | Naf River Estuary | | Bakkhali River Estuary | | Rezukhal Estuary | | St. Martin | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Family** | **N** | **(%)** | **N** | **(%)** | **N** | **(%)** | **N** | **(%)** | **N** | **(%)** | **N** | **(%)** |
| **Ambassidae** | 75 | 23.89 | 8 | 1.02 | 16 | 2.22 | 13 | 2.08 | 30 | 4.69 | 142 | 4.61 |
| **Ammodytidae** | - | - | - | - | - | - | 2 | 0.32 | - | - | 2 | 0.06 |
| **Belonidae** | 55 | 17.52 | | - | - | - | 16 | 2.56 | - | - | 71 | 2.30 |
| **Blenniidae** | - | - | 85 | 10.87 | 33 | 4.57 | - | - | 1 | 0.16 | 119 | 3.86 |
| **Callionymidae** | - | - | 3 | 0.38 | - | - | - | - | - | - | 3 | 0.10 |
| **Carangidae** | 1 | 0.32 | | | 95 | 13.16 | 1 | 0.16 | 1 | 0.16 | 98 | 3.18 |
| **Clupeidae** | 33 | 10.51 | 320 | 40.92 | 288 | 39.89 | 189 | 30.24 | 144 | 22.54 | 974 | 31.60 |
| **Engraulidae** | 56 | 17.83 | 159 | 20.33 | 127 | 17.59 | 312 | 49.92 | 135 | 21.13 | 789 | 25.60 |
| **Gerreidae** | 1 | - | 5 | 0.64 | - | - | 6 | 0.96 | - | - | 12 | 0.39 |
| **Gobiidae** | - | 0.32 | - | - | 6 | 0.83 | 2 | 0.32 | 154 | 24.10 | 162 | 5.26 |
| **Gonorynchidae** | 6 | 1.91 | 29 | 3.71 | - | - | - | 0.48 | - | - | 35 | 1.14 |
| **Hemiramphidae** | - | - | 11 | 1.41 | 1 | 0.14 | 3 | - | 1 | 0.16 | 16 | 0.52 |
| **Lobotidae** | - | - | 2 | 0.26 | - | - | - | - | - | - | 2 | 0.06 |
| **Megalopidae** | - | - | 1 | 0.13 | - | - | 2 | 0.32 | - | - | 3 | 0.10 |
| **Microdesmidae** | - | - | 1 | 0.13 | 1 | 0.14 | | | - | 0.78 | 2 | 0.06 |
| **Mugilidae** | 12 | 3.82 | 2 | 0.26 | 24 | 3.32 | 6 | 0.96 | 5 | - | 49 | 1.59 |
| **Myctophidae** | 7 | 2.23 | 18 | 2.30 | 17 | 2.35 | 10 | 1.60 | - | - | 52 | 1.69 |
| **Ophichthidae** | - | - | 2 | 0.26 | - | - | - | - | - | - | 2 | 0.06 |
| **Pomacentridae** | 1 | 0.32 | 5 | 0.64 | - | - | 23 | 3.68 | 32 | 5.01 | 61 | 1.98 |
| **Phosicthyidae** | 7 | 2.23 | - | - | 3 | 0.42 | - | - | - | - | 10 | 0.32 |
| **Pristigasteridae** | 15 | 4.78 | 53 | 6.78 | 4 | 0.55 | 1 | 0.16 | - | - | 73 | 2.37 |
| **Scaridae** | 6 | 1.91 | - | - | - | - | - | - | - | - | 6 | 0.19 |
| **Sciaenidae** | - | - | 2 | 0.26 | - | - | - | - | - | - | 2 | 0.06 |
| **Scombridae** | - | - | - | - | - | - | - | - | 4 | 0.63 | 4 | 0.13 |
| **Serranidae** | - | - | - | - | - | - | - | - | 2 | 0.31 | 2 | 0.06 |
| **Siganidae** | 6 | 1.91 | 23 | 2.94 | 14 | 1.94 | 4 | 0.64 | 8.00 | 1.25 | 55 | 1.78 |
| **Sillaginidae** | 13 | 4.14 | 21 | 2.69 | 61 | 8.45 | 30 | 4.80 | 7.00 | 1.10 | 132 | 4.28 |
| **Synodontidae** | 3 | 0.96 | - | - | 6 | 0.83 | - | - | - | - | 9 | 0.29 |
| **Sparidae** | 3 | 0.96 | 1 | 0.13 | - | - | 2 | 0.32 | - | - | 6 | 0.19 |
| **Terapontidae** | - | - | 2 | 0.26 | 1 | 0.14 | 3 | 0.48 | 69.00 | 10.80 | 75 | 2.43 |
| **Tetraodontidae** | - | - | 2 | 0.26 | - | - | - | - | 2.00 | 0.31 | 4 | 0.13 |
| **Trichonotidae** | 14 | 4.46 | 26 | 3.32 | 2 | 0.28 | - | - | - | - | 42 | 1.36 |
| **Unidentified** | - | - | 1 | 0.13 | 23 | 3.19 | - | - | 44.00 | 6.89 | 68 | 2.21 |
| **Total count** | **314** | | **782** | | **722** | | **625** | | **639** | | **3082** | |
| **Mean ± SD** | **17.44 ± 22.17** | | **32.58 ± 70.81** | | **40.11 ± 71.08** | | **34.72 ± 81.69** | | **39.94 ± 55.34** | | **93.39 ± 206.70** | |

### 4.3.2 Season

**(a) Moheshkhali para**

The highest number of families was found during monsoon (15) and lowest in summer (05). The count and abundance (%) of Ambassidae was highest (52, 37.96%) and Pamacentridae was lowest (1, 0.73%) during summer. In the monsoon, Engraulidae exhibited the highest abunadance (18, 20.69%), while Sparidae had the lowest (1, 1.15%). During winter, Ambassidae had the highest abundance (20, 20.62%), whereas Carangidae, Scaridae, and Gobidae had the lowest (1, 1.03%) (Figure-05; Appendix-01).

**(b) Naf River Estuary**

The highest number of families was found during the monsoon (15), while both summer and winter had the lowest number of families (05). The count and abundance (%) of Clupeidae was highest (162, 67.50%) during summer while Microdesmidae, Myctophidae, and Sparidae was lowest (2, 0.83%). In the monsoon, Engraulidae was highly abundant (88, 23.66%), whereas Ambassidae was least abundant (1, 0.27%). Clupeidae had the highest abundance (89, 50.86%), while Tetraodontidae and Mugilidae had the lowest (2, 1.14%) during winter (Figure-05; Appendix-01).

**(c) Bakkhali River Estuary**

The number of families found in the estuary was highest during the monsoon (12) and lowest during summer (07). The count and abundance (%) of Carangidae was highest (90, 48.91%) during summer while Microdesmidae and Ambassidae was lowest (1, 0.54%). In the monsoon season, Clupeidae exhibited the highest abundance (105, 47.73%), while Trichonotidae had the lowest (2, 0.91%). During winter, Clupeidae displayed the highest abundance (114, 35.19%), whereas Hemiramphidae, Myctophidae, Pristigasteridae, and Terapontidae had the lowest (1, 0.31%) (Figure-05; Appendix-01).

### (d) Rezukhal Estuary

The highest number of families in this estuary was observed in winter (13), while the lowest number was found during the monsoon (10). The count and abundance (%) of Engraulidae was highest (222, 49.89%) while Carangidae was lowest (1, 0.22%) during summer. In the monsoon season, Terapontidae exhibited the highest abundance (35, 39.77%), while Ammodytidae, Blenniidae, and Megalopidae had the lowest (2, 2.27%). During winter, Engraulidae was highly abundant (43, 33.86%), whereas Pomacentridae, Pristigasteridae, and Siganidae was least (1, 0.79%) (Figure-05; Appendix-01).

### (e) St. Martin

The highest number of families was observed during summer (11), whereas the lowest during winter (5). The count and abundance (%) of Clupeidae was highest (43, 58.11%) and Carangidae and Hemiramphidae was lowest (1, 1.35%) during summer. In the monsoon, Gobiidae exhibited the highest abundance (152, 29.74%), while Ambassidae had the lowest (3, 0.59%). During winter, Clupeidae had the highest abundance (27, 50%), whereas Blenniidae had the lowest (1, 1.85%) (Figure-05; Appendix-01).

## 4.4 Diversity indices

The Simpson's index ranged from 0.51 - 0.89 and Shannon-Weiner index (H) ranged from 1.04 - 2.30 in this study. On the other hand, Margalef's richness index ranged from 0.49 - 3.13 and Pielou's evenness index (J) ranged from 0.48 -0.85 (Appendix-02).

### 4.4.1 Station

In the case of stations, the value (Mean ± SD) of the Margalef richness showed that the species richness was highest in Moheshkhali Para (2.26 ± 1.26) and lowest in St. Martin (1.54 ± 0.70) among all the stations. The value (Mean ± SD) of Simpson's index and Shannon-Weiner index (H) showed that the species diversity was highest in Moheshkhali Para (0.83 ± 0.09 and 1.95 ± 0.52) and lowest in St. Martin (0.69 ± 0.09 and 1.47 ± 0.29) among the stations (Figure-05a; Appendix-02). The Pielou's evenness index (J) values (Mean ± SD) showed that Moheshkhali Para (0.84 ± 0.01) had the highest evenness and Naf River Estuary (0.64 ± 0.15) had the lowest among the stations. Based on one-way ANOVA ($p = 0.05$, $df = 4$, CI = 95%) there was no significant variation ($p > 0.05$) in the Margalef richness index, Simpson's index, Shannon-Weiner index (H) and Pielou's evenness index (J) among the stations (Appendix-02).

### 4.4.2 Season

The values of (Mean ± SD) Simpson's index and Shannon-Weiner index indicated that the species diversity was highest in monsoon (0.80 ± 0.07 and 1.92 ± 0.27) and lowest in summer (0.61 ± 0.07 and 1.22 ± 0.19). The values (Mean ± SD) of Margalef's richness index and Pielou's evenness index indicated that the species richness and evenness were highest in monsoon (2.17 ± 0.67 and 0.77 ± 0.07) and lowest in summer (1.28 ± 0.72 and 0.65 ± 0.14) (Figure-05b; Appendix-03). The values of (Mean ± SD) Simpson's index and Shannon-Weiner index indicated that the species diversity was highest in monsoon (0.80 ± 0.07 and 1.92 ± 0.27) and lowest in summer (0.61 ± 0.07 and 1.22 ± 0.19) as well. Among the seasons, Margalef's richness index and Pielou's evenness index (J) didn't significantly vary ($p > 0.05$) but there was significant variation ($p < 0.05$) in Simpson's index and Shannon-Weiner index (H) in **o**ne-way ANOVA ($p = 0.05$, $df = 4$, CI = 95%) (Appendix-03).

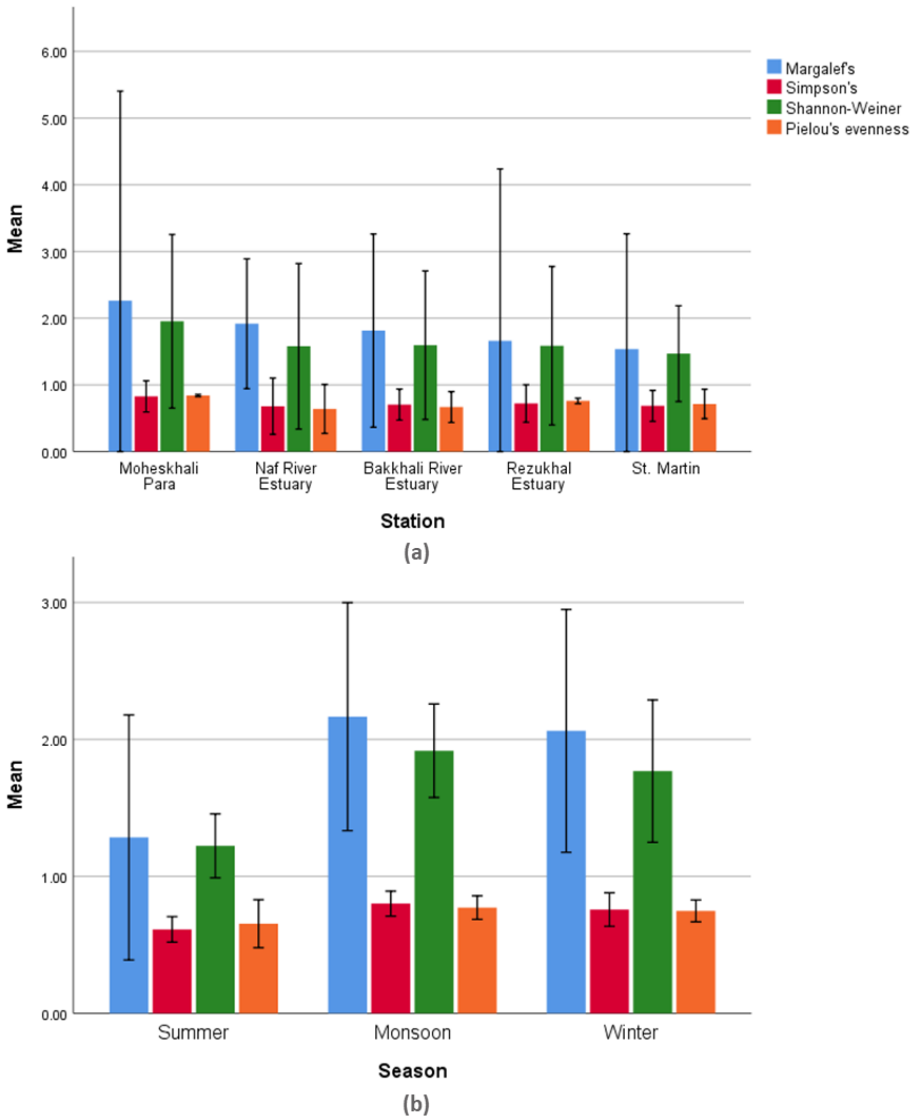


**Figure-05:** Station-wise and season-wise comparison of diversity, richness, and evenness indices; (a) Station-wise comparison and (b) Season-wise comparison

### 4.5 Status of water quality parameters

Temperature, pH, total alkalinity, and salinity ranged from 22.7-32.9 °C, 6.6-8.5, 78-126 mg/L, and 15.3-37 ppt respectively throughout the sampling period. Descriptive statistics of the water quality parameters are given in Table-03. The monthly variation in water quality parameters were shown in the Figure-06 (Appendix-05).

**Table-03:** Mean value and range of the water quality parameters

| Parameters | Min | Max | Mean ± SD |
|---|---|---|---|
| **Temperature (°C)** | 22.7 | 32.9 | 28.71 ± 2.69 |
| **pH** | 6.6 | 8.5 | 8.08 ± 0.39 |
| **Total Alkalinity (mg/L)** | 78 | 126 | 100.33 ± 11.90 |
| **Salinity (psu)** | 15.3 | 37 | 28.54 ± 6.00 |

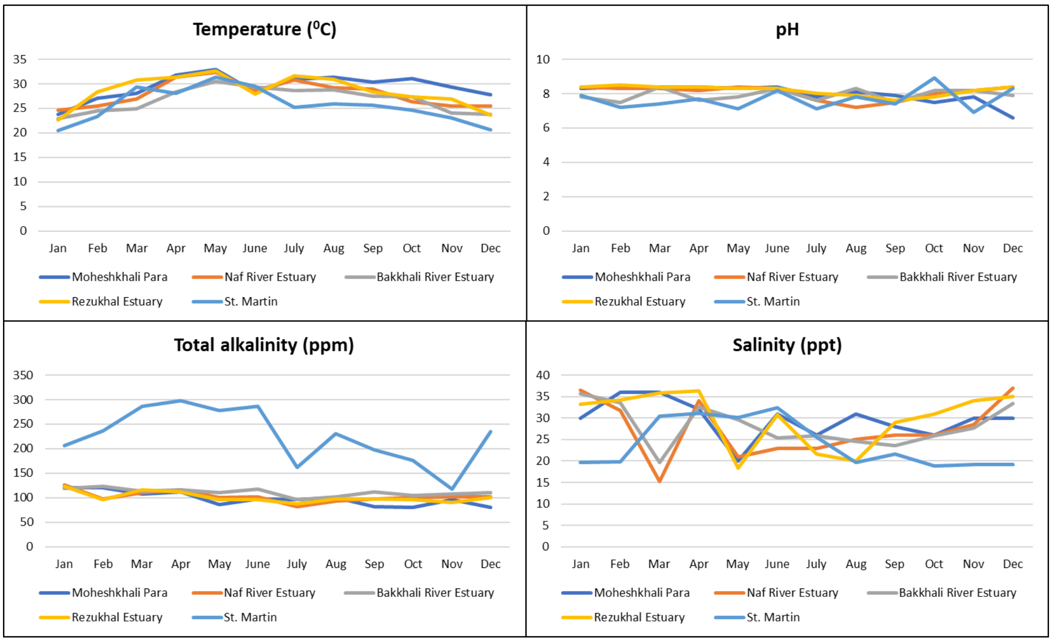


**Figure-06:** Monthly variation of water quality variables in the sampling stations

## 4.6 Relationship of larval abundance with environmental variables

Canonical correspondence analysis (CCA) was used to examine relationships between assemblage structure and environmental factors and to ordinate larvae samples based on taxonomic group (family) and environmental factors. The analysis involved 10 mostly occurred families as objects and temperature ($^{0}$C), pH, alkalinity (ppm), and salinity (ppt) as environmental variables. The first two CCA axes (F1 and F2) represented 66.33% of the cumulative variance that explained larvae abundance and environment relationship. Axis 1 (F1) and Axis 2 (F2) represented a variance of 36.46 % and 29.87% respectively. The position of the family on the CCA biplot is a reflection of the preference to environmental conditions.

The longest CCA vector was pH, followed by temperature, alkalinity, and salinity. The CCA graph showed that the abundance of Ambassidae and Mugillidae was positively associated with alkalinity and pH. Clupidae didn't have any particular preference for any factors as it was close to the origin of the CCA graph. The family Engraulidae seemed to have an association with temperature. Concerning F1, Carangidae, Myctophidae, and Sillaginidae showed a positive correlation with alkalinity whereas Pomacentridae, Blennidae, and Siganidae showed a negative correlation with alkalinity. Concerning F2, Ambassidae and Mugillidae had a positive correlation to salinity and pH, and Pomacentridae, Blennidae, Siganidae, Carangidae, Myctophidae, and Sillaginidae had a negative correlation with salinity and pH. However, the preference of Pomacentridae, Blennidae, Siganidae, Carangidae, Myctophidae, and Sillaginidae was not strong to the mentioned factors (Figure-08).

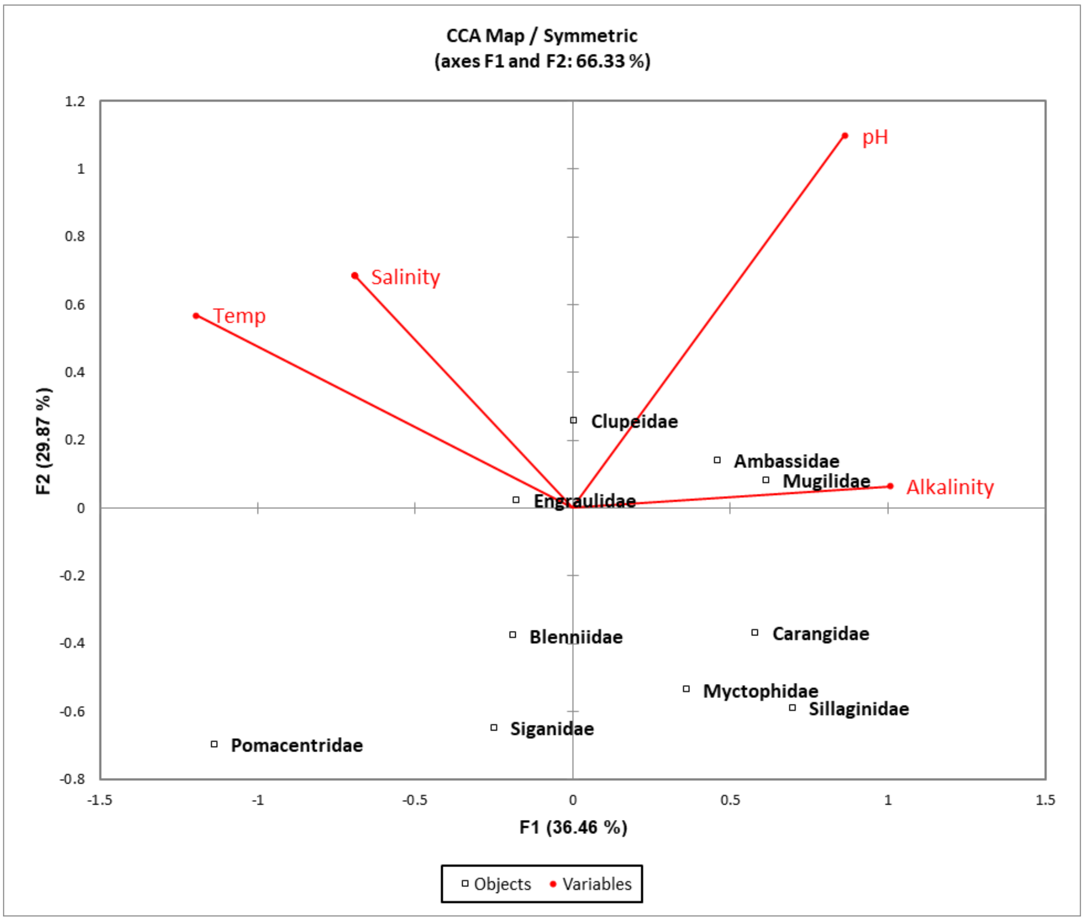


**Figure-08:** Canonical correspondence analysis (CCA) graph showing relationship of larval abundance with environmental variables

Ambassidae

Blenniidae

Pomacentridae



Clupeidae



Engraulidae

Plate-04 (a)

Mugilidae

Trichonotidae

Myctophidae

Pristigasteridae

Sparidae

Sillaginidae

Ammodytidae

Belonidae

Callionymidae

Carangidae

Evermannellidae

Gobiidae

Plate-04 (b)


Gonorynchidae


Hemiramphidae


Megalopidae


Microdesmidae


Ophichthidae


Phosicthyidae


Scaridae


Siganidae


Terapontidae


Tetraodontidae

Plate-04 (c)

**Plate-04:** Identified families of fish larvae

# CHAPTER: 05

# DISCUSSION

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## 5.1 Larval abundance and occurrence

Throughout this study, a total of 3082 fish larvae from 32 different families were discovered, with the Naf River Estuary exhibiting the highest number of fish families (24) and St. Martin showing the lowest (16) (Figure-02; Table-01). Comparable studies in different regions found varying numbers of fish families: 11 families in Gowatr Bay, North Oman Sea (Rabbaniha and Mousavi Golsefid, 2014); 47 families in the Indonesian Fishery Management Area in the South China Sea (Taufik et al., 2022); 42 families in Coastal Kenya (Mwaluma et al., 2022), and 23 families along the west coast of Sri Lanka (Silva et al., 2021). This study identified fish larvae only up to the family level morphologically and did not ascertain the number of genera and species. Continuous sampling efforts and DNA barcode techniques may offer more accurate assessments of fish larval diversity and species identification in future studies (Victor et al., 2009; Ko et al., 2013).

The Bakkhali River estuary, had the greatest station-wise larvae count in this study which is associated with mangrove trees and supports higher phytoplankton productivity (Abu Hena et al. 2013) (Figure-02; Table-01). In this study, the larval count per 1,000 $m^3$ ranged from 54 to 511 among the sampling areas, whereas Lirdwitayaprasit et al. (2008) discovered 485 larvae/1000 $m^3$ in the Andaman Sea area of the Bay of Bengal. These differences in larval variety and abundance highlight the ecological importance and complexity of various coastal locations. Physical processes have a substantial impact on the nutrient cycles, biological production, and pelagic creatures' behavior, as well as the geographical and temporal patterns of biological activities in the ocean. However, little is known about their effects on marine populations in the Bay of Bengal (Muraleedharan et al., 2007). It can be difficult to comprehend how pre-settlement larvae move through the environment, particularly in the dynamic coastal environment where dispersal takes place. The number and distribution of larval fish can be significantly impacted by oceanographic features such as coastal zone fronts (Pattrick et al., 2021). Marine species release pelagic and buoyant eggs carried by ocean currents to nursery areas, and wind-induced variability may also influence larval occurrence (Van der Veer et al., 1998). Even though there is variation in the number of larvae among sample stations, statistical analysis revealed that there was no significant inter-variation ($p > 0.05$) in this study (Table-01). Similar observations were found in Gowatr Bay, the North Oman Sea, and the coastal waters of Sri Lanka (Rabbaniha and Mousavi Golsefid, 2014; Bandara et al., 2019). It is crucial to understand how physical and oceanographic factors affect the distribution and quantity of larvae in the Bay of Bengal, resulting in the need for additional study and a thorough understanding of these processes.

Seasonal variations in the Bay of Bengal exhibit distinct characteristics and ecological influences. During the monsoon and summer, larval counts per 1000 $m^3$ were found higher, except in the Bakkhali River Estuary during winter. The number of fish families also tended to be higher during monsoon, with exceptions observed in Rezukhal during winter and St. Martin during summer (Figure-03). However, statistical analysis did not find significant variation in larval abundance among seasons ($p > 0.05$) (Table-02), contrasting with findings in Gowatr Bay and North Oman Sea (Rabbaniha and Mousavi Golsefid, 2014). Similar results were reported by Jutagate et al. (2016) in the Sirindhron Reservoir of Thailand. Chl-a concentrations and seasonal fluctuations in sea surface temperature may have an effect on the fish population in the Bay of Bengal (Dutta and Sourav, 2021). A regular monitoring program is recommended to better understand the long-term changes in fish assemblage with varying seasons, providing valuable insights into the effects of seasonal variations on fish larval abundance and distribution and contributing to a comprehensive understanding of marine ecosystems in the Bay of Bengal.

### 5.2 Family composition

In this study, the top five families in terms of larval count and abundance were Clupeidae (974, 31.60%), Engraulidae (789, 25.60%), Gobiidae (162, 5.26%), Ambassidae (142, 4.61%), and Sillaginidae (132, 4.28%) across all sampling stations and the entire sampling period (Table-03). In contrast, Taufik et al. (2022) identified Bregmacerotidae, Engraulidae, Pomacentridae, Microdesmidae, and Leiognathidae as the most abundant larval families in the coastal waters of Sri Lanka (Bandara et al., 2019). Similarly, Mwaluma et al. (2022) reported Labridae, Engraulidae, Blenniidae, Scaridae, and Sphyraenidae as the dominant fish families in Coastal Kenya.

### 5.3 Relative abundance

In this study, the relative abundance of fish families varied across different estuaries in the Bay of Bengal. Ambassidae dominated in Moheshkhali Para, while Blenniidae, Clupeidae, Mugilidae, Myctophidae, and Siganidae were most abundant in the Naf River Estuary. Carangidae and Sillaginidae were most abundant in the Bakkhali River Estuary, Engraulidae in the Rezukhal Estuary, and Pomacentridae in St. Martin (Figure-04; Appendix-04). Other studies have reported variability in fish family abundance as well. Rabbaniha and Mousavi Golsefid (2014) found Gobiidae, Clupeidae, and Engraulidae to dominate in Gowatr Bay, North Oman Sea, while Lirdwitayaprasit et al. (2008) reported Photichthyidae, Myctophidae, Bregmacerotidae, Carangidae, and Callionymidae as constant families in the Bay of Bengal. These findings highlight the importance of understanding the ecological dynamics and fisheries biodiversity of the Bay of Bengal and its estuaries.

### 5.4 Diversity indices

A biodiversity index's main objective is to quantify a sample's or population's diversity using a numerical value (Magurran, 1988). Both the diversity of species, species richness and the distribution of individuals within each species were taken into account in this study. Margalef's richness value is commonly used as a comparative indicator. It can vary based on the species number present in an area (Rahman et al., 2021). In this study, the Simpson's Index indicated a moderate to high level of diversity (range: 0.51 to 0.89), while the Shannon-Weiner Index (H) showed a relatively broad range of species diversity (range: 1.04 to 2.30). Margalef's Richness Index ranged from 0.49 to 3.13 which meant variation in the number of species among different stations Pielou's Evenness Index (J) reflected diverse degrees of evenness in species abundance (range: 0.48 to 0.85) (Appendix-02). In a study by Iqbal et al. (2014) at the Rezukhal Estuary, Cox's Bazar, Bangladesh, the Shannon-Weiner diversity index ranged from 1.387 to 2.035, the evenness index from 0.5408 to 0.8981, and the species richness from 1.743

to 2.047. Moheshkhali Para displayed the highest species richness and diversity, as measured by Margalef's richness index, Simpson's index, and Shannon-Weiner index in this study. It also showed the highest evenness according to Pielou's evenness index. Conversely, St. Martin exhibited the lowest species richness, diversity, and evenness (Figure-06a; Appendix-02). However, statistical analysis using one-way ANOVA did not reveal significant variation ($p > 0.05$) in species diversity, richness, and evenness among the stations.

Seasonal analysis revealed higher species diversity, richness, and evenness in the monsoon season than in summer and winter (Figure-06b; Appendix-03). Species diversity showed significant variation among the seasons ($p < 0.05$), while no significant variation was observed in species richness and evenness ($p > 0.05$). These findings align with the study of Rahman et al. (2021) which also reported higher Shannon-Wiener diversity values during the monsoon ($3.46 \pm 0.03$) and lower values in winter ($3.22 \pm 0.04$) in the Payra River. This high diversity was attributed to abundant food resources and favorable environmental conditions along the coast, consistent with other studies (K. Dorairaj, 1998; NB Nair, 1989). In various estuaries, different studies reported varying Shannon-Wiener diversity values. For example, Nabi et al. (2011) found values ranging from 0.95 to 2.62 in the Bakkhali River, and Rahman et al. (2018) reported values ranging from 2.35 to 2.65 in the Kushiyara River. In each instance, low Shannon-Wiener diversity index values indicated fewer species, while high values suggested a greater number of species, which is consistent with the findings of this study. The current study emphasizes the necessity of taking these aspects into account when evaluating biodiversity patterns in estuarine ecosystems. Understanding the dynamics of species richness and diversity in various estuaries, as well as how they react to seasonal variations, offers important insights into the ecological health and operation of these vital ecosystems.

## 5.5 Status of water quality parameters

Water is essential for sustaining life (Bytyci et al., 2018). The estuarine environment in Bangladesh is renowned for its dynamic and diverse nature, influenced by a variety of factors such as monsoon patterns, nutrient influx, salinity intrusion, riverine discharge, siltation, and human activities (Rakib et al., 2022).

The findings of this study on the water quality parameters of temperature, pH, total alkalinity, and salinity in the coastal waters of Cox's Bazar, Bangladesh, are closely aligned with those reported by other studies in the Bay of Bengal and Cox's Bazar. For instance, Mehedi et al. (2000), Raknuzzaman et al. (2018), Aftabuddin et al. (2009), and Hasan et al. (2019) all reported similar values for these parameters in the region. Rashed-Un-Nabi et al. (2011) also observed varying salinity levels in the Bakkhali River Estuary during different seasons.

This convergence of findings suggests that the water quality parameters in the coastal waters of Cox's Bazar are relatively stable and consistent with other coastal areas in the Bay of Bengal region. Additionally, the measured parameters in this study fell within or near the acceptable ranges recommended by standard guidelines for surface water temperature, pH, and alkalinity in the natural environment (Stanley and Seller, 1986; EPA, 1993; ECR, 1997). This suggests that the water quality in the sampling stations is within acceptable limits for sustaining aquatic life and ecological health.

### 5.6 Relationship of larval abundance with environmental variables

The composition and structure of these assemblages are ultimately shaped by environmental factors that control the dispersion and survival of fish larvae (Amorim et al., 2017; Rodriguez, 2019). In this study, Canonical Correspondence Analysis (CCA) revealed the associations between fish families and environmental variables. The longest CCA vector was linked to pH, followed by temperature, alkalinity, and salinity. Similar studies found other influential abiotic factors. AB Rahim and Alias (2020) identified zone, temperature, salinity, dissolved oxygen, turbidity, and pH as important variables. Mwaluma et al. (2022) found that water temperature, dissolved oxygen, and pH are important factors in Coastal Kenya, while Rodrigues et al. (2022) found that river flow and salinity are important factors to influence larval occurrence in the Douro Estuary. Winemiller et al. (2000) found TDP, TDN, chlorophyll a, zooplankton density, and rotifer density to be crucial for influencing dominant fish families.

This study revealed specific correlations between fish families and environmental factors. For instance, Ambassidae and Mugillidae showed positive associations with alkalinity and pH, indicating that their abundance was influenced positively by these factors. In contrast, Clupidae did not show specific preference for any environmental factors. The family Engraulidae appeared to be associated with water temperature.

These findings vary with other studies conducted in different ecosystems. For example, Rodger et al. (2016) found negative correlations between Catostomidae, Clupeidae, Moronidae, and Percidae with water temperature in two Texas Gulf Coast rivers. AB Rahim and Alias (2020) observed that Malacostidae and Muraenidae were linked to the outer neritic zone, characterized by high salinity, dissolved oxygen, and turbidity, but low temperature and pH.

The observed correlations between fish families and environmental factors can be attributed to a variety of mechanisms (Rodriguez, 2019). For instance, Ambassidae and Mugillidae preferred high alkalinity and pH. These conditions may favor their growth and survival. In contrast, Clupeidae were more generalist in their habitat preferences, which may explain why they did not show specific associations with any environmental factors. The findings of this study provide valuable insights into the environmental factors influencing fish assemblages. This information can be used to support the conservation and management of fish populations and their habitats.

# CHAPTER-06

# CONCLUSIONS

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This study investigated the spatiotemporal patterns and environmental relationships of fish larvae along the southeast coast of the Cox's Bazar, Bangladesh. The yearlong observation of fish larval diversity, abundance, and ecological indices in nearshore and estuarine areas, which are potential areas of fish spawning, nursing, and feeding, revealed interactions between larval occurrence and hydrographic conditions. The findings of this study can be used to make informed decisions about sustainable marine fisheries management, such as protecting nursing and spawning grounds and improving fisheries recruitment. By understanding the spatiotemporal patterns and environmental relationships of fish larvae, fisheries managers and researchers can develop more effective management strategies.

Such research can provide information on prospective spawning and nursing sites, as well as habitat conditions, along the Cox's Bazar coast. This information is valuable for Bangladesh, where the economy heavily depends on its coastal and marine region, and marine fisheries make up a sizable portion of the nation's total fish production. Future research like this can help to fill the information gap on the diversity and distribution of fishing resources in this area. By undertaking periodic evaluations of larval abundance, researchers can identify long-term patterns and trends, which can inform sustainable fisheries management and the prudent exploitation and preservation of marine resources in Bangladesh.

# CHAPTER-07

# RECOMMENDATIONS AND FUTURE PERSPECTIVE

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- **Long-term monitoring:** Long-term monitoring programs for fish larvae diversity and abundance should be established in the Cox's Bazar coast given the dynamic nature of marine ecosystems and the possible effects of climate change.
- **Multidisciplinary approach in research:** A multidisciplinary approach that combines knowledge from marine ecology, oceanography, and fisheries research is essential for fully understanding the complex relationships between fish larvae and their environment. This approach can lead to more robust and reliable outcomes.
- **Molecular identification:** Precise species evaluation depends on the precise identification of marine fish larvae. Therefore, the use of molecular methods should be ensured in such research.
- **Habitat mapping:** Detailed habitat mapping in the coastal areas will be required to find possible spawning and nursing grounds for fish larvae. Having a clear understanding of the location of suitable habitats can help in the creation of focused conservation efforts and ecosystem-based management plans.
- **Adaptive management:** Fish larvae abundance and diversity trends should be taken into account when modifying fishing laws, seasonal closures, and protected areas.

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# APPENDICES

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## Appendix-01

### Total scenario of larval abundance in the study area

| Season | Station | Month | Family | Count (Month) | Count (Season) | Seasonal Abundance (%) |
|---|---|---|---|---|---|---|
| Summer | Moheshkhali para | Jun, 22 | Ambassidae | 52 | 52 | 37.96 |
| | | Mar,22 | Blenniidae | 36 | 39 | 28.47 |
| | | Apr, 22 | Blenniidae | 3 | | 0.00 |
| | | Mar,22 | Clupeidae | 4 | 19 | 13.87 |
| | | Jun, 22 | Clupeidae | 15 | | 0.00 |
| | | Mar,22 | Engraulidae | 14 | 26 | 18.98 |
| | | Apr, 22 | Engraulidae | 7 | | 0.00 |
| | | Jun, 22 | Engraulidae | 5 | | 0.00 |
| | | May,22 | Pamacentridae | 1 | 1 | 0.73 |
| Monsoon | Moheshkhali para | Jul,22 | Ambassidae | 3 | 3 | 3.57 |
| | | Jul,22 | Blenniidae | 1 | 8 | 9.20 |
| | | Aug,22 | Blenniidae | 1 | | 0.00 |
| | | Oct,22 | Blenniidae | 6 | | 0.00 |
| | | Jul,22 | Clupeidae | 3 | 8 | 9.20 |
| | | Sep,22 | Clupeidae | 5 | | 0.00 |
| | | Aug,22 | Engraulidae | 9 | 18 | 20.69 |
| | | Sep,22 | Engraulidae | 4 | | |
| | | Oct,22 | Engraulidae | 5 | | |
| | | Oct,22 | Gonorynchidae | 6 | 6 | 6.90 |
| | | Jul,22 | Mugilidae | 3 | 3 | 3.45 |
| | | Jul,22 | Myctophidae | 3 | 4 | 4.60 |
| | | Aug,22 | Myctophidae | 1 | | 0.00 |
| | | Oct,22 | Phosicthyidae | 5 | 5 | 5.75 |
| | | Aug,22 | Pristigasteridae | 2 | | 0.00 |
| | | Oct,22 | Pristigasteridae | 3 | | 0.00 |
| | | Oct,22 | Scaridae | 5 | 5 | 5.75 |
| | | Sep,22 | Siganidae | 4 | 6 | 6.90 |
| | | Oct,22 | Siganidae | 2 | | |
| | | Aug,22 | Sillaginidae | 1 | | |
| | | Oct,22 | Sinodontidae | 3 | 3 | 3.45 |
| | | Aug,22 | Sparidae | 1 | 1 | 1.15 |
| | | Jul,22 | Trichonotidae | 3 | 14 | 16.09 |
| | | Aug,22 | Trichonotidae | 1 | | 0.00 |
| | | Sep,22 | Trichonotidae | 5 | | 0.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Oct,22 | Trichonotidae | 5 | | 0.00 |
| Winter | Moheshkhali para | Jan, 22 | Ambassidae | 20 | 20 | 20.62 |
| | | Nov,22 | Belonidae | 1 | 8 | 8.25 |
| | | Nov,22 | Blenniidae | 6 | | 0.00 |
| | | Dec, 22 | Blenniidae | 1 | | 0.00 |
| | | Dec, 22 | Carangidae | 1 | 1 | 1.03 |
| | | Nov,22 | Clupeidae | 4 | 16 | 16.49 |
| | | Dec, 22 | Clupeidae | 2 | | 0.00 |
| | | Nov,22 | Engraulidae | 12 | 12 | 12.37 |
| | | Nov,22 | Gobidae | 1 | 1 | 1.03 |
| | | Feb, 22 | Mugilidae | 9 | 9 | 9.28 |
| | | Dec, 22 | Myctophidae | 3 | 3 | 3.09 |
| | | Dec, 22 | Phosicthyidae | 2 | 2 | 2.06 |
| | | Nov,22 | Pristigasteridae | 10 | 10 | 10.31 |
| | | Nov,22 | Scaridae | 1 | 1 | 1.03 |
| | | Jan, 22 | Sillaginidae | 8 | 12 | 12.37 |
| | | Feb, 22 | Sillaginidae | 4 | | 0.00 |
| | | Nov,22 | Sparidae | 2 | 2 | 2.06 |
| Summer | Naf River estuary | May,22 | Ambassidae | 3 | 3 | 1.25 |
| | | Mar,22 | Blenniidae | 27 | 27 | 11.25 |
| | | Mar,22 | Clupeidae | 65 | 162 | 67.50 |
| | | May,22 | Clupeidae | 9 | | 0.00 |
| | | Jun, 22 | Clupeidae | 88 | | 0.00 |
| | | May,22 | Engraulidae | 18 | 34 | 14.17 |
| | | Jun, 22 | Engraulidae | 16 | | 0.00 |
| | | May,22 | Gerreidae | 3 | 3 | 1.25 |
| | | May,22 | Lobotidae | 2 | 2 | 0.83 |
| | | Jun, 22 | Megalopidae | 1 | 3 | 1.25 |
| | | Jun, 22 | Microdeymidae | 1 | 2 | 0.83 |
| | | Mar,22 | Myctophidae | 1 | 2 | 0.83 |
| | | May,22 | Sparidae | 1 | 2 | 0.83 |
| Monsoon | Naf River estuary | Jul,22 | Ambassidae | 1 | 1 | 0.27 |
| | | Jul,22 | Blenniidae | 3 | 58 | 15.59 |
| | | Sep,22 | Blenniidae | 2 | | 0.00 |
| | | Oct,22 | Blenniidae | 53 | | 0.00 |
| | | Jul,22 | Callionymidae | 2 | 3 | 0.81 |
| | | Jul,22 | Callionymidae | 1 | | 0.00 |
| | | Oct,22 | Clupeidae | 69 | 69 | 18.55 |
| | | Jul,22 | Engraulidae | 4 | 88 | 23.66 |
| | | Aug,22 | Engraulidae | 1 | | 0.00 |
| | | Oct,22 | Engraulidae | 83 | | 0.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Jul,22 | Gerreidae | 2 | 2 | 0.54 |
| | | Oct,22 | Gonorynchidae | 29 | 29 | 7.80 |
| | | Sep,22 | Ophichthidae | 2 | 2 | 0.54 |
| | | Sep,22 | Pamacentridae | 2 | 5 | 1.34 |
| | | Jul,22 | Pomacentridae | 3 | | 0.00 |
| | | Oct,22 | Pristigasteridae | 53 | 53 | 14.25 |
| | | Jul,22 | Sciaenidae | 2 | 2 | 0.54 |
| | | Sep,22 | Siganidae | 8 | 23 | 6.18 |
| | | Oct,22 | Siganidae | 15 | | 0.00 |
| | | Oct,22 | Sillaginidae | 17 | 17 | 4.57 |
| | | Aug,22 | Terapontidae | 2 | 2 | 0.54 |
| | | Jul,22 | Trichonotidae | 2 | 18 | 4.84 |
| | | Sep,22 | Trichonotidae | 3 | | 0.00 |
| | | Oct,22 | Trichonotidae | 13 | | 0.00 |
| Winter | Naf River estuary | Dec, 22 | Ambassidae | 4 | 4 | 2.29 |
| | | Nov,22 | Clupeidae | 11 | 89 | 50.86 |
| | | Dec, 22 | Clupeidae | 9 | | 0.00 |
| | | Jan, 22 | Clupeidae | 2 | | 0.00 |
| | | Feb, 22 | Clupeidae | 67 | | 0.00 |
| | | Nov,22 | Engraulidae | 7 | 37 | 21.14 |
| | | Dec, 22 | Engraulidae | 10 | | 0.00 |
| | | Jan, 22 | Engraulidae | 17 | | 0.00 |
| | | Feb, 22 | Engraulidae | 3 | | 0.00 |
| | | Jan, 22 | Hemiramphidae | 11 | 11 | 6.29 |
| | | Nov,22 | Mugilidae | 2 | 2 | 1.14 |
| | | Dec, 22 | Myctophidae | 14 | 17 | 9.71 |
| | | Jan, 22 | Myctophidae | 3 | | 0.00 |
| | | Nov,22 | Sillaginidae | 1 | 4 | 2.29 |
| | | Jan, 22 | Sillaginidae | 2 | | 0.00 |
| | | Feb, 22 | Sillaginidae | 1 | | 0.00 |
| | | Jan, 22 | Tetraodontidae | 2 | 2 | 1.14 |
| | | Dec, 22 | Trichonotidae | 4 | 8 | 4.57 |
| | | Dec, 22 | Trichonotidae | 4 | | 0.00 |
| | | Nov,22 | Unidentified | 1 | 1 | 0.57 |
| Summer | Bakkhali River estuary | Jun, 22 | Ambassidae | 1 | 1 | 0.54 |
| | | May,22 | Blenniidae | 6 | 6 | 3.26 |
| | | Mar,22 | Carangidae | 89 | 90 | 48.91 |
| | | Jun, 22 | Carangidae | 1 | | 0.00 |
| | | Apr, 22 | Clupeidae | 64 | 69 | 37.50 |
| | | Jun, 22 | Clupeidae | 5 | | 0.00 |
| | | May,22 | Engraulidae | 16 | 16 | 8.70 |
| | | Jun, 22 | Microdesmidae | 1 | 1 | 0.54 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Jun, 22 | Unidentified | 1 | 1 | 0.54 |
| Monsoon | Bakkhali River estuary | Jul,22 | Ambassidae | 1 | 4 | 1.82 |
| | | Sep,22 | Ambassidae | 3 | | 0.00 |
| | | Jul,22 | Blenniidae | 2 | 8 | 3.64 |
| | | Sep,22 | Blenniidae | 3 | | 0.00 |
| | | Oct,22 | Blenniidae | 3 | | 0.00 |
| | | Sep,22 | Carangidae | 5 | 5 | 2.27 |
| | | Sep,22 | Clupeidae | 5 | 105 | 47.73 |
| | | Oct,22 | Clupeidae | 100 | | 0.00 |
| | | Jul,22 | Engraulidae | 4 | 24 | 10.91 |
| | | Aug,22 | Engraulidae | 6 | | 0.00 |
| | | Oct,22 | Engraulidae | 14 | | 0.00 |
| | | Jul,22 | Mugilidae | 3 | 6 | 2.73 |
| | | Sep,22 | Mugilidae | 3 | | 0.00 |
| | | Jul,22 | Myctophidae | 4 | 4 | 1.82 |
| | | Aug,22 | Phosicthyidae | 1 | 3 | 1.36 |
| | | Sep,22 | Phosicthyidae | 2 | | 0.00 |
| | | Jul,22 | Pomacentridae | 6 | 6 | 2.73 |
| | | Aug,22 | Pristigasteridae | 3 | 3 | 1.36 |
| | | Jul,22 | Sillaginidae | 3 | 50 | 22.73 |
| | | Oct,22 | Sillaginidae | 47 | | 0.00 |
| | | Sep,22 | Trichonotidae | 2 | 2 | 0.91 |
| Winter | Bakkhali River estuary | Dec, 22 | Ambassidae | 9 | 11 | 3.40 |
| | | Jan, 22 | Ambassidae | 2 | | 0.00 |
| | | Nov,22 | Blenniidae | 11 | 19 | 5.86 |
| | | Dec, 22 | Blenniidae | 8 | | 0.00 |
| | | Nov,22 | Clupeidae | 15 | 114 | 35.19 |
| | | Dec, 22 | Clupeidae | 9 | | 0.00 |
| | | Jan, 22 | Clupeidae | 1 | | 0.00 |
| | | Feb, 22 | Clupeidae | 89 | | 0.00 |
| | | Nov,22 | Engraulidae | 4 | 8 | 2.47 |
| | | Dec, 22 | Engraulidae | 4 | | 0.00 |
| | | Jan, 22 | Engraulidae | 16 | 79 | 24.38 |
| | | Feb, 22 | Engraulidae | 63 | | 0.00 |
| | | Nov,22 | Gobiidae | 4 | 6 | 1.85 |
| | | Jan, 22 | Gobiidae | 2 | | 0.00 |
| | | Jan, 22 | Hemiramphidae | 1 | 1 | 0.31 |
| | | Nov,22 | Mugilidae | 1 | 18 | 5.56 |
| | | Jan, 22 | Mugilidae | 17 | | 0.00 |
| | | Dec, 22 | Myctophidae | 3 | 12 | 3.70 |
| | | Dec, 22 | Myctophidae | 3 | | 0.00 |
| | | Dec, 22 | Myctophidae | 6 | | 0.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Jan, 22 | Myctophidae | 1 | 1 | 0.31 |
| | | Dec, 22 | Pristigasteridae | 1 | 1 | 0.31 |
| | | Dec, 22 | Siganiidae | 5 | 14 | 4.32 |
| | | Nov,22 | Siganiidae | 9 | | 0.00 |
| | | Dec, 22 | Sillaginidae | 5 | 11 | 3.40 |
| | | Jan, 22 | Sillaginidae | 6 | | 0.00 |
| | | Nov,22 | Sinodontidae | 6 | 6 | 1.85 |
| | | Dec, 22 | Terapontidae | 1 | 1 | 0.31 |
| | | Jan, 22 | Unidentified | 22 | 22 | 6.79 |
| Summer | Rezukhal Estuary | May,22 | Carangidae | 1 | 1 | 0.22 |
| | | Mar,22 | Clupeidae | 84 | 172 | 38.65 |
| | | Mar,22 | Clupeidae | 84 | | 0.00 |
| | | Jun, 22 | Clupeidae | 4 | | 0.00 |
| | | Mar,22 | Engraulidae | 111 | 222 | 49.89 |
| | | Mar,22 | Engraulidae | 111 | | 0.00 |
| | | May,22 | Engraulidae | 38 | 41 | 9.21 |
| | | Jun, 22 | Engraulidae | 3 | 3 | 0.67 |
| | | May,22 | Gerreidae | 6 | 6 | 1.35 |
| Monsoon | Rezukhal Estuary | Jul,22 | Ammodytidae | 1 | 2 | 2.27 |
| | | Sep,22 | Ammodytidae | 1 | | 0.00 |
| | | Jul,22 | Blenniidae | 2 | 2 | 2.27 |
| | | Jul,22 | Engraulidae | 4 | 6 | 6.82 |
| | | Sep,22 | Engraulidae | 2 | | 0.00 |
| | | Sep,22 | Megalopidae | 2 | 2 | 2.27 |
| | | Jul,22 | Mugilidae | 3 | 6 | 6.82 |
| | | Sep,22 | Mugilidae | 3 | | 0.00 |
| | | Jul,22 | Myctophidae | 4 | 5 | 5.68 |
| | | Sep,22 | Myctophidae | 1 | | 0.00 |
| | | Jul,22 | Pomacentridae | 9 | 21 | 23.86 |
| | | Sep,22 | Pomacentridae | 12 | | 0.00 |
| | | Sep,22 | Siganidae | 3 | 3 | 3.41 |
| | | Jul,22 | Sillaginidae | 3 | 6 | 6.82 |
| | | Sep,22 | Sillaginidae | 2 | | 0.00 |
| | | Sep,22 | Sillaginidae | 1 | | 0.00 |
| | | Sep,22 | Terapontidae | 3 | 35 | 39.77 |
| Winter | Rezukhal Estuary | Dec, 22 | Ambassidae | 1 | 13 | 10.24 |
| | | Jan, 22 | Ambassidae | 10 | | 0.00 |
| | | Feb, 22 | Ambassidae | 2 | | 0.00 |
| | | Nov,22 | Belonidae | 1 | 14 | 11.02 |
| | | Nov,22 | Blenniidae | 9 | | 0.00 |
| | | Dec, 22 | Blenniidae | 4 | | 0.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Nov,22 | Clupeidae | 13 | 17 | 13.39 |
| | | Jan, 22 | Clupeidae | 4 | | 0.00 |
| | | Nov,22 | Engraulidae | 10 | 43 | 33.86 |
| | | Dec, 22 | Engraulidae | 4 | | 0.00 |
| | | Jan, 22 | Engraulidae | 29 | | 0.00 |
| | | Jan, 22 | Gobiidae | 2 | 2 | 1.57 |
| | | Jan, 22 | Hemiramphidae | 3 | 3 | 2.36 |
| | | Dec, 22 | Myctophidae | 2 | 5 | 3.94 |
| | | Jan, 22 | Myctophidae | 3 | | 0.00 |
| | | Dec, 22 | Pamacentridae | 1 | 1 | 0.79 |
| | | Dec, 22 | Pomacentridae | 1 | 1 | 0.79 |
| | | Dec, 22 | Pristigasteridae | 1 | 1 | 0.79 |
| | | Dec, 22 | Siganidae | 1 | 1 | 0.79 |
| | | Nov,22 | Silaginidae | 11 | 24 | 18.90 |
| | | Dec, 22 | Sillaginidae | 2 | | 0.00 |
| | | Jan, 22 | Sillaginidae | 11 | | 0.00 |
| | | Dec, 22 | Sparidae | 2 | 2 | 1.57 |
| Summer | St. Martin | Jun,20 | Ambassidae | 10 | 10 | 13.51 |
| | | Mar,20 | Carangidae | 1 | 1 | 1.35 |
| | | May,20 | Clupeidae | 21 | 43 | 58.11 |
| | | Jun,20 | Clupeidae | 22 | | 0.00 |
| | | Mar,20 | Gobiidae | 2 | 2 | 2.70 |
| | | Mar,20 | Hemiramphidae | 1 | 1 | 1.35 |
| | | Mar,20 | Mugilidae | 1 | 3 | 4.05 |
| | | Apr,20 | Mugilidae | 2 | | 0.00 |
| | | May,20 | Pomacentridae | 4 | 4 | 5.41 |
| | | Mar,20 | Serranidae | 2 | 2 | 2.70 |
| | | Mar,20 | Tetradontidae | 2 | 2 | 2.70 |
| | | Mar,20 | Unidentified | 1 | 6 | 8.11 |
| | | Apr,20 | Unidentified | 5 | | 0.00 |
| Monsoon | St. Martin | Sep,20 | Ambassidae | 3 | 3 | 0.59 |
| | | Aug,20 | Clupeidae | 74 | 74 | 14.48 |
| | | Jul,20 | Engraulidae | 66 | 135 | 26.42 |
| | | Sep,20 | Engraulidae | 5 | | 0.00 |
| | | Oct,20 | Engraulidae | 64 | | 0.00 |
| | | Jul,20 | Gobiidae | 152 | 152 | 29.75 |
| | | Sep,20 | Pomacentridae | 28 | 28 | 5.48 |
| | | Aug,20 | Scombridae | 4 | 4 | 0.78 |
| | | Oct,20 | Siganidae | 8 | 8 | 1.57 |
| | | Sep,20 | Terapontidae | 69 | 69 | 13.50 |
| | | Jul,20 | Unidentified | 38 | 38 | 7.44 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Winter | St. Martin | Dec,20 | Ambassidae | 2 | 17 | 31.48 |
| | | Jan,20 | Ambassidae | 15 | | 0.00 |
| | | Nov,20 | Blenniidae | 1 | 1 | 1.85 |
| | | Nov,20 | Clupeidae | 2 | 27 | 50.00 |
| | | Dec,20 | Clupeidae | 25 | | 0.00 |
| | | Feb,20 | Mugilidae | 2 | 2 | 3.70 |
| | | Jan,20 | Sillaginidae | 6 | 7 | 12.96 |
| | | Feb,20 | Sillaginidae | 1 | | 0.00 |

## Appendix-02

## Biodiversity indices (Station)

| Index | Station | Mean ± SD | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Margalef's richness index | Moheskhali Para | 2.26 ± 1.26 | 0.233 | 0.319 | 0.859 |
| | Naf River Estuary | 1.92 ± 0.39 | | | |
| | Bakkhali River Estuary | 1.81 ± 0.58 | | | |
| | Rezukhal Estuary | 1.66 ± 1.04 | | | |
| | St. Martin | 1.54 ± 0.70 | | | |
| | **Total** | **1.84 ± 0.77** | | | |
| | **Range** | **0.49 - 3.13** | | | |
| Simpson's Index | Moheskhali Para | 0.83 ± 0.09 | 0.011 | 0.802 | 0.551 |
| | Naf River Estuary | 0.68 ± 0.17 | | | |
| | Bakkhali River Estuary | 0.70 ± 0.09 | | | |
| | Rezukhal Estuary | 0.72 ± 0.11 | | | |
| | St. Martin | 0.69 ± 0.09 | | | |
| | **Total** | **0.72 ± 0.11** | | | |
| | **Range** | **0.51 - 0.89** | | | |
| Shannon-Weiner Index (H) | Moheskhali Para | 1.95 ± 0.52 | 0.102 | 0.493 | 0.742 |
| | Naf River Estuary | 1.58 ± 0.50 | | | |
| | Bakkhali River Estuary | 1.60 ± 0.45 | | | |
| | Rezukhal Estuary | 1.59 ± 0.48 | | | |
| | St. Martin | 1.47 ± 0.29 | | | |
| | **Total** | **1.64 ± 0.42** | | | |
| | **Range** | **1.04 - 2.30** | | | |
| Pielou's evenness index (J) | Moheskhali Para | 0.84 ± 0.01 | 0.019 | 2.465 | 0.113 |
| | Naf River Estuary | 0.64 ± 0.15 | | | |
| | Bakkhali River Estuary | 0.67 ± 0.09 | | | |
| | Rezukhal Estuary | 0.76 ± 0.02 | | | |
| | St. Martin | 0.71 ± 0.09 | | | |
| | **Total** | **0.72 ± 0.10** | | | |
| | **Range** | **0.48 -0.85** | | | |
| **95% Confidence interval, p = 0.05, df =2** | | | | | |

## Appendix-03

### Biodiversity indices (Season)

| Index | Season | Mean ± SD | F | Significance |
|---|---|---|---|---|
| Margalef's richness index | Summer | 1.28 ± 0.72 | 2.359 | 0.137 |
| | Monsoon | 2.17 ± 0.67 | | |
| | Winter | 2.06 ± 0.71 | | |
| Simpson's index | Summer | 0.61 ± 0.07 | 7.030 | 0.010 |
| | Monsoon | 0.80 ± 0.07 | | |
| | Winter | 0.76 ± 0.09 | | |
| Shannon-Weiner Index (H) | Summer | 1.22 ± 0.19 | 7.007 | 0.010 |
| | Monsoon | 1.92 ± 0.27 | | |
| | Winter | 1.77 ± 0.42 | | |
| Pielou's evenness index (J) | Summer | 0.65 ± 0.14 | 2.026 | 0.174 |
| | Monsoon | 0.77 ± 0.07 | | |
| | Winter | 0.75 ± 0.06 | | |
| | | | | **95% Confidence interval, p = 0.05, df =2** |

## Appendix-04

### Relative abundance of 10 mostly occurring families of fish larva

| Family | Moheshkhali para (%) | Naf River Estuary (%) | Bakkhali River Estuary (%) | Rezukhal Estuary (%) | St. Martin (%) |
|---|---|---|---|---|---|
| Ambassidae | 53 | 5.63 | 11.27 | 9.15 | 21.13 |
| Blenniidae | 4 | 65.55 | 27.73 | 1.68 | 0.84 |
| Carangidae | 1 | 2.04 | 94.90 | 1.02 | 1.02 |
| Clupeidae | 3 | 32.85 | 29.57 | 19.40 | 14.78 |
| Engraulidae | 7 | 20.15 | 16.10 | 39.54 | 17.11 |
| Mugilidae | 24 | 4.08 | 48.98 | 12.24 | 10.20 |
| Myctophidae | 13 | 32.69 | 30.77 | 19.23 | 3.85 |
| Pomacentridae | 2 | 8.20 | 4.92 | 32.79 | 52.46 |
| Siganidae | 11 | 41.82 | 25.45 | 7.27 | 14.55 |
| Sillaginidae | 10 | 15.91 | 46.21 | 22.73 | 5.30 |

**Appendix-05**

## Monthly variation of water quality variables in the study area

| Station | Month | Temperature (°C) | pH | Total Alkalinity (mg/L) | Salinity (psu) |
|---|---|---|---|---|---|
| Moheshkhali Para | Jan | 23.8 | 8.3 | 120 | 30 |
| | Feb | 27.1 | 8.4 | 120 | 36 |
| | Mar | 28.1 | 8.4 | 108 | 36 |
| | Apr | 31.8 | 8.4 | 112 | 32 |
| | May | 32.9 | 8.3 | 86 | 20 |
| | June | 28.3 | 8.4 | 98 | 31 |
| | July | 30.9 | 7.8 | 96 | 26 |
| | Aug | 31.3 | 8.1 | 100 | 31 |
| | Sep | 30.4 | 7.9 | 82 | 28 |
| | Oct | 31.1 | 7.5 | 80 | 26 |
| | Nov | 29.3 | 7.8 | 96 | 30 |
| | Dec | 27.8 | 6.6 | 80 | 30 |
| Naf River Estuary | Jan | 24.7 | 8.4 | 126 | 36.5 |
| | Feb | 25.5 | 8.3 | 98 | 31.7 |
| | Mar | 26.9 | 8.3 | 110 | 15.3 |
| | Apr | 31.4 | 8.2 | 116 | 34 |
| | May | 32.4 | 8.4 | 100 | 21 |
| | June | 28.6 | 8.3 | 102 | 23 |
| | July | 30.8 | 7.6 | 82 | 23 |
| | Aug | 29.2 | 7.2 | 94 | 25 |
| | Sep | 28.9 | 7.5 | 98 | 26 |
| | Oct | 26.3 | 8 | 100 | 26 |
| | Nov | 25.5 | 8.2 | 102 | 28.5 |
| | Dec | 25.5 | 8.4 | 102 | 37 |
| Bakkhali River Estuary | Jan | 24.7 | 8.4 | 126 | 36.5 |
| | Feb | 25.5 | 8.3 | 98 | 31.7 |
| | Mar | 26.9 | 8.3 | 110 | 15.3 |
| | Apr | 31.4 | 8.2 | 116 | 34 |
| | May | 32.4 | 8.4 | 100 | 21 |
| | June | 28.6 | 8.3 | 102 | 23 |
| | July | 30.8 | 7.6 | 82 | 23 |

| | | | | | |
|---|---|---|---|---|---|
| | Aug | 29.2 | 7.2 | 94 | 25 |
| | Sep | 28.9 | 7.5 | 98 | 26 |
| | Oct | 26.3 | 8 | 100 | 26 |
| | Nov | 25.5 | 8.2 | 102 | 28.5 |
| | Dec | 25.5 | 8.4 | 102 | 37 |
| Rezukhal Estuary | Jan | 22.7 | 8.4 | 124 | 33 |
| | Feb | 28.4 | 8.5 | 96 | 34 |
| | Mar | 30.8 | 8.4 | 116 | 36 |
| | Apr | 31.4 | 8.4 | 112 | 36 |
| | May | 32.6 | 8.3 | 96 | 18 |
| | June | 27.9 | 8.3 | 96 | 30 |
| | July | 31.6 | 8 | 88 | 21 |
| | Aug | 30.9 | 7.9 | 98 | 20 |
| | Sep | 28.3 | 7.6 | 98 | 29 |
| | Oct | 27.4 | 7.8 | 96 | 31 |
| | Nov | 26.9 | 8.2 | 90 | 34 |
| | Dec | 23.6 | 8.4 | 100 | 35 |
| St. Martin | Jan | 20.5 | 7.9 | 206 | 19.6 |
| | Feb | 23.4 | 7.2 | 236 | 19.8 |
| | Mar | 29.4 | 7.4 | 287 | 30.5 |
| | Apr | 28.1 | 7.7 | 298 | 31.1 |
| | May | 31.4 | 7.1 | 278 | 30.17 |
| | June | 29.5 | 8.2 | 286 | 32.4 |
| | July | 25.2 | 7.1 | 162 | 25.5 |
| | Aug | 25.9 | 7.8 | 230 | 19.7 |
| | Sep | 25.7 | 7.4 | 198 | 21.6 |
| | Oct | 24.6 | 8.9 | 176 | 18.9 |
| | Nov | 23.01 | 6.9 | 118 | 19.1 |
| | Dec | 20.6 | 8.3 | 235 | 19.2 |

# BRIEF BIOGRAPHY OF THE AUTHOR

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The author's name is Antar Sarkar, the elder son of Mr. Litan Sarkar and Mrs. Trisna Sarkar. The author was born on 15$^{th}$ July 1997 and grew up in Chattogram, the business capital and port city of Bangladesh. He passed his secondary level from the East Kadhurkhil High School Chattogram, and his higher secondary level from the Kazem Ali School and College, Chattogram. Then he got admitted to the Chattogram Veterinary and Animal Sciences University (CVASU) in 2016 and completed his graduation, B.Sc. Fisheries (Hons.), from the Faculty of Fisheries in 2021. Now, he is pursuing his master's degree from the Department of Fisheries Resource Management from the same faculty of CVASU. He loves to discover new things and dig deeper into the unknown mystery of fisheries science. He has a keen interest in fisheries resource conservation and management and wants to build his career in this sector. As a citizen of Bangladesh, he always desires to contribute to the sustainable development and proper management of the enormous fisheries resource of this country.