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# Larval Fish Assemblages in Coastal Waters of Bangladesh: Spatial and Seasonal Dynamics

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**Abstract:** The distribution of fish larvae in estuaries is crucial for comprehending the functioning of these ecosystems and their role as nursery grounds for marine fish species. Data regarding larval fish assemblages in the coastal waters of Bangladesh are currently scarce. This study examines the spatial and seasonal dynamics of larval fish communities in these waters using a two-year sampling effort with a bongo net. This study investigates the diversity, abundance, and distribution of larval fishes at four sites (Bakkhali River Estuary, Moheshkhalipara, Naf River Estuary, and Rezu Khal Estuary) on the southeastern coast of Bangladesh. A total of 10,387 fish larvae representing 25 families were identified. Clupeidae (42.9%), Engraulidae (35.5%), Ambassidae (10.1%), Myctophidae (2.1%), and Gobiidae (1.9%) were the five most dominant families based on the larval catch composition. Marked seasonal differences in the larval fish abundance were observed. However, these differences were not observed when comparing the four sampled sites. Additionally, the correlation between environmental variables and the larval abundance indicated that salinity negatively influences ($p < 0.001$) the larval fish abundance. This is the first comprehensive investigation of larval fish assemblages in the coastal waters of Bangladesh. The findings of this study enhance our understanding of the nursery habitat requirements for the early development stages of both migratory and resident species in subtropical coastal waters, providing valuable information for potential applications in management and conservation efforts.

**Keywords:** Bay of Bengal; estuary; fish larvae; biodiversity; spatiotemporal distribution

## 1. Introduction

The coastal region of Bangladesh is blessed with a warm tropical climate and abundant rainfall, further enriched by terrestrial nutrients, resulting in a globally significant ecosystem [1,2]. Larval and adult fishes are considered distinct ecospecies due to their drastically different ecological requirements [3]. Fish larvae exhibit distinct morphological features that facilitate their differentiation from adult specimens [4]. Fish larvae abundance and distribution patterns have been known indicators for a long time, and thus, it is a useful tool for sustainable fishery management [5,6]. It is now widely accepted that data derived from fish eggs and larvae play a crucial role in fishery science, contributing to accurate fish population assessments and management strategies [7].

The fish larvae distribution and abundance are influenced by a variety of factors, including habitat, seasonality, and water parameters [8,9]. Significant environmental factors, such as water temperature, salinity, and turbidity, directly impact fish larvae, affecting their growth, food resources, survival, abundance, and dispersal [10]. Identifying key correlations between fish fauna and environmental conditions is essential for incorporating habitat information into fish abundance models [10,11]. The abundance of fish larvae is influenced by early replenishment, survival rate, and environmental factors, but the relationship between fish resources and the marine environment is complex, involving numerous interconnected factors and influences [12,13].

Some previous studies have investigated the association between the frequency of occurrence, life history changes in fish larvae, and the mismatch in peak abundance distributions [14,15]. The identification of fish eggs and larvae presents challenges, owing to their indistinct external features at initial developmental stages [16]. However, body structure, color patterns, and meristic and morphometric traits are crucial for species identification [17]. For instance, meristic traits like myomere, vertebrae, and fin ray counts are particularly useful as they may be species-specific [17,18]. The accurate identification and classification of fish larval species are critical for effective fisheries management as they allow us to estimate parent population size, predict future recruitment, and identify critical spawning and nursery sites [19].

Numerous studies have confirmed the species composition of fishery resources in the coastal waters of Bangladesh, e.g., [20–22]. However, our understanding of the ecology of fish larvae in these regions remains limited. Previous research has confirmed the presence of 98 fish species in the southern coastal waters of Bangladesh, with a predominant contribution from species belonging to the Perciformes and Cypriniformes families [20]. Additionally, some earlier investigations have primarily focused on the seasonal variation in the primary production, composition, and abundance of mesozooplankton [23,24].

Fish larvae data may be useful as a supplementing information for fishery management and conservation efforts [25,26]. The overall aim of this investigation is to enhance our understanding of the ecology of fish larvae from the coastal waters of tropical and subtropical regions. This ecological information is essential for conserving these valuable resources. The specific objective of this study was to investigate the abundance of fish larvae and their distribution in relation to environmental variables at four sites (Bakkhali River Estuary, Moheshkhalipara, Naf River Estuary, and Rezu Khal Estuary) on the southeastern coast of Bangladesh. The insights from this study could guide decisions towards sustaining fish populations in the Bay of Bengal and therefore, the data presented in this paper may have management and conservation implications.

## 2. Materials and Methods

### *2.1. Study Sites*

The study was conducted for 24 months at four sampling sites along the southeastern coast of Bangladesh: Bakkhali River Estuary (21.471501 N, 91.950445 E), Moheshkhalipara Coast (20.8636944 N, 92.250555 E), Naf River Estuary (20.730300 N, 92.3421011 E), and Rezu Khal Estuary (21.2952777 N, 92.035000 E) (Figure 1a). Among the four sampling sites, the Bakkhali River Estuary, the Naf River Estuary, and the Rezu Khal Estuary are situated in estuarine environments, while the Moheshkhalipara coast is categorized as a coastal area.

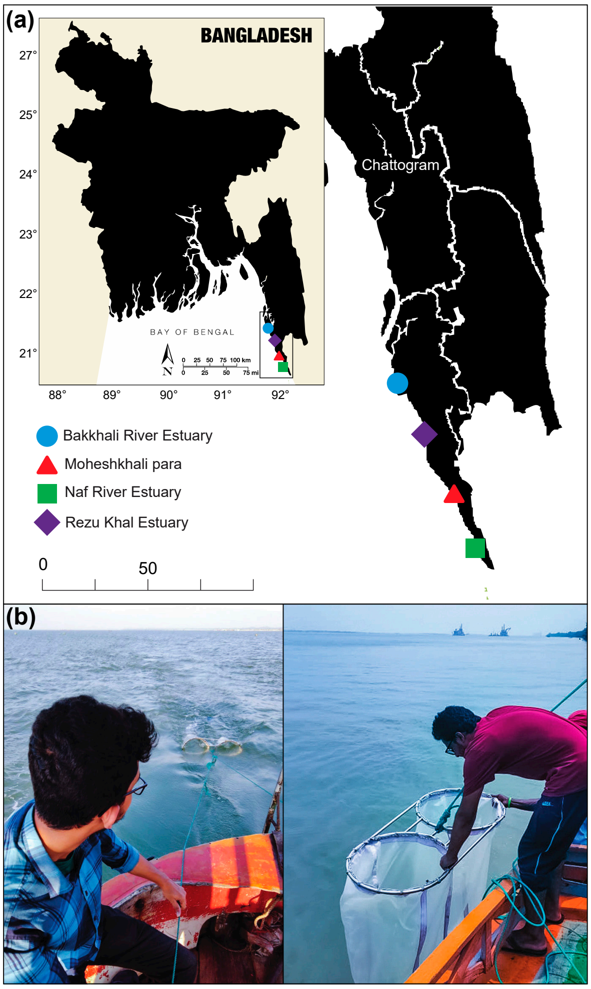


**Figure 1.** Location of the sampling sites and sample collection using a bongo net. (**a**) The mapping of four selected research sites on the southeastern coast of Bangladesh, which is denoted as the Bakkhali River Estuary (blue), the Moheshkhali para Coast (red), the Naf River Estuary (green), and the Rezu Khal Estuary (purple). (**b**) Sampling of fish larvae using a bongo net during field investigation (source; authors).

### 2.2. Sampling Procedure for the Collection of Fish Larvae

Monthly sampling was conducted between January 2020 and December 2021 using a 0.50 m diameter, 1.3 m long, and 500 µm mesh size bongo net (Figure 1b). Each tow duration was roughly 10 min, covering approximately 2 km of surface area. The bongo net was pulled horizontally at a depth of 0.5–1.5 m to capture a wide range of fish larvae (Figure 1b). A digital flow meter (Model: KC Denmark A/S 23.090–23.091) was attached to the net mouth to calculate the volume of seawater filtered during each tow. After each tow, samples were preserved in 90% ethanol for transportation to the laboratory.

### 2.3. Sample Processing in the Laboratory

Samples were carefully sorted in the laboratory to isolate and identify fish larvae. The first step involved discarding the ethanol from the sample. Then, the samples were thoroughly washed with distilled water to remove any sand particles, plastics, leaves, and other debris. The washed larvae were placed back in a jar with 90% ethanol for storage. Individual larvae were then examined under an Optika Italy C-B3 stereo microscope at low magnification (10×) to identify them up to family level using the guidelines described previously [18,27,28]. Briefly, larvae were classified into distinct groups according to the pictorial descriptions of the different larval families provided in references [18,27,28]. These categorized larvae were subsequently cross-referenced with their detailed morphological profiles. Key morphological traits for classification encompassed body morphology and dimensions, pigmentation patterns, fin morphology, meristic counts, as well as the presence and maturation of sensory systems, occasionally extending to skeletal structures.

*2.4. Determination of the Frequency of Occurrence*

The frequency of occurrence was determined based on the ecological index described in [29], and the following formula was used for the calculation:

$$C = \frac{P}{Q} \times 100$$

where $C$ = frequency of occurrence of the family (%), $P$ = the number of samples where the family occurred, and $Q$ = the total number of samples.

The identified families were further divided into three categories based on the value of frequency of occurrence, which were (1) frequent (when C > 50%), (2) moderate (when 25% $\leq$ C $\leq$ 50%), and (3) accidental (when C < 25%) [30]. In this study, no accidental families were encountered.

*2.5. Assessment of Environmental Parameters*

Water quality parameters such as temperature, salinity, dissolved oxygen (DO), pH, alkalinity, total dissolved solids (TDSs), and transparency were measured to evaluate their potential influence on fish larval abundance and distribution. Temperature and DO were measured using an electronic probe (Model: JANEWAY-9500), salinity using a refractometer (Model: Hanna HI-96822), and water transparency using a Secchi disk. Total alkalinity was determined using the Gran titration method, where Phenol-phthalein and Methyl Orange were used as an indicator. pH and TDS were measured in the laboratory using electrode probe methods (Model: Hanna HI-2211).

*2.6. Data Visualization and Statistical Analysis*

The Shannon–Wiener diversity index [31] was used to express the diversity of the fish larval assemblages, evenness was measured by Pielou's evenness index [32], and richness [33] was calculated using the following formulas.

- Shannon $-$ Wiener diversity index, $H' = -\sum_{n=1}^{n} P_i ln(P_i)$
  where $H'$ is the diversity index, $P_i$ is the proportion of each species in the sample, and $ln(P_i)$ is the natural logarithm of this proportion.
- Margalef's richness index, $d = \frac{S-1}{lnN}$
  where $S$ is the number of species in a sample, $N$ is the total number of individuals, and $ln$ is the natural logarithm.
- Pielou's evenness index, $J = \frac{H'}{lnS}$
  where $H'$ = Shannon–Wiener diversity index, $S$ = total number of species in the sample.

To determine the seasonal differences in environmental parameters and fish larvae abundance, monthly data were categorized into three distinct seasons: pre-monsoon hot season (March, April, May), rainy monsoon season (June, July, August, September, and October), and winter season (November, December, January, and February) [34,35]. Two-way analysis of variance (ANOVA) was used to assess significant differences in fish larvae abundance and environmental parameters among sites (four levels), and seasons (three levels). Pearson's correlation analysis was employed to investigate the relationships between fish larvae abundance and physicochemical variables. The analyses were carried out in the R environment [36] using the Vegan [37] and ggplot2 [38] packages.

## 3. Results

*3.1. Environmental Parameters*

Our two-year study at four coastal water sites in Bangladesh revealed a wide range of environmental parameters. Specifically, the temperatures fluctuated between 13.9 °C and 35.5 °C (Figure 2a), the salinity levels ranged from 8 to 36 ppt (Figure 2b), the DO concentrations varied between 3.8 and 9 mg/L (Figure 2c), the pH values ranged from 6.1 to 9.1 (Figure 2d), the TDSs fell within the range of 320 to 655 ppm (Figure 2e), the alkalinity values ranged from 52 to 309 ppm (Figure 2f), and the water transparency extended from 26 to 126 cm (Figure 2g). Notably, significant seasonal variations were observed in the water temperature, salinity, DO, pH, TDS, and transparency (Table 1).

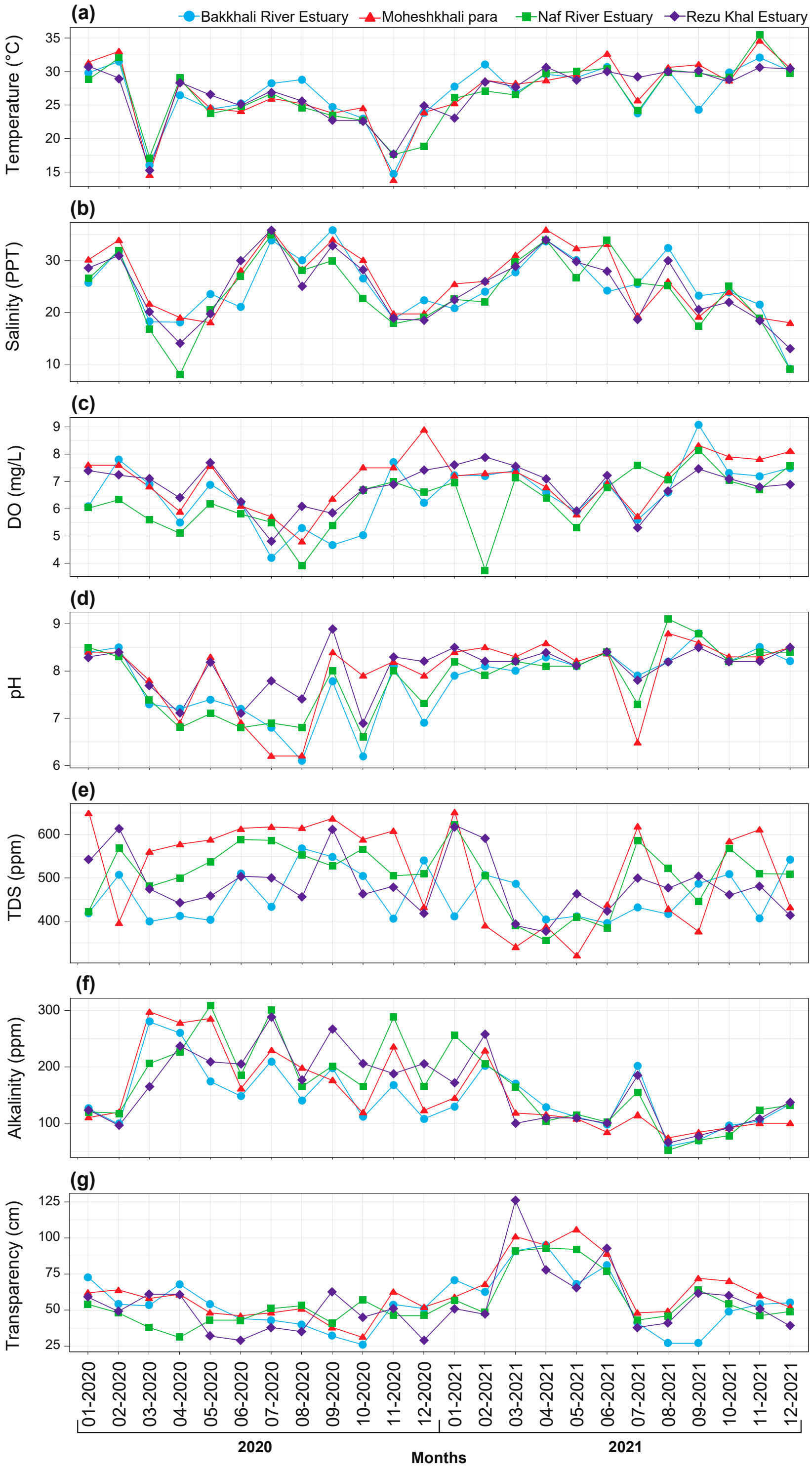


**Figure 2.** Monthly variation in water quality parameters at four sites (Bakkhali River Estuary, Moheshkhalipara, Naf River Estuary, and Rezu Khal Estuary) throughout two years of sampling: (**a**) temperature, (**b**) salinity, (**c**) DO, (**d**) pH, (**e**) TDS, (**f**) alkalinity, and (**g**) water transparency.

**Table 1.** Two-way ANOVA for testing the effect of seasons and sampling sites on biological and environmental variables over the study period (2020–2021). Asterisks indicate significant differences (two-way ANOVA, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). Significant $p$ values are in bold.

| Variables | Source | DF | F Value | Pr (>F) |
|---|---|---|---|---|
| Larval abundance (ind./1000 $m^3$) | Season | 2 | 6.08 | **0.002** ** |
| | Site | 3 | 2.02 | 0.112 |
| Pielou's evenness | Season | 2 | 2.20 | 0.119 |
| | Site | 3 | 1.28 | 0.288 |
| Richness | Season | 2 | 2.46 | 0.091 |
| | Site | 3 | 3.1 | **0.031** * |
| Shannon | Season | 2 | 0.84 | 0.437 |
| | Site | 3 | 0.71 | 0.549 |
| Temperature (°C) | Season | 2 | 7.85 | **<0.001** *** |
| | Site | 3 | 0.04 | 0.9903 |
| Salinity (PPT) | Season | 2 | 52.91 | **<0.001** *** |
| | Site | 3 | 1.06 | 0.369 |
| DO (mg/L) | Season | 2 | 5.86 | **0.004** ** |
| | Site | 3 | 2.81 | **0.044** * |
| pH | Season | | 5.36 | **0.006** ** |
| | Site | 3 | 0.93 | 0.430 |
| TDS (ppm) | Season | 2 | 7.57 | **<0.001** *** |
| | Site | 3 | 2.66 | 0.053 |
| Alkalinity (ppm) | Season | 2 | 2.52 | 0.086 |
| | Site | 3 | 0.44 | 0.726 |
| Transparency (cm) | Season | 2 | 12.18 | **<0.001** *** |
| | Site | 3 | 1.15 | 0.332 |

### *3.2. Fish Community Composition*

The fish investigated (10,387 individuals) comprised 25 families (Table 2). The average number of fish larvae was 2597 larvae/1000 $m^3$ in each site. Based on the percentage of the catch, the families Clupeidae (42.91%), Engraulidae (35.53%), Ambassidae (10.13%), Myctopidae (2.09%), and Gobiidae (1.95%) were predominant in the study areas (Table 2). In addition, among the 25 identified families, 8 contained economically important species [39] (Table 2). Representative pictures of the dominant fish larval families observed in the present investigation are shown in Figure 3.

**Table 2.** The abundance of fish larvae at different sampling sites (expressed as larvae per 1000 $m^3$). The economically significant groups are identified by an asterisk (*).

| SL | Family Name | Abundance | | | |
|---|---|---|---|---|---|
| | | Bakkhali Estuary | Moheshkhalipara | Naf Estuary | Rezu Khal Estuary |
| 1 | Clupeidae * | 705 | 924 | 1452 | 1376 |
| 2 | Engraulidae * | 226 | 445 | 898 | 2122 |
| 3 | Ambassidae | 363 | 237 | 399 | 53 |
| 4 | Myctopidae | 2 | 73 | 39 | 103 |
| 5 | Gobiidae | 36 | 159 | 1 | 7 |
| 6 | Mugilidae | 22 | 5 | 0 | 143 |
| 7 | Terapontidae | 2 | 69 | 0 | 15 |
| 8 | Blenniidae | 36 | 2 | 16 | 30 |
| 9 | Sillaginidae | 12 | 10 | 11 | 33 |
| 10 | Polynemidae | 2 | 35 | 0 | 3 |
| 11 | Sparidae | 2 | 7 | 3 | 22 |
| 12 | Pomacentridae | 0 | 32 | 0 | 1 |
| 13 | Carangidae * | 0 | 11 | 6 | 9 |
| 14 | Megalopidae | 21 | 0 | 0 | 4 |
| 15 | Scaridae | 6 | 1 | 0 | 15 |

**Table 2.** *Cont.*

| SL | Family Name | Abundance | | | |
|---|---|---|---|---|---|
| | | **Bakkhali Estuary** | **Moheshkhalipara** | **Naf Estuary** | **Rezu Khal Estuary** |
| 16 | Hemiramphidae * | 0 | 1 | 11 | 7 |
| 17 | Siganidae | 0 | 8 | 0 | 1 |
| 18 | Synodontidae * | 0 | 5 | 4 | 0 |
| 19 | Scombridae * | 0 | 4 | 0 | 0 |
| 20 | Gerreidae * | 2 | 0 | 0 | 1 |
| 21 | Sciaenidae | 0 | 0 | 1 | 1 |
| 22 | Serranidae * | 0 | 2 | 0 | 0 |
| 23 | Tetradontidae | 0 | 2 | 0 | 0 |
| 24 | Drepaneidae | 0 | 1 | 0 | 0 |
| 25 | Uranoscopidae | 1 | 0 | 0 | 0 |
| | Unidentified | 24 | 50 | 27 | 28 |
| | Total | 1462 | 2083 | 2868 | 3974 |


**Figure 3.** Photos of the dominant fish larvae, collected from January 2020 to December 2021 in four different locations during this investigation (source: authors). Fish larvae were identified up to the family level using the guidelines described previously [18,27,28].

Among the 25 identified families, 11 were frequent and 14 were moderate. The ratios of frequent:moderate:accidentally found families were 44:56:00 (Table 3).

**Table 3.** Descriptive statistics of the identified fish larvae represented at the family level alongside their frequency of occurrence. The larvae families are categorized according to frequency of occurrence and identified them by an asterisk (*).

| Family | Total Larvae per 1000 $m^3$ | Mean Larvae per 1000 $m^3$ | % of Total Catch | Rank | Frequency of Occurrence | Frequent | Moderate |
|---|---|---|---|---|---|---|---|
| Clupeidae | 4457 | 1114 | 42.91 | 1 | 100 | * | |
| Engraulidae | 3691 | 923 | 35.53 | 2 | 100 | * | |
| Ambassidae | 1052 | 263 | 10.13 | 3 | 25 | | * |
| Myctopidae | 217 | 54 | 2.09 | 4 | 100 | * | |
| Gobiidae | 203 | 51 | 1.95 | 5 | 100 | * | |
| Mugilidae | 170 | 43 | 1.64 | 6 | 75 | * | |
| Terapontidae | 86 | 22 | 0.83 | 7 | 75 | * | |
| Blenniidae | 84 | 21 | 0.81 | 8 | 100 | * | |
| Sillaginidae | 66 | 17 | 0.64 | 9 | 50 | | * |
| Polynemidae | 40 | 10 | 0.39 | 10 | 75 | * | |
| Sparidae | 34 | 9 | 0.33 | 11 | 100 | * | |
| Pomacentridae | 33 | 8 | 0.32 | 12 | 50 | | * |
| Carangidae | 26 | 7 | 0.25 | 13 | 75 | * | |
| Megalopidae | 25 | 6 | 0.24 | 14 | 50 | | * |
| Scaridae | 22 | 6 | 0.21 | 15 | 75 | * | |
| Hemiramphidae | 19 | 5 | 0.18 | 16 | 50 | | * |
| Siganidae | 9 | 2 | 0.09 | 17 | 50 | | * |
| Synodontidae | 9 | 2 | 0.09 | 18 | 50 | | * |
| Scombridae | 4 | 1 | 0.04 | 19 | 25 | | * |
| Gerreidae | 3 | 1 | 0.03 | 20 | 50 | | * |
| Sciaenidae | 2 | 1 | 0.02 | 21 | 50 | | * |
| Serranidae | 2 | 1 | 0.02 | 22 | 25 | | * |
| Tetradontidae | 2 | 1 | 0.02 | 23 | 25 | | * |
| Drepaneidae | 1 | 1 | 0.01 | 24 | 25 | | * |
| Uranoscopidae | 1 | 1 | 0.01 | 25 | 25 | | * |
| Unidentified | 129 | 32 | 1.24 | | | | |
| Total | 10,387 | | 100.0 | | | | |

### *3.3. Spatial and Temporal Variation in Fish Abundance and Diversity*

Figure 4 presents a comparison of the fish larval abundance at the family level in the selected sites for a two-year sampling period. Among the study sites, the Moheshkhalipara coast exhibited the highest number of families (21) followed by the Rezu Khal Estuary (19), Bakkhali River Estuary (15), and Naf River Estuary (12). The Naf River Estuary displayed the least number of larval families among the stations. No significant difference was observed in the larval abundance among the sites ($p > 0.05$; Table 1). The highest abundance was recorded in the Rezukhal Estuary (3974 larvae/1000 $m^3$), whereas the lowest number of larvae was found in the Bakkhali River Estuary (1462 larvae/1000 $m^3$) (differences were not statistically significant; Table 2). In most cases, April to September in the Bakkhali River Estuary presented a higher larval abundance compared to the other sampling months (Figure 4a). The largest quantity of larvae was observed in Moheskhalipara in July, and this location generally exhibited the highest larval abundance from April to November (Figure 4b). The Naf River and Rezu Khal estuaries experienced the highest larval abundance during August and September (Figure 4c,d). Notably, distinct fluctuations in the larval fish abundance were observed across seasons, as shown in Table 1. Generally, higher occurrences of larvae were prevalent during the monsoon season (refer to Supplementary Figure S1), whereas lower occurrences were observed during winter.

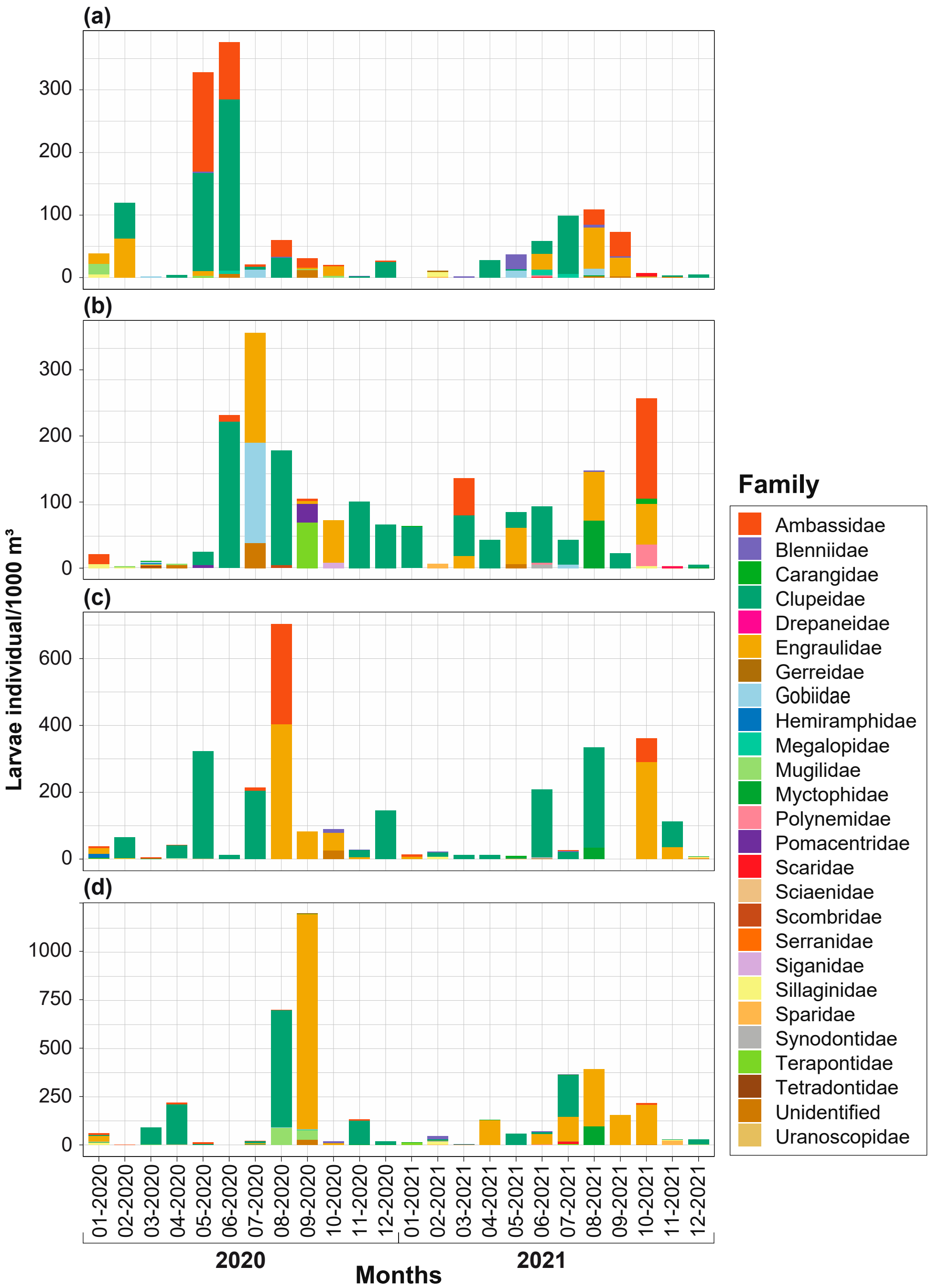


**Figure 4.** A comparative analysis of the fish larvae abundance at the family level in four sites for two years of sampling: (**a**) Bakkhali River Estuary, (**b**) Moheshkhalipara, (**c**) Naf River Estuary, and (**d**) Rezu Khal Estuary.

The highest diversity index (1.94) and evenness (1.00) were observed at the Moheskhalipara coast in March 2020, indicating a well-balanced and diverse fish larval community. The highest species richness (1.01) was documented in the Rezu Khal Estuary in September 2020, representing the presence of a broad range of fish larval species. Additionally, the Moheskhalipara also exhibited the second-highest richness (0.91) in March 2020 (Figure 5). In contrast, the Bakkhali River Estuary exhibited the lowest diversity and richness values throughout the study period, particularly during the months of March to April in both 2020 and 2021. The lowest evenness was observed in the Naf River Estuary in May 2020 (Figure 5), suggesting a lack of balance in the abundance of different fish larval species.

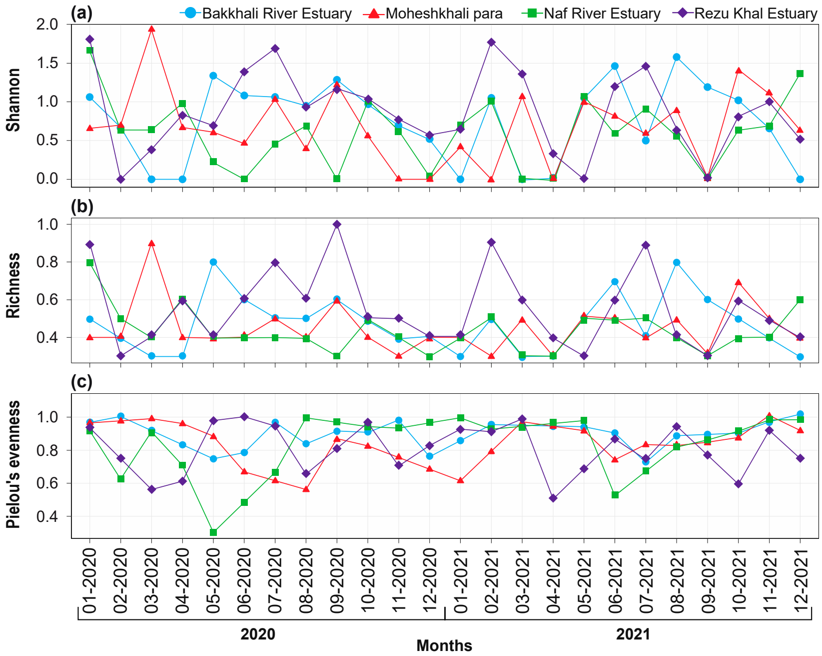


**Figure 5.** (**a**) Shannon diversity, (**b**) species richness, and (**c**) evenness of fish larvae at four estuaries (Bakkhali River Estuary, Moheshkhalipara, Naf River Estuary, and Rezu Khal Estuary) over two years of sampling.

### *3.4. Influence of Environmental Parameters on the Larval Fish Distribution*

Correlation analyses were conducted to investigate the relationship between environmental parameters and the fish larval abundance (Figure 6). The findings revealed a negative correlation between the salinity ($p < 0.001$) and DO ($p < 0.05$) with the larval abundance (Figure 6).

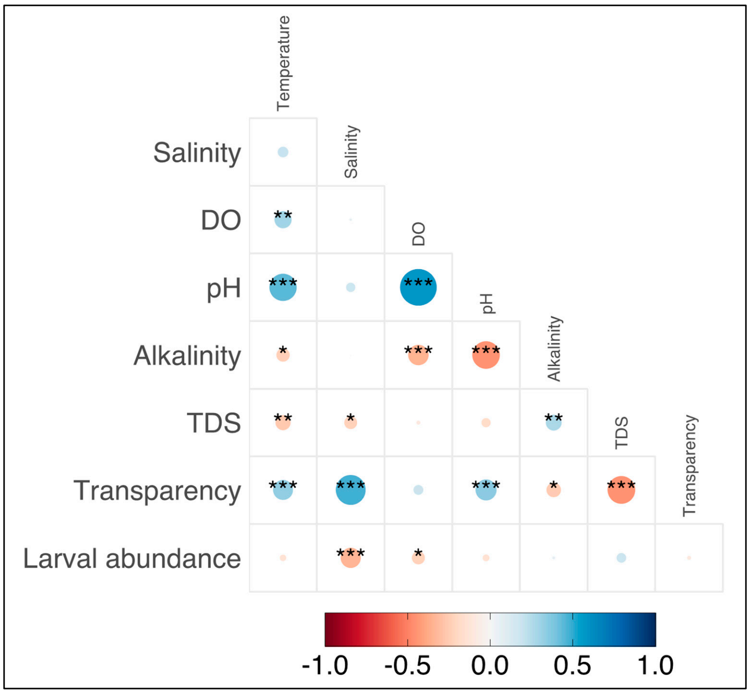


**Figure 6.** The Pearson correlation analysis between larval abundance and abiotic factors was measured in the study areas. The number of asterisks denotes the significance of the correlation: * denotes $0.05 < p < 0.01$, ** denotes $0.01 < p < 0.001$, *** denotes $p < 0.001$. The colors and size of circles indicate correlation values, from 1 (blue) to $-1$ (red).

## 4. Discussion

This study provides the first comprehensive assessment of the fish larval abundance and associated ecological variables in coastal waters along the southeastern coast of Bangladesh. The study identified a total of 25 families of larvae; eight of these comprised economically important species (Table 2). The results of different studies in regard to the number of recorded fish families are shown in Table 4. This diversity is lower than the number of fish larvae families recorded in other parts of the Indian Ocean, such as 52 families in the Bay of Bengal [30] and 92 neritic and 21 mesopelagic teleost fish larvae families in the Tropical Indian Ocean [39]. In another study, 80 species belonging to 69 larvae families were also identified in the Indian Ocean using morphological and molecular methods [40]. In the southwestern part of the Sea of Oman, 40 larvae fish families were identified [41]. This lower diversity could be attributed to the narrower shelf along the southeastern coast of Bangladesh, which may limit the retention of nutrients carried by rivers and restrict the growth of phytoplankton, a key food source for fish larvae [30].

**Table 4.** The comparison table shows the results of different studies in regard to the number of recorded fish families.

| References | Location | Number of Families | Remarks |
|---|---|---|---|
| [9] | Marudu Bay, Sabah, Malaysia | 20 | Mangrove estuarine sites |
| [25] | North coast of Jamaica | 39 | Total 41 species with abundance of reef fisheries |
| [29] | Fortaleza Lagoon, Cidreira, Brazil | 12 | Total 22 species reported |
| [30] | Bay of Bengal (Indian Ocean) | 52 | - |
| [39] | Eastern Indian Ocean | 113 | Including neritic and mesopalagic species |
| [40] | Indian Ocean | 69 | Both morphological and molecular techniques utilized to identify species |
| [41] | Southwestern part of the Sea of Oman | 40 | - |
| [42] | Pendas River estuary, Malaysia | 19 | Mangrove estuarine sites |
| Present study | Bangladeshi coastal waters (Bay of Bengal) | 25 | Eight families are commercially important |

Our study found five dominant families (Clupeidae, Engraulidae, Ambassidae, Myctopidae, and Gobiidae) to be consistently present across all the study sites (Table 2). This finding is inconsistent with the results reported by [30], showing that the families Photichthyidae, Myctophidae, Bregmacerotidae, Gonostomatidae, Callionymidae, and Carangidae were the most abundant in the Bay of Bengal. Four of the most common larvae families, Sparidae, Scombridae, Clupeidae, and Nemipteridae, were identified in the southwestern part of the Sea of Oman in a previous study [41]. The most prevalent family among the 19 families of the Pendas River estuary of the southwestern part of Malaysia was Clupeidae [42], which aligns with the findings of our study.

This research classified the identified families into three levels: frequent, moderate, and accidental. Out of the 25 families, 11 (44%) were classified as frequent and 15 (56%) as moderate, meaning that all the detected families were between 25% and 100% of the time at the study sites (Table 3). This finding is consistent with a previous study that found only a number of frequent (28 families) and moderate (22 families) families in the Bay of Bengal. However, they also found 50 accidental families in the western part of the Bay of Bengal [30].

The Moheshkhalipara coast was characterized by a relatively larger (differences were not statistically significant) number of larval families, greater diversity indices, and abundance compared to the other three study sites (Table 2 and Figures 4 and 5). This suggests that this site provides the most favorable habitats for fish larvae. The Rezu Khal Estuary may have a high larval abundance because it has an abundance of food and serves as a nursery ground for several commercial fish species [23,43]. Earlier research indicated that the installation of a rubber dam, which created a regulated environment and reduced species count, was responsible for the minimal diversity observed in the Bakkhali River Estuary [44]. The observed diversity indices (see Figure 5) were comparable to those observed in the Pendas River Estuary of the southwestern part of Malaysia (diversity index 1.48; richness 1.72; and evenness 0.77) [42].

Noticeable seasonal fluctuations in the larval abundance were apparent, particularly with a marked increase during the monsoon season. This surge can be attributed to multiple fish species actively breeding during this period [30]. These variations in the larval abundance are notably influenced by significant fluctuations in water quality parameters throughout the seasons, particularly factors such as water temperature, which is known to influence fish spawning [45]. Several field investigations highlight that water temperature and salinity events play a marked role in reproduction, larval recruitment, and abundance in the coastal and estuarine areas [45,46]. Our results in the seasonality of the larval fish abundance are consistent with earlier investigations carried out in the Indian Ocean [30].

Earlier investigations have demonstrated that water quality plays a crucial role in fish assemblages within an aquatic ecosystem and contributes significantly to their development. Abiotic environmental factors, including temperature, DO levels, salinity, alkalinity, pH, as well as nutrition, feeding, and hormones, all have an impact on fish growth, especially during their early life stages [47,48]. This study revealed a negative correlation between the larval abundance and water salinity (Figure 4), aligning with the established knowledge that salinity is a critical factor influencing the survival, abundance, and spatial distribution of fish larvae, particularly in estuarine coastal ecosystems (see review [49]). Typically, peak larval abundance is observed in the mesohaline zone, ranging from 5 to 17 PSU [50].

Our study has shed light on the abundance and distribution of fish larvae at four coastal sites in Bangladesh, highlighting the influence of environmental parameters on these patterns. Given the limited research on fish larvae in the Bay of Bengal, we aimed to contextualize our findings by comparing them to those observed in other parts of the Indian Ocean and adjacent seas. We advocate for the extended monitoring of the larval distribution and abundance in the region, along with the implementation of DNA barcoding for more precise identification, to generate more substantial results.

The study's findings offer valuable insights into the fish larval abundance and distribution along the southeastern coast of Bangladesh, providing crucial information for informed conservation and fishery management strategies. Identifying Moheshkhalipara coast as a key nursery habitat and understanding the seasonal fluctuations in the larval abundance, especially during the monsoon season, can enhance catch optimization and minimize impacts on juvenile fish populations. The negative correlation between the larval abundance and water salinity highlights the importance of salinity management for larval survival, while the identification of dominant larval families focuses conservation efforts on key species. Employing DNA barcoding for precise larval identification can further strengthen conservation and fishery management practices, enabling better population monitoring, stock assessment, and compliance with regulations. By incorporating these findings into conservation and fishery management strategies, Bangladesh can safeguard its valuable fish resources for sustainable fisheries in the future.

## 5. Conclusions

This study presents the first comprehensive ecological information on the diversity, abundance, and spatiotemporal distribution of fish larvae in the southeastern coast of Bangladesh. The findings reveal that the region supports a rich and dynamic fish larvae community, with marked variations in abundance and diversity across seasons and sites. Notably, the negative correlation between the larval abundance and water salinity suggests that salinity plays a critical role in larval survival. These findings have important implications for sustainable marine fishery management, particularly in determining the appropriate time to protect juveniles and enhance the recruitment of marine fisheries. Long-term studies utilizing DNA meta-barcoding are warranted to further explore the species composition of fish larvae resources and refine conservation and management strategies. Overall, this study provides a valuable foundation for understanding and managing fish larvae populations in the coastal waters of Bangladesh, laying the groundwork for sustainable fisheries in the region.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/conservation4010003/s1, Figure S1: A comparative analysis of the fish larvae abundance across seasons (Premon.:Pre-monsoon, Mon.: Monsoon, and Wint.: Winter) in four sites (Bakkhali River Estuary, Moheshkhalipara, Naf River Estuary, and Rezukhal Estuary).

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