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Macrobenthic Assemblages, Distribution and Functional Guilds from a Freshwater-Dominated Tropical Estuary

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Abstract: Assessment of benthic diversity and estuarine ecological quality is becoming increasingly important. Estuaries are not only highly productive and variable environments, but they are also areas of high anthropogenic perturbations. In this study, benthic macrofauna were sorted, identified and analyzed from a freshwater-dominated tropical estuary along the Bay of Bengal to assess their community structure, distribution and functional guilds, and to uncover the environmental drivers influencing their distributional patterns. Results revealed that the studied physio-chemical variables (DO, pH, alkalinity and temperature) were significantly varied ($p < 0.05$) among the sites. *Capitella* sp. was dominant (18%) of the forty morphospecies recorded, indicating organic richness of the area. The ANOVA results revealed that macrobenthic density differed significantly ($p < 0.01$) between the study locations, and diversity indices (Shannon diversity index, H′) also differed significantly ($F_{4,12} = 5.89$; $p = 0.02$). The benthic density decreased from the head to the mouth, which could be related to salinity fluctuations and large freshwater discharges. Upstream sites were completely segregated from downstream and mid-estuarine sites, according to cluster analysis (CA). The SIMPER results clarified the site grouping pattern, showing that *Mysis*-1 spp., *Capitella* spp. and *Nephtys*-1 were the most significant contributors. From the communities, five functional trophic groups were identified where deposit feeders were the most dominant (66.44%). Most of the macrobenthos had strong positive correlations with DO ($r = 0.92$) and water temperature ($r = 0.86$) and a negative correlation with soil pH ($r = -0.28$), per correlation and CCA analyses. Individually, soil pH ($r = 0.88$) and alkalinity ($r = 0.898$) showed strong positive correlation with *Capitella* sp. and *Chironomus* sp.2. The above results indicate that macrobenthos of this estuary do not follow the usual pattern of spatial distribution, and they are structured by DO, alkalinity and soil pH. In addition, dominance of some pollution indicator species (*Capitella* sp. and *Chironomus* sp.) and deposit feeders indicates a poor ecological condition of the estuary.

Keywords: macrobenthos; community structure; temporal variation; environmental drivers; Meghna estuary

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1. Introduction

Estuaries are the most dynamic and productive ecosystems, with hydrodynamic conditions that vary dramatically and irregularly [1]. In terms of the supply of terrestrial- and marine-origin nutrients, freshwater flow, sediment stabilization [2–5], anthropogenic inputs and complicated hydrodynamics, these habitats are inextricably linked to their surrounding ecosystems, such as rivers, streams and coastal lagoons. Furthermore, transitional ecosystems are responsible for changes in physico-chemical qualities such as salinity, water temperature, and nutrient load, as well as changes in the biological ordination of the macrofaunal community [5].

Macrobenthic organisms are essential components of estuarine ecosystems, as they exchange nutrients and dissolved gases, re-suspend the bottom layer of water bodies [6–8], disperse and bury sediments and produce secondary products. It has been established that the abundance, distribution, and ordination of benthic communities are closely linked to physico-chemical characteristics and are good environmental indicators [9–14], and that they are used in the assessment of human-induced and congenial disturbances of both population size and biomass in marine and estuarine ecosystems [15–18].

The abiotic and biotic components of an estuary determine the distribution patterns of benthic diversity in soft-bottom systems [19–23]. Because of their dynamic biotic and abiotic natures, the faunal composition of an estuary can vary significantly on a spatial scale of meters to kilometers and a temporal range of days to years [24,25]. The linkage between macrobenthos and physico-chemical variables can be used to characterize seabed habitats, the physical and chemical environment in which a species or a community lives [26–28], to demonstrate the shaping of macrobenthic biodiversity [29] and to establish integrated estuarine management [30].

On a large spatial scale, physio-chemical properties of water and sediment columns such as salinity [31], pH [32] and dissolved oxygen levels [33,34] are the most crucial variables that influence the diversity, abundance and distribution patterns of macrofaunal communities [35,36]. The degree of salinity fluctuations in particular areas of an estuary may shift the faunal diversity and species distributions [34,37,38]. It is well established that the species richness and diversity pattern of a benthic community decrease with decreasing salinity in most of the estuary [30,39]. Freshwater discharge lower salinity as well as increase levels of nutrients and organic materials, supporting different macrobenthic communities than those found in higher-salinity conditions [40,41]. Consequently, a declining salinity level may lead to a loss or a reducing pattern in marine diversity or scarcity of marine fauna [42–44].

The Meghna is the biggest freshwater-dominated estuary in Bangladesh due to heavy rainfall and freshwater discharges from upstream, as well as enriched living resources such as aquatic macrophytes (i.e., tropical moist forest, mangroves, salt marshes, sea grass, seaweeds), fisheries, coastal birds, animals, coral reefs and non-living resources such as deltas, salt beds, minerals and sand dunes [45,46]. The bedforms of the Meghna estuary are among the most intensively surveyed areas of benthic invertebrates and their relationship with highly variable hydrological factors (hydrodynamic conditions and physico-chemical properties of water columns) in Bangladesh. Nevertheless, as periods observation of hydrological factors over time are effortful and costly in many situations, their contribution may be underrated in benthic ecological investigations [47]. Several studies on macrobenthos have been carried out in the Meghna estuary [45,48–51]. However, these studies were based on preliminary observations and only discussed the occurrence and composition of macrobenthos in the Meghna River estuary. Further, there were no previous studies focused on the trophic groups of the benthic communities from this area. Therefore, by considering the knowledge gap and importance of macrobenthos as an indicator of pollution and productivity, our study aimed to (i) describe the diversity of macrobenthic assemblages in the estuary, (ii) identify the functional feeding guilds of assemblages and (iii) explore the relationship between the physico-chemical parameters and biological variables of the estuary.

2. Materials and Methods

2.1. Study Area

The Meghna estuary (latitude 20°30′ and 22° N and longitude 91°45′ and 92°15′ E) is located in the easternmost sector of the Bangladeshi coastline along the Bay of Bengal. The Meghna estuary is flanked by Hatiya Island to the east, Bhola to the west, greater Noakhali to the north and the Bay of Bengal to the south. This area has been greatly influenced by seasonal monsoon winds, like other parts of the country [52]. In addition, the subtidal zone is predominantly covered by soft sediments including muddy and sandy-clay loam texture [50]. The hydrological situation showing increasing intricacy near the coastal areas is mainly affected by semidiurnal tides (mean tidal range 0.07 m–4.42 m). In this context, four sampling sectors were established which were categorized: Station S1 was located in Chandpur (Upper Meghna estuary). Stations S2, S3 and S4 were located in the transitional area between the Meghna River and Bay of Bengal (Figure 1). Station S1 was situated nearby the launch ghat of the town of Chandpur. The water is turbid, and the riverbed is mostly sandy clay, being somewhat muddy and slightly vegetative. Station S2 was greatly influenced by human intervention due to urbanization and was subjected to high erosion due to tidal influence. The riverbed was mostly composed of sandy clay and devoid of vegetation. Tidal influence was very strong at station S3, but erosion had not occurred because of wave protection from a seawall. Vegetation was absent, and the substratum was basically sandy. Station S4 was located at the extreme downstream area of the Meghna estuary and was artificially mangrove-dominated. The tidal influence and turbidity were strong there.

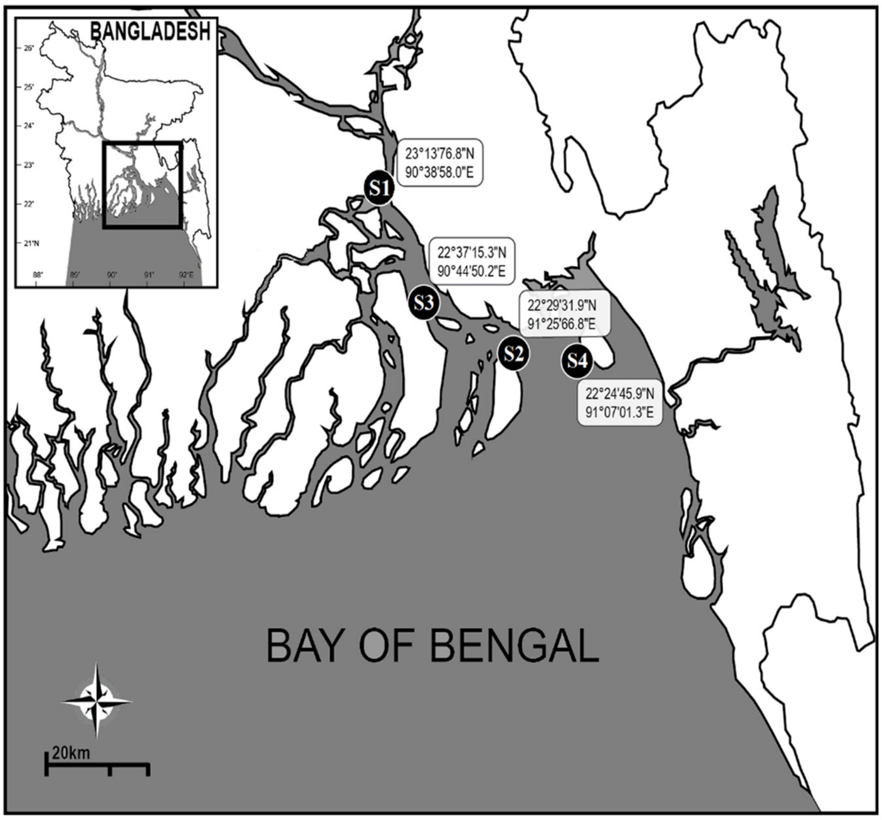

Figure 1. Map of Meghna estuary indicating the locations of four intertidal stations (S1 = Chandpur; S2 = Hatiya; S3 = Bhola; S4 = Shandwip).

2.2. Benthos Sample Collection, Identification and Classification of Feeding Guilds

To investigate the macrofaunal assemblages of the intertidal zone along the Meghna River estuary, sampling was carried out in the four subtidal sectors during August–

September 2017 (rainy season). Benthic macrofauna were collected with a Petersen grab (area: 0.0225 m^2) at a penetration depth of 15 cm from a passenger boat during a low-tide situation. The excavated sediment samples were sieved through a 500-µm stainless steel hand sieve with river water. The retained biological materials were placed in plastic vials with debris and immediately fixed in 10% formalin. A small amount of dilute Rose Bengal was added to the preserved samples to increase the visibility of organisms. The formalin was later washed out, and biological materials were separated from the debris under a dissecting microscope (Leica EZ4 E, Wetzlar, Germany). The sorted organisms were then preserved using 70% ethanol and kept in small vials. Later, the organisms were identified to the lowest taxonomic level (up to species) following the works of Currie and Small [2], Hossain and Marshall [32] and Yamani [53]. Feeding groups were classified according to Gaston and Nasci [10]. Finally, identification was checked in international database, WoRMS (https://www.marinespecies.org, accessed on 12 November 2017.

2.3. Measurement of Environmental Parameters

In order to examine the physico-chemical variables, they were measured at the same sites as the biology. The following physico-chemical attributes were used in the macrofaunal database for each sample: dissolved oxygen (DO), water temperature (°C), water and soil pH, alkalinity (ppm), hardness (µS) and salinity (ppt). In situ DO was measured by a Lutron series portable DO meter (AF. 01223, Taiwan). Water pH, alkalinity and hardness were measured using a HANNA series portable pH meter (HI 96107, Romania), alkalinity test kit (HI 3811, Romania) and portable hardness meter (TIII 14375, Romania), respectively. The soil pH measurement was reported using a portable soil pH moisture meter (KS 05). The salinity and temperature of the sub-surface water were measured using a BRIX series salinity meter (RHB 32ATC) and centigrade thermometer (UK), respectively.

2.4. Statistical Analysis

The physico-chemical variables and macrofaunal assemblages were analyzed multivariately via cluster analysis, analysis of variance (ANOVA), canonical correspondence analysis (CCA) and Spearman's rank correlation analysis. A Bray–Curtis similarity index was generated using square-root transformation to ameliorate the presence of less abundant data [13] and normalize the physico-chemical variables.

For benthic macrofaunal analysis, the faunal abundance data was formalized to ind.m^{-2} before analyzing univariate statistics. Diversity indices such as species richness (S), evenness index (J), diversity index (H') and abundance (A) and trophic groups were used to compare and describe the faunal structure for each sampling station, and significant differences of diversity indices among stations were examined by analysis of variance (ANOVA). Similarity percentage analysis (SIMPER) was also performed to determine which organisms contributed to dissimilarities between stations. For physico-chemical variables, mean values of physical variables were estimated as the total value of each sector divided by the total stations. The physical variables were compared among stations by one-way ANOVA ($p < 0.05$).

Mean individual abundance (IST) was calculated as total macrofaunal species divided by total stations. Trophic groups, dominance, species abundance (IST) and rank were counted for each species. Each morphospecies was categorized into one of the following feeding groups: surface deposit feeder (SDF), sub-surface deposit feeder (SSDF), filter feeder (FF), omnivorous (OMN) or carnivorous (CAR) [53–57]. Cluster employing paired-group linking based on the Bray–Curtis similarity matrix was practiced to analyze the community structure of macrobenthos.

In addition, Spearman's rank correlation analysis and canonical correspondence analysis (CCA) were performed to show the correlations between diversity indices (abundance, species richness, evenness index and diversity index) and physico-chemical variables in order to explore which variables were most responsible for their distributions between stations (run in PAST, version 4.07).

3. Results

3.1. Physico-Chemical Characteristics

The physico-chemical characteristics (mean and SE) at the four sites are shown in Table 1. Physio-chemical drivers showed significant variation among all stations ($p < 0.01$). The highest values of water temperature (31.33 ± 0.67 °C) and DO (9.03 ± 0.35 mL/L) were recorded at station S4, near the downstream region, and the lowest values (24.17 ± 0.17 °C and 5.07 ± 0.07 mL/L) at station S1. Soil pH and salinity were highest (6.7 ± 0.09 and 0.27 ± 0.03 ppt respectively) at station S4 and lowest (5.83 ± 0.03 and 0.03 ± 0.03 ppt respectively) at station S3. At station S4, the water was slightly alkaline and recorded higher values than at the other stations (where it was neutral). Average alkalinity varied between 70.67 and 116 ppm, being higher at station S4 and lower at station S2.

Table 1. Mean values ± standard error (SE) and significance of one-way ANOVA of physico-chemical characteristics in the Meghna estuary during the study period. (S1 = Chandpur, S2 = Hatiya, S3 = Bhola, S4 = Shandwip).

Sites/Physico-Chemical Variables	S1	S2	S3	S4	*p*
	Mean ± SE	**Mean ± SE**	**Mean ± SE**	**Mean ± SE**	
DO (ml/L)	5.07 ± 0.07	9.1 ± 0.21	8.1 ± 0.32	9.03 ± 0.35	0.008 *
Soil pH	6.6 ± 0.06	6.17 ± 0.03	5.83 ± 0.03	6.7 ± 0.09	0.01 *
Water pH	6.8 ± 0.1	7.27 ± 0.09	7.4 ± 0.0	7.0 ± 0.15	0.01 *
Salinity (ppt)	0.097 ± 0.003	0.17 ± 0.03	0.03 ± 0.03	0.27 ± 0.03	0.003 *
Water Temperature (°C)	24.17 ± 0.17	28.17 ± 0.17	28.23 ± 0.23	31.33 ± 0.67	0.02 *
Hardness (µS)	120 ± 11.55	346.67 ± 68.39	176.67 ± 8.82	175.33 ± 47.35	0.02 *
Alkalinity (ppm)	83 ± 8.74	70.67 ± 2.03	77.67 ± 4.84	116 ± 5.29	0.002 *

Significant differences are indicated with the asterisk (*). * $p < 0.05$.

3.2. Composition, Diversity and Assemblages of Macrobenthos

A total of 15,695 individuals belonging to 40 morphospecies were recorded in the Meghna estuary over the sampling period. Polychaeta and Clitellata comprised 9 and 4 species belonging to five and two different families, respectively; 18 Crustaceans consisted of Mysida (3 species), Amphipoda (7 species), Decapoda (2 species), Isopoda (1 species), Maxillopoda (1 species) and Insecta (4 species); Mollusca comprised 8 species, mostly Gastropoda (6 species) with some Bivalvia (2 species). Other less represented groups, such as fish larvae, were represented by a single morphospecies (Table 2). Polychaeta was the most dominant group, comprising 47% of the total abundance. Crustaceans were the most diverse group, bearing 30% of the total abundance, followed by Mollusca (10%) and Insecta (9%). The rest of the macrofaunal groups belonged to Clitellata and fish larvae, which contributed about 4% of the total abundance. Polychaeta was dominant at all stations except S4, and Insecta was only found at station S1. A higher portion of Clitellata (10%) was found in station S1 and was absent at stations S3 and S4 (Figure 2). The 10 most abundant species in the estuary, comprising 75.34% of the collected macrobenthos, were *Capitella* sp. (18.62%); *Mysis* sp.1 (13.61%); Shrimp larvae (7.94%); *Nephtys* sp.1 (7.37%); *Chironomus* sp.2 (7.28%); *Tellina modesta* (5.67%); *Nereis* sp.1 (5.30%); *Nereis* sp.2 (5.11%); *Namanereis* sp. (4.44%); and *Paranthura* sp. (3.21%). The remaining species present in the estuary were represented by few individuals (Table 2).

The diversity indices did not show significant variations among the stations, except diversity index (Figure 3). Evenness index ($F_{(4,12)} = 1.54$; $p = 0.28$) and species richness ($F_{(4,12)} = 1.77$; $p = 0.23$) were greater at station S1 and lower at station S2. Mean abundance was higher at station S1 and lower at S3 ($F_{(4,12)} = 0.67$; $p = 0.59$). Abundance varied according to the presence of the *Capitella* sp. and *Mysis* sp.1. Higher values of the diversity index (H′) were registered at station S3 and lower values at station S2, with significant differences between stations ($F_{(4,12)} = 5.89$; $p = 0.02$).

Table 2. Macrobenthic community structure of the intertidal zone of the Meghna estuary. Average (Av) and standard error (SE) of species abundance (IST), percentage of dominance (%D) and R (rank) are presented. Tropic groups: surface deposit feeder (SDF); sub-surface deposit feeder (SSDF); filter feeder (FF); omnivorous (OMN); carnivorous (CAR).

	Trophic Group	IST (Individuals/m^2)						%D	R
		S1	S2	S3	S4	Av	SE		
Phylum Annelida									
Class Polychaeta									
Lumbrineridae sp.	SSDF	0	0	251.67	14.67	66.58	38.80	1.70	14
Nereididae sp.1	SSDF	0	222.33	326	281.67	207.5	79.19	5.30	7
Nereididae sp.2	SSDF	0	252	192.67	355.67	200.08	77.50	5.11	8
Nereididae sp.3	SSDF	0	0	163	252	103.75	54.82	2.65	11
Nephtyidae sp.1	SSDF	192.67	622	192.67	148	288.83	136.90	7.37	4
Nephtyidae sp.2	SSDF	59.33	0	0	44.33	25.92	17.69	0.66	21
Namaneredidae sp.	SSDF	29.33	133.33	340.67	192.67	174	69.98	4.44	9
Capitellidae sp.	SSDF	2918.3	0	0	0	729.58	526.86	18.62	1
Spionidae sp.	SSDF	207.33	0	0	0	51.83	41.25	1.32	16
Class Clitellata									
Oligocheate sp.1	SSDF	177.67	0	0	0	44.42	34.16	1.13	17
Oligocheate sp.2	SSDF	222.33	0	0	0	55.58	32.43	1.42	15
Nematid sp.1	SSDF	0	66.5	0	0	11.08	11.08	0.28	24
Nematid sp.2	SSDF	14.67	0	0	0	3.67	3.67	0.09	26
Phylum Arthopoda									
Class Malacostraca									
Order Mysida									
Mysidae sp.1	OMN	0	1896	222.33	14.67	533.25	467	13.61	2
Mysidae sp.2	OMN	0	148.33	0	0	37.08	25.59	0.95	18
Mysidae sp.3	OMN	0	0	0	14.67	3.67	3.67	0.09	26
Order Amphipoda									
Ampeliscidae sp.1	FF	0	74	0	29.33	25.83	18.49	0.70	22
Ampeliscidae sp.2	FF	0	0	0	14.67	3.67	3.67	0.09	26
Ampeliscidae sp.3	FF	0	14.67	14.67	0	7.33	4.94	0.19	25
Leucothoidae sp.	FF	0	0	0	14.67	3.67	3.67	0.09	26
Corophiidae sp.	SDF	0	44.33	0	0	11.08	11.08	0.28	24
Melitidae sp.	CAR	0	0	44.33	0	11.08	7.97	0.28	24
Oedicerptidae sp.	FF	0	0	0	370.33	92.58	92.58	2.36	13
Order Decapoda									
Crab larvae	OMN	14.67	0	59.33	0	18.5	14.95	0.47	23
Shrimp larvae	OMN	0	29.33	59	1155.67	311	222.16	7.94	3
Order Isopoda									
Paranthuridae sp.	SDF	0	503.67	0	0	125.92	121.97	3.21	10
Class Maxillopoda									
Calanoida sp.	CAR	0	14.67	0	0	3.67	3.67	0.09	26
Class Insecta									
Ephemeroptera	SDF	0	0	0	14.67	3.67	3.67	0.09	26
Chironomidae sp.1	SDF	148	0	0	0	37	23.75	0.94	19
Chironomidae sp.2	SDF	1140.67	0	0	0	285.17	192.44	7.28	5
Chironomidae sp.3	SDF	118.67	0	0	0	29.67	29.67	0.76	20
Phylum Mollusca									
Class Gastropoda									
Viviparidae sp.1	SDF	74	0	0	0	18.5	12.76	0.47	23
Viviparidae sp.2	SDF	74	0	0	0	18.5	10.18	0.47	23
Cingulopsidae sp.	SDF	385.33	0	14.67	0	100	81.19	2.55	12
Planorbidae sp.	SDF	14.67	0	0	0	3.67	3.67	0.09	26
Trochidae sp.	SDF	14.67	0	0	0	3.67	3.67	0.09	26
Cyclophoridae sp.	SDF	14.67	0	0	0	3.67	3.67	0.09	26
Class Bivalvia									
Tellina modesta	FF	0	0	0	889	222.25	214.29	5.67	6
Aspatharia pfeifferiana	FF	14.67	0	0	0	3.67	3.67	0.09	32

Table 2. *Cont.*

	Trophic Group	IST (Individuals/m^2)						%D	R
		S1	S2	S3	S4	Av	SE		
Other									
Fish larvae	SDF	0	14.67	0	133.33	37	33.20	0.94	20

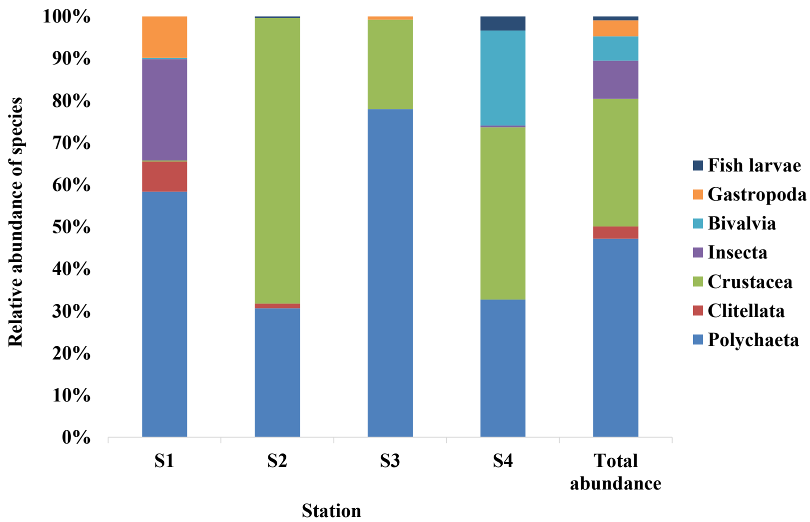

Figure 2. Taxonomic composition (%) of relative abundance at different stations.

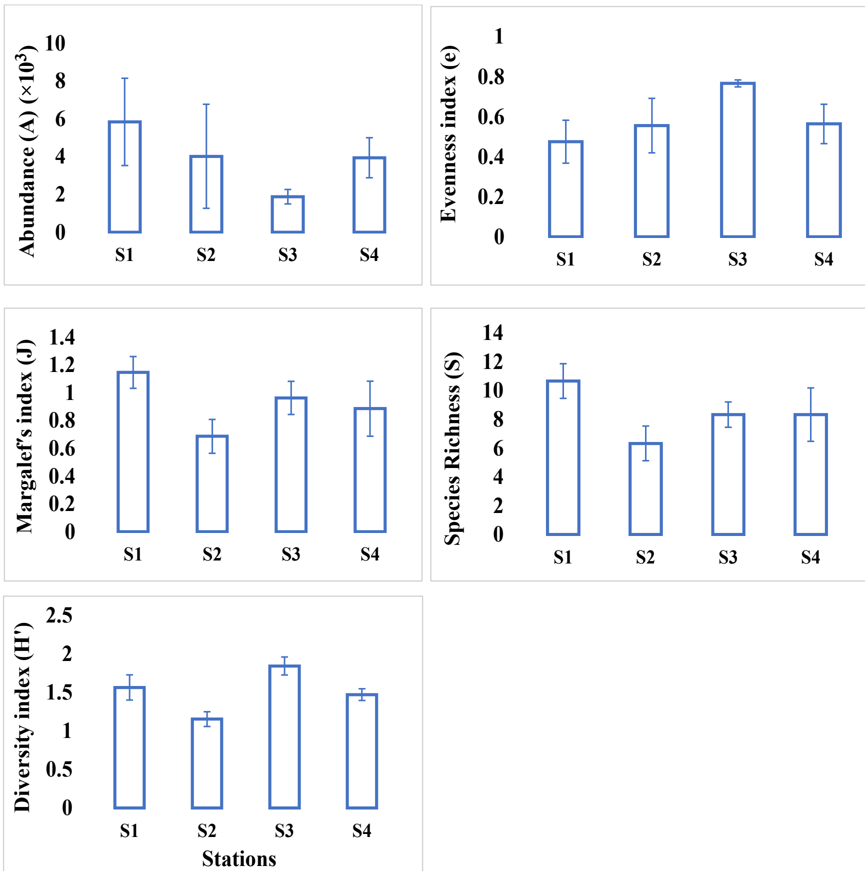

Figure 3. Mean abundance (ind.m^{-2}), evenness, Margalef's index, average number of species (species richness) and diversity index in the intertidal zone of the Meghna estuary.

Hierarchical clustering (CA) of all macrobenthos among replicate samples showed that 40 morphospecies yielded three groups based on their similarity of occurrences (Figure 4). Macrobenthic communities showed distinct characteristics at different locations as well as between the replicates of stations. The macrobenthic communities at station S2, S3 and S4 were more similar to each other (Group A and B), with a similarity of 34.06%. The differences between group C and groups A and B were due to changes in the density of dominant species *Capitella* sp. which were only identified at station S1. ANOSIM results showed significant differences between groups ($p < 0.01$). SIMPER analysis indicated that overall average dissimilarity among sites was 80.46%, and the difference was primarily driven by *Mysis* sp.1 (7.303%), *Capitella* sp. (7.25%) and *Nephtys* sp.1 (7.24%) (Table 3).

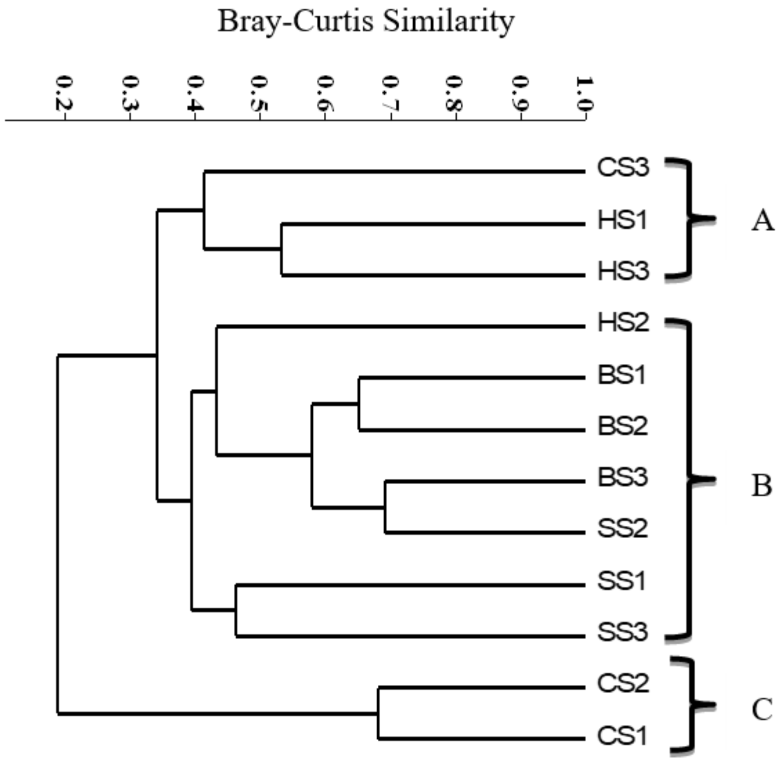

Figure 4. Hierarchical clustering of square-root-transformed macrobenthic data using group-average linking on Bray–Curtis similarities, showing the grouping of macrofaunal samples. (CS1, CS2, CS3 = S1; HS1, HS2, HS3 = S2; BS1, BS2, BS3 = S3; SS1, SS2, SS3 = S4).

Table 3. Simper result for macrobenthos at the Meghna estuary during study period.

Taxon	Av. Dissim	Contrib. %
Mysis sp.1	5.876	7.303
Capitella sp.	5.831	7.247
Nephtys sp.1	5.822	7.236
Shrimp larvae	4.817	5.987
Nereis sp.1	4.676	5.812
Nereis sp.2	4.643	5.771
Namanereis sp.	4.469	5.555
Chironomus sp.2	3.668	4.559
Tellina modesta	3.453	4.292
Nereis sp.3	3.306	4.109

Av. Dissim. = Average dissimilarity, Contrib. = Contribution.

3.3. Trophic Structure of Macrobenthic Community

In the intertidal zone of the four stations, 40 morphospecies from 5 trophic groups represented by SSDF (13 species), SDF (13 species), FF (7 species), OMN (5 species) and CAR (2 species) were recorded. The density of trophic groups was dominated by deposit feeders, mainly SSDF (50.17%) and SDF (17.27%), which constituted 66.44% of the total. OMN were second among trophic groups (23.03%) due to the presence of only 2 species: *Mysis* sp.1 and shrimp larvae. Other groups such as FF and CAR constituted less than 10% of the total macrobenthic abundance (Table 4).

Table 4. Mean abundance (ind.m^{-2}) and number of trophic groups of macrobenthic assemblages per station in the intertidal area of the Meghna estuary.

Trophic Group	Species Number	Station				Total	% Contr.
		S1	S2	S3	S4		
SSDF	**13**	**3822**	1296	1467	1289	7874	50.17
SDF	13	1985	563	15	148	2711	17.27
FF	7	15	89	15	1318	1437	9.16
OMN	5	15	2074	341	1185	3615	23.03
CAR	2	0	15	44	0	59	0.38
Total	**40**	**5837**	**4037**	**1882**	**3940**	**15,696**	**100**

Contri = Contribution; SSDF = Sub-surface deposit feeder; SDF = Surface deposit feeder; FF = Filter feeder; OMN = Omnivorous; CAR = Carnivorous.

SSDF abundance did not differ significantly ($F_{(4,52)} = 1.87$; $p > 0.05$) among stations and was higher at all stations compared to other trophic groups. The same trend was observed for SDF density ($F_{(4,52)} = 2.08$; $p > 0.05$), with lower numbers at stations S3 and S4 compared to stations S1 and S2. At stations S2 and S3, a few samples of carnivorous species were recorded. At station S4, a high proportion of FF was recorded due to the presence of *Tellina modesta.*

3.4. Relationship between Biological and Physico-Chemical Drivers

The Spearman′s rank correlation analysis between physico-chemical and biological parameters indicates that they were not significantly correlated ($p < 0.05$), with the exception of some parameters (Table 5). The correlation of dissolved oxygen (DO) with richness (S) and diversity index (H′) was negatively significant at $p < 0.05$. Soil pH was positively correlated with abundance (A) ($p < 0.05$), which indicated that abundance (A) was increased with increased soil pH. Salinity, hardness and alkalinity showed positive and highly significant correlation ($p < 0.01$) with abundance (A) and evenness index (e). This indicates that increased salinity and alkalinity were associated with increased abundance.

Table 5. Spearman's rank correlations between macrobenthic community and environmental variables at the study sites. Species richness (S); abundance (A); diversity index (H′); evenness index (e); margalef's index (J).

Physico-Chemical Parameters	S	A	H′	e	J
DO (ml/L)	**−0.236** *	−0.084	**−0.435***	−0.049	**−0.267** *
Soil pH	0.081	**0.366** *	−0.327	−0.514	0.011
Water pH	−0.392	−0.239	0.036	0.329	−0.339
Salinity (ppt)	−0.294	**0.05** **	−0.443	−0.317	−0.331
Water temp. (°C)	−0.366	−0.171	−0.168	0.096	−0.297
Hardness (µS)	−0.196	−0.112	−0.238	**0.189** **	−0.259
Alkalinity (ppm)	−0.130	**0.109** **	0.035	0.014	−0.091

Significant correlations are shown in bold and indicated. * indicates significant at 5 % level and ** highly significant.

The CCA ordination diagram revealed the relationship between physico-chemical variables and most contributing species (Figure 5). The first two axes (CCA1 and CCA2) explained 53.03% and 26.43%, combining to 79.46% of the total variance. The first axis showed weak positive correlations with soil pH and DO (r = 0.30) and negative correlations with water pH (r = −0.34), salinity (r = −0.09), hardness (r = −0.38), alkalinity (r = −0.08) and DO (r = −0.76). The second axis showed positive correlations with DO (r = 0.01), water pH (r = 0.46) and hardness (r = 0.46). This axis also reflected negative correlations with soil pH (r = −0.49), alkalinity (r = −0.44) and salinity (r = −0.33).

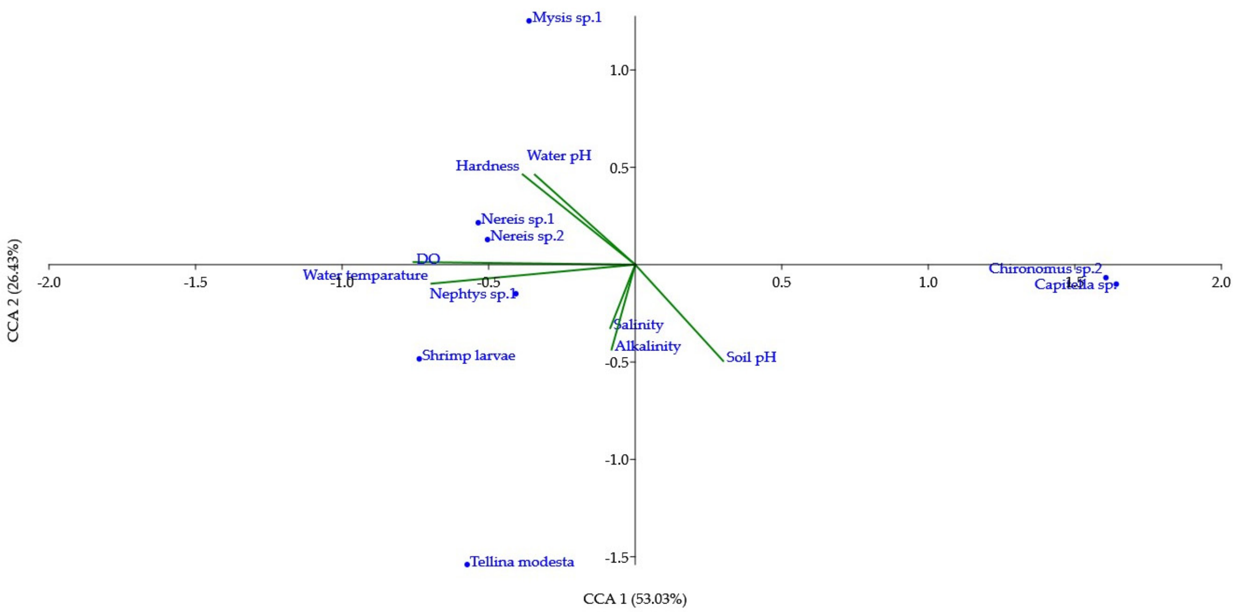

Figure 5. CCA ordination diagram based on the analysis of abundance data (>5% of total abundance), shows the species distributions in relation to environmental variables.

Species from the intertidal zone, at higher soil pH, were situated on the right side of the biplot (e.g., *Chironomus* sp.2 and *Capitella* sp.). This indicates that the distribution of these taxa was at the outer stations of the estuary. Species such as *Nephtys* sp.1, shrimp larvae, *Tellina modesta*, *Mysis* sp.1, *Nereis* sp.1 and *Nereis* sp.2 were positively correlated with hardness, DO, water temperature, salinity, alkalinity and water pH and negatively correlated with soil pH, while *Capitella* sp. and *Chironomus* sp.2 were negatively correlated with the mentioned abiotic variables. This trend suggests that these species are mainly distributed across the inner stations.

4. Discussion

4.1. Macrobenthic Community Structure

The macrobenthic community structure in the Meghna estuary correspondingly contrasted in abundance and composition with other estuarine benthic communities at the regional level [48,50,58–62] and worldwide [2,30,32,39,63]. In our study, 40 morphospecies were recorded, which was fairly incongruous with a former study that found 17 taxa in the Meghna estuary [51]; 17 taxa in the Feni estuary [64] was widely coherent with another estuary in Bangladesh, viz. 33 species in the Karnafuli estuary [60]; 47 taxa in the Naf River estuary [62] was comparatively lower than marks recorded for other estuarial and coastal areas, such as 71 species at the Halishahar coast in Bangladesh [65].

Polychaeta were numerically recorded as dominant species along this estuary [48,59,66] and other estuaries [62]; this dominance was primarily related to the high abundance of *Mysis* sp.1, *Capitella* sp. and *Nephtys* sp.1. However, this dominance was marked by high abundance of Oligochaeta in Meghna estuary [50,51] and Crustacea in the Feni estuary [64] rather than Polychaeta. However, some abundant species in the present study, e.g., Mysis and shrimp larvae, were not recorded in previous studies [50,51].

Investigation of benthic organisms showed a decline in abundance and diversity from the sea to upstream, like the pattern reported by Nandan et al. [67]. Abundance recorded its highest values at an upstream station (S1) and its lowest in the mouth of the estuary (S3), which is consistent with the previous studies, but the lower abundance found in the mouth of the estuary [50,51] may be ascribed to the reclamation of that particular area, sediment contamination and high current speed [68,69].

The diversity index (H′) varied from 1.15 to 1.82, showing its highest average values at station S3 (Bhola), which was similar to the value reported by [51]. By contrast, diversity values were lower in the Bakkahali estuary [70] and the Meghna estuary [71] but higher in the Feni estuary [64]. In addition, the present study showed that the ratio of the evenness index increased with the increasing of H′. The evenness index appeared to be quite analogous to that of the previous study in the Meghna estuary [70–72].

4.2. Functional and Trophic Structure of Macrobenthos

Almost all biologists consider the feeding ecology of macrobenthos to exhibit a significant response to community disturbance [73–75], and this trophic ecology provides a functional pathway to elucidate the changes in complex communities that happen in estuaries [30]. In the Meghna River estuary, macrobenthic assemblages in the current study were numerically dominated by deposit feeders (mainly SSDF and SDF) (Table 4). This dominance indicates the presence of detritus which acts as an energy source for macrobenthic organisms, and the appearance of food (detritus) in sediment alters the distribution of the deposit feeder community [76,77]. Although the deposit feeders were dominant at all stations, there was some dissimilarity among stations. The percentages of SSDF and SDF were considerably higher at station S1; on the contrary, the abundance of omnivores was relatively higher at station S2. Soft sediment disturbance and pollution might be causes of this unevenness among the stations in terms of macrobenthic trophic composition [10,14,78–80].

4.3. Relationship between Macrobenthos and Physico-Chemical Variables

Benthic studies in estuaries have demonstrated that the distribution of macrobenthos shows a clear affinity with abiotic variables [30,34,71,81–86], and this is consistent with the current study. In our study area, Spearman's rank correlations indicated that abundance had significantly positive correlations with soil pH, salinity and alkalinity, which was true in most other research findings [32,45]. Alkalinity was significantly negatively correlated with abundance and DO but significantly positively correlated with hardness in the Bakkhali and Meghna estuary [45]. In our study, alkalinity was significantly positively correlated with abundance, and it was negatively correlated with DO and hardness but not significantly. This difference might be explained by seasonal variation.

According to CCA, Mysis sp.1 was positively correlated with water temperature. The same aptitude was recorded in the Gironde estuary in France (mysids *Mesopodopsis slabberi* and *Neomysis integer*) [81,87]. The most abundant species *Capitella* sp. was negatively correlated with salinity, and *Nereis* sp.1 and *Nereis* sp.2 were positively correlated with salinity in our study. Generally, captellids are dominant in the less saline areas and nereids in the more saline areas of the estuary [32,88]. The opposite trend was marked in the Sungai Brunei estuary, Borneo and the Schelde estuary in northwest Europe [30,32,89]. This might be attributed to freshwater input in the study area. *Nephtys* sp.1 was positively related to salinity and temperature, which showed fair agreement with the previous findings [30,89] (*Nephtys cirrosa* and *Nepthys hombergii*), whereas the opposite aptitude was recorded by [90] (*Nephtys oligobranchia*). Finally, it seems that different species prefer different habitat characteristics for their colonization.

5. Conclusions

The changes in macrobenthic community composition, structure and functional feeding guilds and their relationship with physico-chemical parameters were investigated along the Meghna River estuary. *Nereis* sp., *Nephtys* sp. and *Capitella* sp. were found to be common in study sites in 40 different morphospecies. Polychaeta was the dominant taxonomic group in the macrobenthic community. In this estuary, high abundance of benthos in the upstream sites represented an unusual distributional pattern. Furthermore, the highest abundance of *Capitella* spp. And deposit feeder groups indicated organic enrichment and detritus materials. Spearman's rank correlation and CCA showed that DO, sediment pH, alkalinity and water temperature were crucial environmental factors influencing macrobenthic distribution and diversity. However, for better and clearer understanding of distributional patterns, it is necessary to gain additional knowledge, especially regarding organic enrichment, water depth and sediment grain size present in this estuary.

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References

1. Carcedo, M.C.; Fiori, S.M.; Piccolo, M.C.; Abbate, M.C.L.; Bremec, C.S. Variations in macrobenthic community structure in relation to changing environmental conditions in sandy beaches of Argentina. *Estuar. Coast. Shelf. Sci.* **2015**, *166*, 56–64. [CrossRef]
2. Currie, D.R.; Small, K.J. Macrobenthic community responses to long-term environmental change in an east Australian sub-tropical estuary. *Estuar. Coast. Shelf. Sci.* **2005**, *63*, 315–331. [CrossRef]
3. Lercari, D.; Defeo, O. Effects of freshwater discharge in sandy beach populations: The mole crab *Emerita brasiliensis* in Uruguay. *Estuar. Coast. Shelf Sci.* **1999**, *49*, 457–468. [CrossRef]
4. Lercari, D.; Defeo, O. Variation of a sandy beach macrobenthic community along a human-induced environmental gradient. *Estuar. Coast. Shelf Sci.* **2003**, *58*, 17–24. [CrossRef]
5. Lercari, D.; Defeo, O. Large-scale diversity and abundance trends in sandy beach macrofauna along full gradients of salinity and morphodynamics. *Estuar. Coast. Shelf Sci.* **2006**, *68*, 27–35. [CrossRef]
6. Doi, H.; Chang, K.H.; Ando, T.; Imai, H.; Nakano, S.I.; Kajimoto, A.; Katano, I. Drifting plankton from a reservoir subsidize downstream food webs and alter community structure. *Oecologia* **2008**, *156*, 363–371. [CrossRef] [PubMed]
7. Herman, P.M.J.; Middelburg, J.J.; Van de Koppel, J.; Heip, C.H.R. Ecology of estuarine macrobenthos. *Adv. Ecol. Res.* **1999**, *29*, 195–240.
8. Uddin, M.H.; Shahjahan, M.; Amin, A.R.; Haque, M.M.; Islam, M.A.; Azim, M.E. Impacts of organophosphate pesticide, sumithion on water quality and benthic invertebrates in aquaculture ponds. *Aquac. Rep.* **2016**, *3*, 88–92. [CrossRef]
9. Snelgrove, P.V. Getting to the bottom of marine biodiversity: Sedimentary habitats: Ocean bottoms are the most widespread habitat on earth and support high biodiversity and key ecosystem services. *BioScience* **1999**, *49*, 129–138. [CrossRef]
10. Gaston, G.R.; Nasci, J.C. Trophic structure of macrobenthic communities in the Calcasieu Estuary, Louisiana. *Estuaries* **1988**, *11*, 201. [CrossRef]
11. Kremen, C. Assessing the indicator properties of species assemblages for natural areas monitoring. *Ecol. Appl.* **1992**, *2*, 203–217. [CrossRef] [PubMed]

12. Bulger, A.J.; Hayden, B.P.; Monaco, M.E.; Nelson, D.M.; McCormick-Ray, M.G. Biologically-based estuarine salinity zones derived from a multivariate analysis. *Estuaries* **1993**, *16*, 311–322. [CrossRef]
13. Warwick, R.M.; Clarke, K.R. Increased variability as a symptom of stress in marine communities. *J. Exp. Mar. Biol. Ecol.* **1993**, *172*, 215–226. [CrossRef]
14. Brown, S.S.; Gaston, G.R.; Rakocinski, C.F.; Heard, R.W. Effects of sediment contaminants and environmental gradients on macrobenthic community trophic structure in Gulf of Mexico estuaries. *Estuaries* **2000**, *23*, 411–424. [CrossRef]
15. White, P.S.; Pickett, S.T. *Natural Disturbance and Patch Dynamics: An Introduction*; Academic Press: London, UK, 1985; p. 472.
16. Dolbeth, M.; Cardoso, P.G.; Ferreira, S.M.; Verdelhos, T.; Raffaelli, D.; Pardal, M.A. Anthropogenic and natural disturbance effects on a macrobenthic estuarine community over a 10-year period. *Mar. Pollut. Bull.* **2007**, *54*, 576–585. [CrossRef] [PubMed]
17. Whomersley, P.; Huxham, M.; Bolam, S.; Schratzberger, M.; Augley, J.; Ridland, D. Response of intertidal macrofauna to multiple disturbance types and intensities–an experimental approach. *Mar. Environ. Res.* **2010**, *69*, 297–308. [CrossRef]
18. Baeta, A.; Niquil, N.; Marques, J.C.; Patrício, J. Modelling the effects of eutrophication, mitigation measures and an extreme flood event on estuarine benthic food webs. *Ecol. Model.* **2011**, *222*, 1209–1221. [CrossRef]
19. Soto, E.; Quiroga, E.; Ganga, B.; Alarcón, G. Influence of organic matter inputs and grain size on soft-bottom macrobenthic biodiversity in the upwelling ecosystem of central Chile. *Mar. Biodivers.* **2017**, *47*, 433–450. [CrossRef]
20. Sanvicente-Añorve, L.; Leprêtre, A.; Davoult, D. Large-scale spatial pattern of the macrobenthic diversity in the eastern English Channel. *J. Mar. Biolog. Assoc. UK* **1996**, *76*, 153–160. [CrossRef]
21. Sanvicente-Añorve, L.; Leprêtre, A.; Davoult, D. Diversity of benthic macrofauna in the eastern English Channel: Comparison among and within communities. *Biodivers. Conserv.* **2002**, *11*, 265–282. [CrossRef]
22. Rees, H.L.; Pendle, M.A.; Waldock, R.; Limpenny, D.S.; Boyd, S.E. A comparison of benthic biodiversity in the North Sea, English Channel, and Celtic Seas. *ICES J. Mar. Sci.* **1999**, *56*, 228–246. [CrossRef]
23. Ellingsen, K.E. Soft-sediment benthic biodiversity on the continental shelf in relation to environmental variability. *Mar. Ecol. Prog. Ser.* **2002**, *232*, 15–27. [CrossRef]
24. Morrisey, D.J.; Howitt, L.; Underwood, A.J.; Stark, J.S. Spatial variation in soft-sediment benthos. *Mar. Ecol. Prog. Ser.* **1992**, *81*, 197–204. [CrossRef]
25. Morrisey, D.J.; Underwood, A.J.; Howitt, L.; Stark, J.S. Temporal variation in soft-sediment benthos. *J. Exp. Mar. Biol. Ecol.* **1992**, *164*, 233–245. [CrossRef]
26. Van Hoey, G.; Degraer, S.; Vincx, M. Macrobenthic community structure of soft-bottom sediments at the Belgian Continental Shelf. *Estuar. Coast. Shelf Sci.* **2004**, *59*, 599–613. [CrossRef]
27. Bolam, S.G.; Eggleton, J.; Smith, R.; Mason, C.; Vanstaen, K.; Rees, H. Spatial distribution of macrofaunal assemblages along the English Channel. *J. Mar. Biolog. Assoc. UK* **2008**, *88*, 675–687. [CrossRef]
28. Shumchenia, E.J.; King, J.W. Comparison of methods for integrating biological and physical data for marine habitat mapping and classification. *Cont. Shelf Res.* **2010**, *30*, 1717–1729. [CrossRef]
29. Pearson, T.H.; Rosenberg, R. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. Mar. Biol.* **1978**, *16*, 229–311.
30. Ysebaert, T.; Herman, P.M.J.; Meire, P.; Craeymeersch, J.; Verbeek, H.; Heip, C.H.R. Large-scale spatial patterns in estuaries: Estuarine macrobenthic communities in the Schelde estuary, NW Europe. *Estuar. Coast. Shelf Sci.* **2003**, *57*, 335–355. [CrossRef]
31. Montagna, P.A.; Kalke, R.D. The effect of freshwater inflow on meiofaunal and macrofaunal populations in the Guadalupe and Nueces Estuaries, Texas. *Estuaries* **1992**, *15*, 307–326. [CrossRef]
32. Hossain, M.B.; Marshall, D.J. Benthic infaunal community structuring in an acidified tropical estuarine system. *Aquat. Biosyst.* **2014**, *10*, 11. [CrossRef] [PubMed]
33. Cooksey, C.; Hyland, J. Sediment quality of the Lower St. Johns River, Florida: An integrative assessment of benthic fauna, sediment-associated stressors, and general habitat characteristics. *Mar. Pollut. Bull.* **2007**, *54*, 9–21. [CrossRef]
34. Levin, L.A.; Gage, J.D. Relationships between oxygen, organic matter and the diversity of bathyal macrofauna. *Deep Sea Res. Part. II Top. Stud. Oceanogr.* **1998**, *45*, 129–163. [CrossRef]
35. Snelgrove, P.V.R.; Butman, C.A. Animal-sediment relationships revisited: Cause versus effect. *Oceanogr. Lit. Rev.* **1995**, *8*, 668.
36. Gray, J.S.; Elliott, M. *Ecology of Marine Sediments: From Science to Management*, 2nd ed.; Oxford University Press: Oxford, UK, 2009; p. 225.
37. Warwick, R.M. Comparative study of the structure of some tropical and temperate marine soft-bottom macrobenthic communities. *Mar. Biol.* **1987**, *95*, 641–649. [CrossRef]
38. McLusky, D.S.; Hull, S.C.; Elliott, M. Variations in the intertidal and subtidal macrofauna and sediments along a salinity gradient in the upper Forth Estuary. *Neth. J. Aquat. Ecol.* **1993**, *27*, 101–109. [CrossRef]
39. Lucero, R.C.H.; Cantera, J.R.K.; Romero, I.C. Variability of microbenthic assemblages under abnormal climatic conditions in a small scale tropical estuary. *Estuar. Coast. Shelf Sci.* **2006**, *68*, 17–26. [CrossRef]
40. Kostecki, C.; Roussel, J.M.; Desroy, N.; Roussel, G.; Lanshere, J.; Le Bris, H.; Le Pape, O. Trophic ecology of juvenile flatfish in a coastal nursery ground: Contributions of intertidal primary production and freshwater particulate organic matter. *Mar. Ecol. Prog. Ser.* **2012**, *449*, 221–232. [CrossRef]
41. Nishijima, W.; Nakano, Y.; Nakai, S.; Okuda, T.; Imai, T.; Okada, M. Impact of flood events on macrobenthic community structure on an intertidal flat developing in the Ohta River Estuary. *Mar. Pollut. Bull.* **2013**, *74*, 364–373. [CrossRef]

42. De Jonge, V.N.; Elliot, M. Eutrophication. In *Encyclopedia of Ocean Sciences*; Steele, J., Thorpe, S., Turekian, K., Eds.; Academic Press: London, UK, 2001; Volume 2, pp. 852–870.
43. Stramma, L.; Schmidtko, S.; Levin, L.A.; Johnson, G.C. Ocean oxygen minima expansions and their biological impacts. *Deep-Sea Res. I Oceanogr. Res. Pap.* **2010**, *57*, 587–595. [CrossRef]
44. Gewin, V. Oceanography: Dead in the water. *Nature* **2010**, *466*, 812–814. [CrossRef] [PubMed]
45. Sarker, M.J.; Patwary, M.S.A.; Uddin, A.M.M.B.; Hasan, M.M.; Tanmay, M.H.; Kanungo, I.; Parvej, M.R. Macrobenthic Community Structure-An Approach to Assess Coastal Water Pollution in Bangladesh. *Fish Aquac. J.* **2016**, *7*, 2. [CrossRef]
46. Kamal, A.H.M.; Khan, M.A.A. Coastal and estuarine resources of Bangladesh: Management and conservation issues. *Maejo Int. J. Sci. Technol.* **2009**, *3*, 313–342.
47. Dutertre, M.; Hamon, D.; Chevalier, C.; Ehrhold, A. The use of the relationships between environmental factors and benthic macrofaunal distribution in the establishment of a baseline for coastal management. *ICES J. Mar. Sci.* **2013**, *70*, 294–308. [CrossRef]
48. Hossain, M.B. Polychaete faunal biodiversity of Meghna river estuarine bed, Bangladesh. *J. Prog. Sci. Tech.* **2009**, *7*, 275–278.
49. Hossain, M.B. Macro-zoo-benthos of the Meghna River estuarine bed with special reference to Polychaete faunal biodiversity. *Int. J. Sustain. Agric. Res.* **2009**, *5*, 11–16.
50. Hossain, M.B.; Das, N.G.; Sharmeen, R. Seasonal and spatial distribution of macrozoobenthos of the Meghna River estuarine bed. *Int. J. Sustain. Agric. Res.* **2009**, *5*, 11–16.
51. Sharif, A.S.M.; Islam, S.; Islam, M. Occurrence and Distribution of Macrobenthos in Relation to Physico-chemical Parameters in the Lower Meghna River Estuary, Bangladesh. *Int. J. Mar. Sci.* **2017**, *7*, 102–113.
52. Hossain, M.S.; Das, N.G.; Sarker, S.; Rahaman, M.Z. Fish diversity and habitat relationship with environmental variables at Meghna river estuary, Bangladesh. *Egypt. J. Aquat. Res.* **2012**, *38*, 213–226.
53. Al-Yamani, F.Y.; Skryabin, V.; Boltachova, N.; Revkov, N.; Makarov, M.; Grintsov, V.; Kolesnikova, E. *Illustrated Atlas on the Zoobenthos of Kuwait*; Kuwait Institute for Scientific Research: Kuwait City, Kuwait, 2012; pp. 1–364.
54. Tomikawa, K.; Kakui, K.; Yamasaki, H. A new species of Psammogammarus (Amphipoda: *Melitidae*) from Kuchinoerabu Island, Japan, with a note on its feeding habits. *Zool. Sci.* **2010**, *27*, 615–626. [CrossRef]
55. Hunt, O.D. The food of the bottom fauna of the Plymouth fishing grounds. *J. Mar. Biolog. Assoc. UK* **1925**, *13*, 560–599. [CrossRef]
56. Viherluoto, M. Food Selection and Feeding Behaviour of Baltic Sea Mysid Shrimps. 2001. Available online: https://helda.helsinki.fi/bitstream/handle/10138/22351/foodsele.pdf?sequence=2 (accessed on 25 November 2017).
57. Gerdol, V.; Hughes, R.G. Feeding behaviour and diet of Corophium volutator in an estuary in southeastern England. *Mar. Ecol. Prog. Ser.* **1994**, *114*, 103–108. [CrossRef]
58. Hossain, M.B.; Hossain, M.M.M. A preliminary study on intertidal macrobenthos of Chittagong coast in Bangladesh. *Int. J. Ani. Fish. Sci.* **2009**, *2*, 170–175.
59. Asadujjaman, M.; Hossain, M.B.; Shamsuddin, M.; Amin, M.A.; Azam, A.K.M. Occurrence and Abundance of Macrobenthos of Hatiya and Nijhum Dweep Islands, Bangladesh. *Middle East J. Sci. Res.* **2012**, *11*, 184–188.
60. Islam, M.S.; Sikder, M.N.A.; Al-Imran, M.; Hossain, M.B.; Mallick, D.; Morshed, M.M. Intertidal macrobenthic fauna of the Karnafuli estuary: Relations with environmental variables. *World Appl. Sci. J.* **2013**, *21*, 1366–1373.
61. Sharif, A.S.; Bakar, M.A.; Bhuyan, M.S. Assessment of water quality of the Meghna river estuary using multivatiate analyses and RPI. *Int. J. Chem. Pharm. Technol.* **2017**, *2*, 57–73.
62. Noman, M.A.; Mamunur, R.; Islam, M.S.; Hossain, M.B. Spatial and seasonal distribution of Intertidal Macrobenthos with their biomass and functional feeding guilds in the Naf River estuary, Bangladesh. *J. Oceanol. Limnol.* **2019**, *37*, 1010–1023. [CrossRef]
63. Khan, R.A. Biodiversity of macrobenthos on the intertidal flats of Sunderban estuarine region, India. *Rec. Zool. Surv. India* **2003**, *101*, 181–205.
64. Matin, A.; Hossain, M.B.; Iqbal, M.; Billah, M.M.; Al Asif, A.; Billah, M.M. Diversity and abundance of Macrobenthos in a subtropical estuary, Bangladesh. *Species* **2018**, *19*, 140–150.
65. Alam, M.S. Ecology of the Intertidal Macrobenthos of Halishahar Coast, Chittagong Bangladesh. Ph.D. Thesis, Department of Zoology, University of Chittagong, Chittagong, Bangladesh, 1993.
66. Hossain, M.J.; Sarker, M.J.; Uddin, M.N.; Islam, A.; Tumpa, I.J.; Hossain, Z. Macrobenthos Presence in the Estuarine Waters of the Meghna River, Ramghati, Laksmipur, Bangladesh. *World Appl. Sci. J.* **2018**, *36*, 598–604.
67. Nandan, S.B.; Azis, P.K.A. Water quality and benthic faunal diversity of a polluted eastuary on the south-west coast of India. *Indian J. Environ. Prot.* **1996**, *16*, 12–22.
68. Karel, E. Ecological effects of dumping of dredged sediments; options for management. *J. Coast. Conserv.* **1999**, *5*, 69–80.
69. Lu, L.; Goh, B.P.L.; Chou, L.M. Effects of coastal reclamation on riverine macrobenthic infauna (Sungei Punggol) in Singapore. *J. Aquat. Ecosyst. Stress Recovery* **2002**, *9*, 127–135. [CrossRef]
70. Hena, A.M.; Kohinoor, S.M.; Siddique, M.A.; Ismail, J.; Idris, M.H.; Amin, S.M. Composition of macrobenthos in the Bakkhali channel system, Cox's Bazar with notes on soil parameter. *Pak. J. Biol. Sci.* **2012**, *15*, 641–646. [CrossRef]
71. Hossain, M.B. *Macrobenthos Community Structure of a Tropical Estuary*; LAP Publishing Company: Saarbrücken, Germany, 2011; p. 84.
72. Belaluzzaman, A.M. Ecology of the Intertidal Macrobenthic Fauna in Cox's Bazar Coastal Area, Bangladesh. Master's Thesis, Institute of Marine Sciences and Fisheries, University of Chittagong, Chittagong, Bangladesh, 1995; p. 55.

73. Boesch, D.F.; Rosenberg, R. Response to stress in marine benthic communities. In *Stress Effects on Natural Ecosystems*; Barrett, G.W., Rosenberg, R., Eds.; J. Wiley: Chichester, NY, USA, 1981; pp. 179–200.
74. Gaston, G.R.; Rakocinski, C.F.; Brown, S.S.; Cleveland, C.M. Trophic function in estuaries: Response of macrobenthos to natural and contaminant gradients. *Mar. Freshw. Res.* **1998**, *49*, 833–846. [CrossRef]
75. Hossain, M.B. Trophic functioning of macrobenthic fauna in a tropical acidified Bornean estuary (Southeast Asia). *Int. J. Sed. Res.* **2019**, *34*, 48–57. [CrossRef]
76. Whitlatch, R.B. Animal-sediment relationships in intertidal marine benthic habitats: Some determinants of deposit-feeding species diversity. *J. Exp. Mar. Biol. Ecol.* **1981**, *53*, 31–45. [CrossRef]
77. Rossi, F. Short-term response of deposit-feeders to an increase of the nutritive value of the sediment through seasons in an intertidal mudflat (Western Mediterranean, Italy). *J. Exp. Mar. Biol. Ecol.* **2003**, *290*, 1–17. [CrossRef]
78. Maurer, D.; Vargas, J.A. Diversity of soft-bottom benthos in a tropical estuary: Gulf of Nicoya, Costa Rica. *Mar. Biol.* **1984**, *81*, 97–106. [CrossRef]
79. Gaston, G.R.; Edds, K.A. Long-term study of benthic communities on the continental shelf off Cameron, Louisiana: A review of brine effects and hypoxia. *Gulf Caribb. Res.* **1994**, *9*, 57–64. [CrossRef]
80. Long, E.R.; Macdonald, D.D.; Smith, S.L.; Calder, F.D. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environ. Manag.* **1995**, *19*, 81–97. [CrossRef]
81. Selleslagh, J.; Lobry, J.; N'Zigou, A.R.; Bachelet, G.; Blanchet, H.; Chaalali, A.; Sautour, B.; Boët, P. Seasonal succession of estuarine fish, shrimps, macrozoobenthos and plankton: Physico-chemical and trophic influence. The Gironde estuary as a case study. *Estuar. Coast. Shelf Sci.* **2012**, *112*, 243–254. [CrossRef]
82. Hampel, H.; Elliott, M.; Cattrijsse, A. Macrofaunal communities in the habitats of intertidal marshes along the salinity gradient of the Schelde estuary. *Estuar. Coast. Shelf Sci.* **2009**, *84*, 45–53. [CrossRef]
83. Como, S.; Magni, P. Temporal changes of a macrobenthic assemblage in harsh lagoon sediments. *Estuar. Coast. Shelf Sci.* **2009**, *83*, 638–646. [CrossRef]
84. Zhang, J.; Xu, F.; Liu, R. Community structure changes of macrobenthos in the South Yellow Sea. *Chin. J. Oceanol. Limnol.* **2012**, *30*, 248–255. [CrossRef]
85. Nishijima, W.; Umehara, A.; Okuda, T.; Nakai, S. Variations in macrobenthic community structures in relation to environmental variables in the Seto Inland Sea, Japan. *Mar. Pollut. Bull.* **2015**, *92*, 90–98. [CrossRef] [PubMed]
86. Xie, Z.; Zhang, J.; Cai, K.; Wu, D.; Wang, B. Temporal and spatial distribution of macrobenthos communities and their responses to environmental factors in Lake Taihu. *Acta Ecol. Sin.* **2016**, *36*, 16–22. [CrossRef]
87. David, V.; Sautour, B.; Chardy, P.; Leconte, M. Long-term changes of the zooplankton variability in a turbid environment: The Gironde estuary (France). *Estuar. Coast. Shelf Sci.* **2005**, *64*, 171–184. [CrossRef]
88. McLusky, D.S.; Elliot, D. The Estuarine Ecosystem. In *Ecology, Threats and Management*, 3rd ed.; Oxford University Press: Oxford, UK, 2006; p. 214.
89. Ysebaert, T.; Herman, P.M. Spatial and temporal variation in benthic macrofauna and relationships with environmental variables in an estuarine, intertidal soft-sediment environment. *Mar. Ecol. Prog. Ser.* **2002**, *244*, 105–124. [CrossRef]
90. Yan, J.; Xu, Y.; Sui, J.; Li, X.; Wang, H.; Zhang, B. Long-term variation of the macrobenthic community and its relationship with environmental factors in the Yangtze River estuary and its adjacent area. *Mar. Pollut. Bull.* **2017**, *123*, 339–348. [CrossRef]