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Zooplankton in the lower Meghna River and its Estuary with Relation to Physico-Chemical Parameters, Bangladesh

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Abstract
The present study was conducted to explore the occurrence and distribution of zooplankton of the lower Meghna River Estuary and the effects of ecological variables on the distribution of zooplankton. Samples were collected seasonally at Sandwip, Hatiya Bhola, Barisal, and Chandpur to examine spatial and temporal variability in zooplankton abundance. A total of 37 major zooplankton taxonomic group were identified of which 32 and 23 were recorded during monsoon and post-monsoon season. Water was slightly acidic with very low salinity in major part of the estuary (accept Sandwip 15ppt and Hatiya 10ppt in post-monsoon). The water temperature, secchi depth, H^-CO_3, CO_2, DO, alkalinity, salinity and pH were significantly liable for the variations in zooplankton community structure ($p<0.05$). Canonical Corresponding Analysis (CCA) revealed that most of the zooplankton showed close affinity to secchi depth, CO_2, DO, H^-CO_3, water temperature and salinity in both season. Temporally the zooplankton diversity (H') did not show much variation (1.10±0.77 and 1.01±0.73 for monsoon and post-monsoon seasons respectively). Bray-Curtis similarity-based hierarchical clustering of zooplankton for sites showed Hatiya and Sandwip from a cluster whereas Bhola, Barisal and Chandpur formed single cluster in the both season.

Keywords: zooplankton, spatial and temporal environmental variable, biodiversity, occurrence and distribution, Meghna River and its estuary

1. Introduction
Bangladesh is blessed with a widespread coastline of about 710 km [1]. The river Meghna, one of the major rivers in Bangladesh discharges the joint flow of the Ganges-Padma, the Brahmaputra-Jamuna and the Meghna (joint flow of the Surma-Kushiyara) itself. The Meghna River ends in the Bay of Bengal form huge widespread estuarine is regularly influenced by the strong interactions of biotic and abiotic factors [2] due to tropical monsoon (southerly or southwesterly winds) and winter (north and northwest winds). Estuary is exclusively important part of aquatic habitat [3], is a great contributor of highly productive ecosystem [4], plays a significant role in the global carbon balance [5] and nutrient recycling [6] and serve as a favorable breeding and nursing environment for many commercially important shell and fin fishes [7]. Moreover many marine, brackish and fresh water animals largely depend on estuarine environment in their life history or entire life cycle.

The associated physicochemical parameters of estuarine ecosystems always affects zooplankton composition abundance and distribution that lead significant spatial and temporal alteration of community composition [8, 9, 10]. Zooplankton is the essential component of aquatic ecosystems [4] play significant role in nutrient cycle and transport in an estuary [11] have been studied on various bodies of water, including lakes, river, estuary and seas [12, 13, 14].

This study is aimed to investigate the zooplankton composition, abundance and diversity occurring in the lower Meghna River and its Estuary, to find spatial distribution pattern and the relation with physico-chemical parameters.

2. Materials and Methods
2.1 Study Area
The present study was conducted in the lower Meghna and its estuary at Sandwip (22°29.319'N, 91°25.668'E), Hatiya (22°24.459'N, 91°07.013'E), Bhola (22°37.153'N, 90°44.562'E), Barisal (22°41.962'N, 90°22.524'E) and Chandpur (23°13.768'N, 90°38.58'E). This study area ranged from the lower Meghna River at Chandpur to its estuary near Sandwip of Chittagong. The total length of the study area covering five districts (Chittagong, Noakhali, Bhola, Barisal and Chandpur) was about 172 miles (Fig. 1).

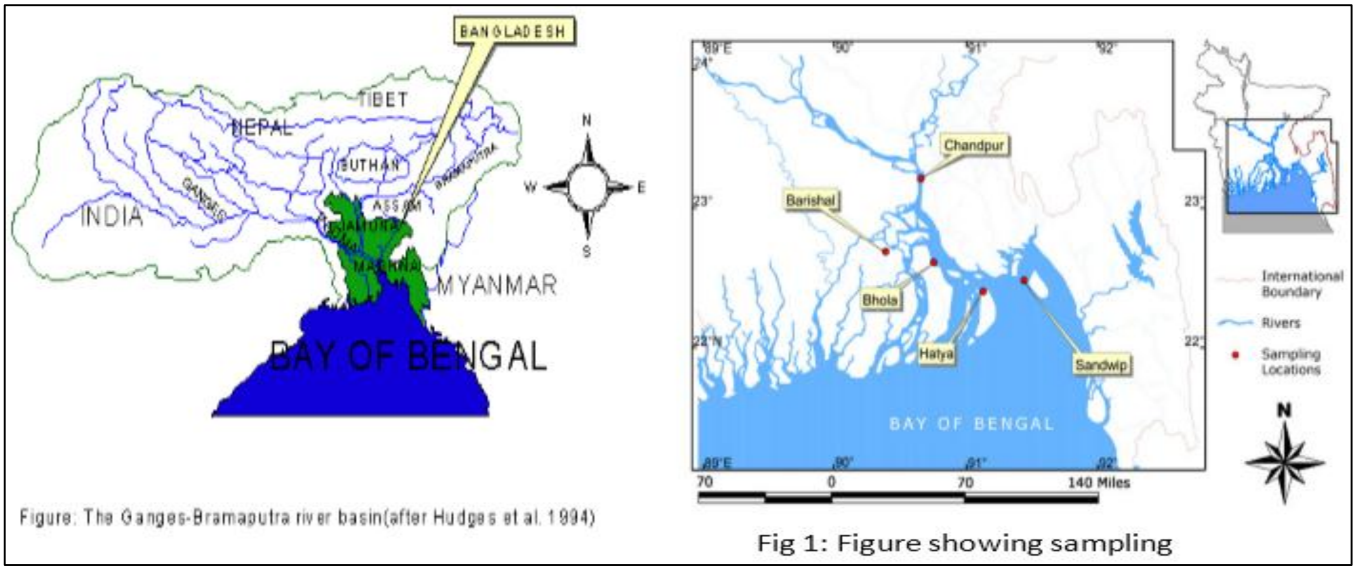


Fig 1: Map showing the sampling sites of the study area

2.2 Sample Collection and Preservation Water

Water samples of each sites were collected from on board passenger ships of BIWTA (Bangladesh Inland Water Transport Authority) during monsoon and post-monsoon seasons. Samples were drawn by a Kemmerer water sampler and were taken in labeled containers. In situ air and water temperature was determined using a graduated Centigrade thermometer; water pH was determined using pH paper (color pH ast ®, pH, indicator, strips, Cat.9582. Made in Germany); turbidity was determined using a white secchi disc of 30 cm diameter [15]; water salinity was determined using a hand held refractometer (ATAGO, S/Mill, salinity. 0-100 ‰, Japan.). In the laboratory, Dissolved Oxygen concentration was determined by the Winkler Method (H. O. PUB. No. 607. 1955); Total Suspended Solids (TSS) and TOM (Total Organic Matter) were determined (following Jin- Eong et al. [16]). BOD was determined by Light and dark bottle method [17]. HCO_3 CO_2 and alkalinity were determined following APHA [18].

Zooplankton

Zooplankton samples were collected from the subsurface water using a zooplankton net of 300 µm mesh from five sites during the study period. A flow meter was attached at the mouth of the net and weight was attached (as required) to keep the net at subsurface level while towing. The net was towed for about 15 minutes and the samples were kept in a labelled container for identification. The collected samples were immediately preserved in 70% ethanol and transferred to the laboratory for study. The collected samples were stained with 1-3% Rose-Bengle dye and left for overnight for efficient sorting. All the zooplanktons rendered pink color that made the sorting effortless. The stained plankton was sorted out from debris with fine brush, needle, forceps and a magnifying glass was used during sorting. The sorted organisms were preserved in 70% ethanol again. The sorted organisms were brought under microscope and identified following Mizuno [19]; Yamazi [20, 21, 22, 23]; Pennak [24]; Davis [25]; APHA [18]; Santhanam and Srinivasan [26]; Newell and Newell [27, 28]; Sterrer [29]; Parsons et al. [30]; Mahmood [31]; Pinkin et al. [15]; Wickstead [32]; Suess [33]; Rahman [34]; Ahmed [35]; Islam [36]; Elias [37]; Ahmed [38]; Zafar [39]; Belal [40]; Mohi [41] etc.

2.3 Statistical Analysis

One Way Analysis of Variance (ANOVA, Post-hoc LSD test) was done to find the influence of physico-chemical variables in the distribution of zooplankton (by SPSS v.22). Canonical Corresponding Analysis (CCA) was executed to understand the ecological relationship between physico-chemical parameters and zooplankton community during monsoon and post-monsoon seasons (by PAST v.3.1). Cluster analysis (Dendogram) was performed for the confirmation of similarity among the sites in terms of zooplankton occurrence (using PRIMER v.6). Zooplankton diversity was also analyzed (using PRIMER v.6)

3. Results and Discussion

Estuaries are subjected to regular variation in environmental conditions regarded as a typical feature of the estuary [42]. Variations in physico-chemical parameters influences the bio-chemical activity of both vertebrates and invertebrates. These abiotic factors control the rate of metabolic changes, response patterns of bodies to environmental stressors and the efficacy of immune systems [43, 44]. Major abiotic factors play significant role in the occurrence and distribution of zooplankton [45]. Zooplankton are available across an inclusive range of environmental surroundings, although the occurrence of some species is restricted by some abiotic factors such as dissolved oxygen, pH, temperature, salinity, or other physico-chemical parameters [46]. Sleigh [47] reported six vital environmental factors (water, temperature, pH, light, oxygen and salinity) for aquatic living organisms. Sharma et al. [48] suggested that monitoring of these physico-chemical factors is very important to identify the probable influence of the variables on the distribution and abundance of zooplankton. In the present study, water was recorded slightly acidic with low salinity in major part of the estuary (accept Sandwip 15ppt and Hatiya 10ppt in post-monsoon). $H^{-}CO_3$, water temperature, secchi depth, CO_2, DO, alkalinity, salinity and pH are significantly liable for the variations in most zooplankton community structure (p<0.05).

Water temperature is regarded as one of the imperative factors that controls the distribution and abundance of aquatic living organisms [49]. Geological, hydrological, climatic and anthropogenic factors massively influence the water quality [50, 51]. Abrupt change in water temperature causes unusual changes in composition and abundance of aquatic living organisms [52]. Hall and Burns [53] reported that water temperature impacts the growth and development of living organisms even influence their mortality. Adeniji and Ovie [54] suggested optimum temperature range (22-31°C) for the survival and best growth of aquatic organisms in subtropical estuaries. In the recent study, highest water temperature (31°C) was at Sandwip and the lowest (21°C) at Bhola in monsoon. While in post-monsoon, maximum (22.5°C) was at Hatiya and the minimum (21°C) at Chandpur (Table 1). The distribution and abundance of Polychaeta (F=398.626 & p=0.037), Amphipoda (F=633.690 & p=0.029) and Doliolida (F=1.488E6 & p=0.001) was closely related to water temperature during post-monsoon. Surface water temperature was (1-3) ºC lower than that of the air temperature in the study. This observation more or less similiar with the works of Mahmood and Khan [55]; Elias [37], Mahmood [56]; Chapman [57]; Zafar [58]; Iqbal [59]; Noori [60]; Martin et al. [61] and George et al. [62].

Salinity is the pointer of freshwater intrusion in the near shore coastal water as well as extrusion of tidal water in inland water bodies [62]. Salinity acts as a limiting parameter that hugely influences the dispersal of plankton community [63]. Excessively high or low salinity also prompt organisms to migrate in order to escape unfavorable environmental conditions [64]. Perumal et al. [64] also mentioned that changes in salinity can also contribute indirectly to food shortages and thereby impact the zooplankton abundance. During monsoon, only 1‰ salinity was recorded at Sandwip, while at all other sites salinity was almost zero. During post-monsoon maximum salinity was 15‰ at Sandwip and minimum was 10‰ at Hatiya (Table 1) and other three sites were almost zero. The distribution pattern of Nemertea (F=315.053 & p=0.003), Zoea (F=110.642 & p=0.009) and Polychaeta (F=896.658 & p= 0.001) showed strong relation to salinity during post-monsoon.

In present study the highest secchi depth (55 cm) was at Chandpur and the lowest (4 cm) at Sandwip during monsoon. In post-monsoon, maximum secchi depth (65 cm) recorded at Bhola and the minimum (35 cm) at Sandwip (Table 1). In monsoon the distribution and abundance of Ostracoda (F=1.135E3 & p=0.022) and Trichoptera (F=5.14 & p=0.01) were hugely affected by secchi depth. Ezra [65], Venkateswarlu et al. [66] and Haruna et al. [67] reported that transparency increased the occurrence of zooplankton via the growth of phytoplankton.

pH is commonly known as the controlling variable in water since many properties, processes and reaction are pH dependent [68]. Low or high pH causes zooplankton abundance reduction [69, 70, 71], while low alkaline condition contribute high primary production that favors the occurrence and diversity of zooplankton [72, 73]. In the present study, during monsoon maximum pH 7 was recorded at Barisal and Chandpur whereas the lowest pH 6.4 was recorded at Sandwip and Hatiya. In case of post-monsoon maximum pH 7 was at Sandwip and Hatiya and the minimum pH 6.5 was documented at Bhola and Chandpur (Table 1). The pH recorded in the present study fall within the FEPA [74], WHO [75], Pandey [76] and Ragnar [77] standard range of 6.0-9.0. It was also similar to the findings of Inuwa [78], Mustapha [79] and Mustapha [80]. The abundance and occurrence of Calanoida (F=63.433 & p=0.016), Caridean shrimp (F=3.953E4 & p=0.000), Diptera (F=1.470E3 & p=0.019) and Coleoptera (F=19.740 & p=0.048) were significantly related to water pH during monsoon. The distribution pattern of Calanoida (F=84.704 & p=0.012), Hydromedusa (F=39.025 & p=0.025), Lucifer (F=126.888 & p= 0.008) and *Sagitta* (F=28.741 & p=0.034) showed strong relation to pH during post-monsoon.

Dissolved oxygen (DO) an important ecological factor that decides environmental health of water bodies and support a well-balanced aquatic living organisms [62, 81]. In monsoon, maximum DO (2.8 ml/L) was at Chandpur while the minimum (1.5ml/L) at Sandwip. Again the highest DO (5.5 ml/L) was at Chandpur and Barisal whereas the lowest (3.7 ml/L) was at Sandwip during post-monsoon (Table 1). The distribution and abundance of Caridean shrimp (F=1.364 & p=0.006) and Zoea (F=223.952 & p=0.049 was closely related to DO during post-monsoon. Edward and Ugwwnba [82] zooplankton had a positive significant ($p<0.05$) correlation with dissolved oxygen.

During monsoon, maximum (0.99 ml/L) of CO_2 was at Barisal and Chandpur, while minimum value (0.34 ml/L) was found at Sandwip and Hatiya. During post-monsoon supreme amount of CO_2 (0.5 ml/L) was found at Bhola and minimum value was (0.3ml/L) at Barisal and Chandpur (Table 1). The distribution pattern of Calanoida (F=63.433 & p=0.016), Caridean shrimp (F=3.953E4 & p=0.000) and Coleoptera (F=19.740 & p= 0.048) showed strong relation to CO_2 during monsoon.

Greatest concentration of H^-CO_3 (0.000367 mg/L) was found at Hatiya and Bhola and the lowest concentration (0.00012 mg/L) was recorded at Chandpur during monsoon. The maximum H^-CO_3 (0.00036 mg/L) was found at Chandpur and Bhola while the minimum (0.00018 mg/L) was documented at Hatiya during post-monsoon (Table 1).

Maximum alkalinity (2.1 mg/L) was found at Sandwip and the minimum amount (0.7 mg/L) was recorded at Barisal during monsoon. The highest alkalinity (1.05 mg/L) was found at Sandwip and the smallest (0.95 mg/L) was documented at Chandpur during post-monsoon (Table 1). The abundance and occurrence of Cladocera (F=1.024E3 & p=0.023) significantly related to concentration of alkalinity during post-monsoon. Edward and Ugwwnba [82] found a positive significant ($p<0.05$) correlation existed between the zooplankton and alkalinity.

Table 1: Physico-chemical parameters of surface water during monsoon (M) and post-monsoon (PM).

Parameters/ Stations	Sandwip		Hatiya		Bhola		Barisal		Chandpur	
	M	PM	M	PM	M	PM	M	PM	M	PM
Air Temperature (^{0}C)	33	28	27.2	29	25.5	23	32	28	26	25
Water Temperature (^{0}C)	31	23	28	22.5	28.5	21	29	22	29	21
Secchi Depth (cm)	4	35	7	45	12	65	12	37	55	60
TSS (mg/L)	10.8275	1.2922	7.688	1.3377	3.6595	1.3007	5.4435	1.3267	0.3175	1.3332
TOM (mg/L)	0.856	0.6396	0.7955	0.6116	0.774	0.5361	0.79	0.5876	0.4835	0.5636
pH	6.4	7	6.4	7	6.8	6.5	7	6.6	7	6.5
DO (ml/L)	1.9	3.7	2	3.9	2.5	5.2	2.7	5.5	2.8	5.5
BOD (ml/L)	17	0	21	2	38	13	35	6	34	7

CO_2 (ml/L)	0.396	0.34	0.396	0.4	0.594	0.5	0.99	0.3	0.99	0.3
Alkalinity (mg/L)	2.1	1.05	1.5	1	1.8	1.05	0.7	1.1	1.00	0.95
H^-CO_3 (mg/L)	0.000244	0.000244	0.0004	0.0002	0.0004	0.0004	0.0002	0.0003	0.0001	0.0004
Salinity (‰)	1	15	0	10	0	0	0	0	0	0

Occurrence and Distribution of Zooplankton

A total of 37 major zooplankton taxa were identified during the both season of which 32 and 32 taxa were recorded during monsoon and post-monsoon season respectively. During monsoon highest number of zooplankton were at Sandwip (2419.60 indivs/m^3) and lowest at Bhola (29.90 indivs/m^3). On the other hand during post-monsoon the highest (49670.30 indivs/m^3) and the lowest (19913.70 indivs/m^3) were recorded at Bhola and Hatiya respectively. Copepoda (Calanoida and Cyclopoida) were common in all sites and seasons. But *Lucifer* and *Sagitta* were restricted in Sandwip and Hatiya only in post-monsoon.

In Sandwip 11 zooplankton group were recorded in both season of which Calanoida, Caridean shrimp, Cyclopoida, Zoea were recorded in both seasons. During monsoon Calanoida (75.13%) and Cyclopoida (21.82%) occupied major portion where as in post-monsoon Cladocera (76.58%), Cyclopoida (13.48%) and Doliolida (7.79%) contributed lions share. At Hatiya 15 and 8 major taxa were identified during monsoon and post-monsoon respectively. Amphipoda, Calanoida, Caridean shrimp, Cyclopoida, Megalopa, Mysis during the both season. Calanoida (80.6%) & Cyclopoida (10.99%) were recorded major part during monsoon whereas in post-monsoon Cladocera (86.19%) & Calanoida (8.32%) occupied major percentage. In case of Bhola 8 and 9 taxonomic were documented in monsoon and post-monsoon respectively. Calanoida, Caridean shrimp, Coleoptera, Cyclopoida, Megalopa and Zoea were recorded in the site during the both season. Calanoida (70.16%) and Caridean shrimp (22.01%) showed major part during monsoon while Cladocera (65.61%), Calanoida (13.96%) and Doliolida (11.91%) were during post-monsoon season. In Barisal 18 and 11 taxonomic group were documented in monsoon and post-monsoon respectively. Amphipoda and Cladocera were recorded during both season. During monsoon Ephemeroptera (16.66%), Cladocera (14.45%), Diptera (14.45%), Amphipoda (12.21%) and Fish juvenile (10%) contributed as major groups where as in post-monsoon Calanoida (84.97%), Cladocera (8.07%) and Cyclopoida (3.29%) were most portion. At Chandpur 18 and 11 taxonomic group were documented in monsoon and post-monsoon respectively. During the both seasons Calanoida, Cladocera, Fish juvenile, Megalopa and Mysis were recorded at Chandpur. Cyclopoida (61.84%) and Calanoida (16.88%) where major portion during monsoon while in post-monsoon Calanoida (93.29%) and Acetes (3.42%) were recorded as dominating group.

Table 2: Zooplankton (%) occurred at five sites during monsoon (M) and post-monsoon (PM).

Sl.	Zooplankton/sites	Sandwip		Hatiya		Bhola		Barisal		Chandpur	
		M	PM	M	PM	M	PM	M	PM	M	PM
1	*Acetes*	-	-	-	-	-	-	-	0.41	-	3.42
2	Adult drone fly	-	0.11	-	-	-	-	-	-	0.59	-
3	Adult sea wage fly	-	-	-	-	-	-	2.21	-	-	-
4	Amphipoda	0.04	-	0.09	0.04	-	0.66	12.21	0.01	0.18	-
5	Archiogestropoda	-	-	0.13	-	-	-	2.21	-	-	-
6	Bivalvia	-	-	-	-	-	-	2.21	-	-	-
7	Branchiopoda	-	-	-	-	-	-	1.1	-	0.12	0.13
8	Calanoida	75.13	0.43	80.6	8.32	70.16	13.96	-	84.97	16.88	93.29
9	Caridean shrimp	0.09	0.01	0.06	0.02	22.01	0.01	-	0.01	0.18	-
10	Cladocera	-	76.58	-	86.19	-	65.61	14.45	8.07	3.46	0.62
11	Coleoptera	-	0.08	-	-	0.03	0.04	7.76	-	0.12	-
12	Crab larvae	0.03	-	-	-	0.03	-	1.1	-	-	-
13	Cyclopoida	21.82	13.48	10.99	2.9	6.48	7.13	-	3.29	61.84	-
14	Diptera	-	0.24	0.04	-	-	-	14.45	-	3.52	-
15	Doliolida	-	7.79	-	1.96	-	11.91	-	-	-	0.02
16	Egg	-	-	-	-	-	-	2.21	-	-	-
17	Ephemeroptera	-	-	-	-	-	-	16.66	-	2.05	-
18	Fish juvenile	0.09	-	0.09	-	-	-	10	-	0.06	0.02
19	Hemiptera	-	-	-	-	-	-	-	-	3.17	-
20	Hydromedusa	-	-	0.13	-	-	-	-	0.75	-	0.79
21	Isopoda	-	-	0.04	-	-	-	4.45	-	-	-
22	*Lucifer*	0.2	-	0.57	-	-	-	-	1.3	-	0.77
23	Megalopa	0.04	-	0.05	0.53	0.03	0.67	-	0.75	0.23	0.02
24	Mesogastropoda	-	-	-	-	-	-	2.21	-	-	-
25	Mysidacea	-	-	-	-	-	-	-	-	0.76	-
26	Mysis	0.09	-	0.82	0.03	0.33	-	-	0.03	0.18	0.05
27	Nemertea	-	0.05	-	-	-	-	1.1	-	-	-
28	Ostracoda	-	-	0.18	-	-	-	1.1	-	1.11	-
29	Penaeidae shrimp	-	-	-	-	-	-	-	-	-	0.07
30	Plecoptera	-	-	-	-	-	-	-	-	0.47	-
31	Polychaeta	-	0.08	-	-	-	-	-	-	0.06	-

32	Porifera	-	-	-	-	-	-	-	-	-	0.03
33	Rotifera	-	-	-	-	-	-	-	-	-	0.01
34	*Sagitta*	1.89	-	5.4	-	-	-	-	0.42	-	0.51
35	Spider & Mite	-	-	-	-	-	-	-	-	2.76	-
36	Trichoptera	-	-	-	-	-	-	1.1	-	2.29	-
37	Zoea	0.58	1.15	0.82	-	0.92	0.01	3.34	-	-	0.27
Total (%)		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Legend: - = Absent

Multivariate Analysis

Canonical Corresponding Analysis (CCA)

The Redundancy Analysis (RDA) triplot generally used to explaining the favored abiotic environmental factors for the characterizing and dominant zooplankton both in monsoon and post-monsoon seasons and also showed the influence of environmental parameters (Fig. 2 & 3).

During the monsoon season, when a low-salinity environment prevailed in majority portion of the estuary, Archiogestropoda and Calanoida showed a positive relation with salinity while Crab larvae, Adult sea wage, Bivalvia, Branchiopoda, Amphipoda, Ephemeroptera, Caridean shrimp, Coleoptera and Diptera showed close affinity to secchi depth, CO_2 and DO. Several characterizing zooplankton exhibited strong affinity to H^-CO_3 but had no proper trend with salinity (Fig. 2). *Lucifer*, Mysis, *Sagitta* etc. showed that they were not influenced by the environmental variables at all.

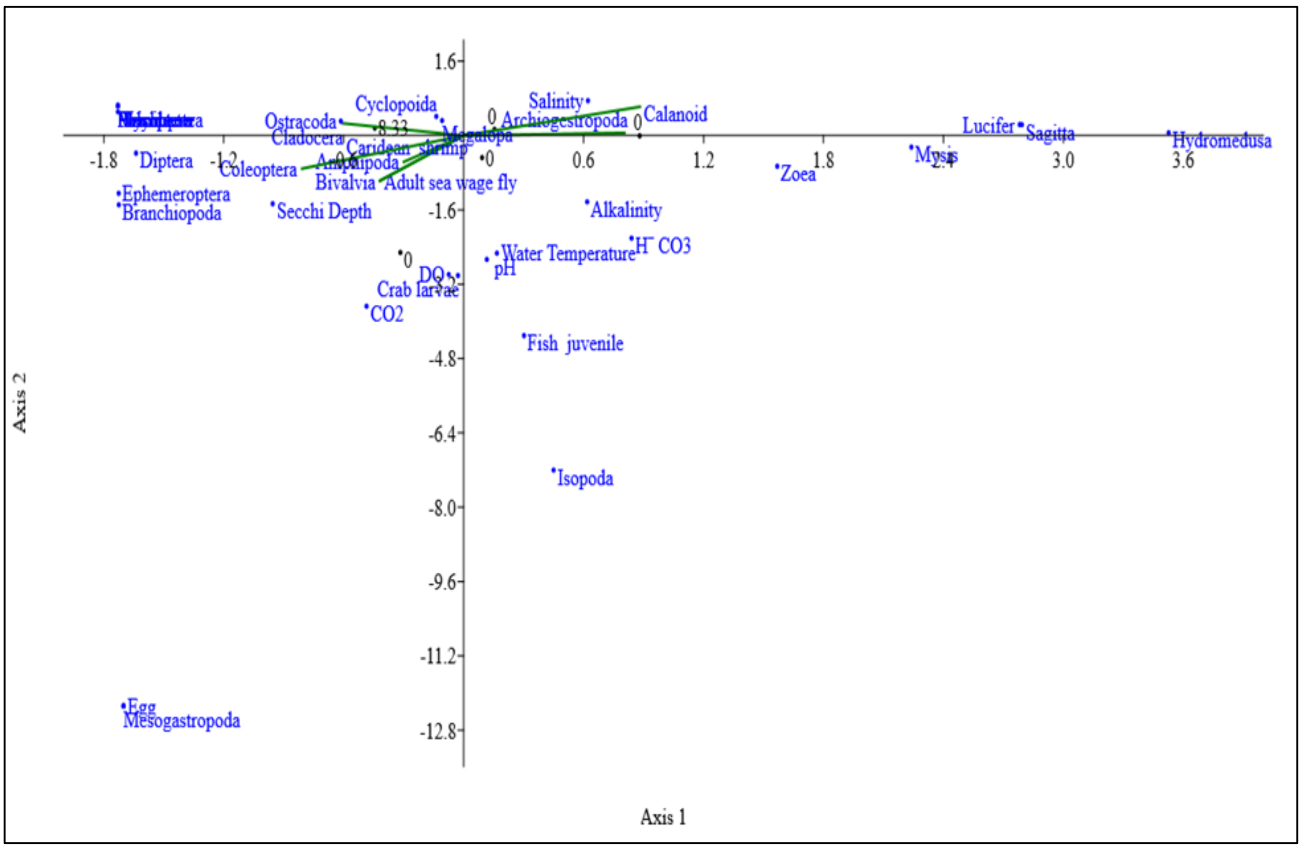


Fig 2. The redundancy analysis (RDA) triplot displaying the ecological relationship between physico-chemical parameters and zooplankton during monsoon season.

During the post-monsoon season, Adult drone fly, Nemertea, Polychaeta, Diptera and Zoea showed positive affinity to salinity (Fig. 3). Archiogestropoda, Branchiopoda and Mysis exhibited positive relation with H^-CO_3, CO_2, water temperature, DO and secchi depth. But most of the zooplankton were not influenced by physico-chemical factors during post-monsoon (Fig. 3).

Therefore, an exhaustive study on the inter-relation among the zooplankton and environmental factors was executed for each season, and the triplot in the RDA was helpful in both imagining all the data points plotted in the coordinate system and recognizing the inter-relationship among zooplankton and environmental factors.

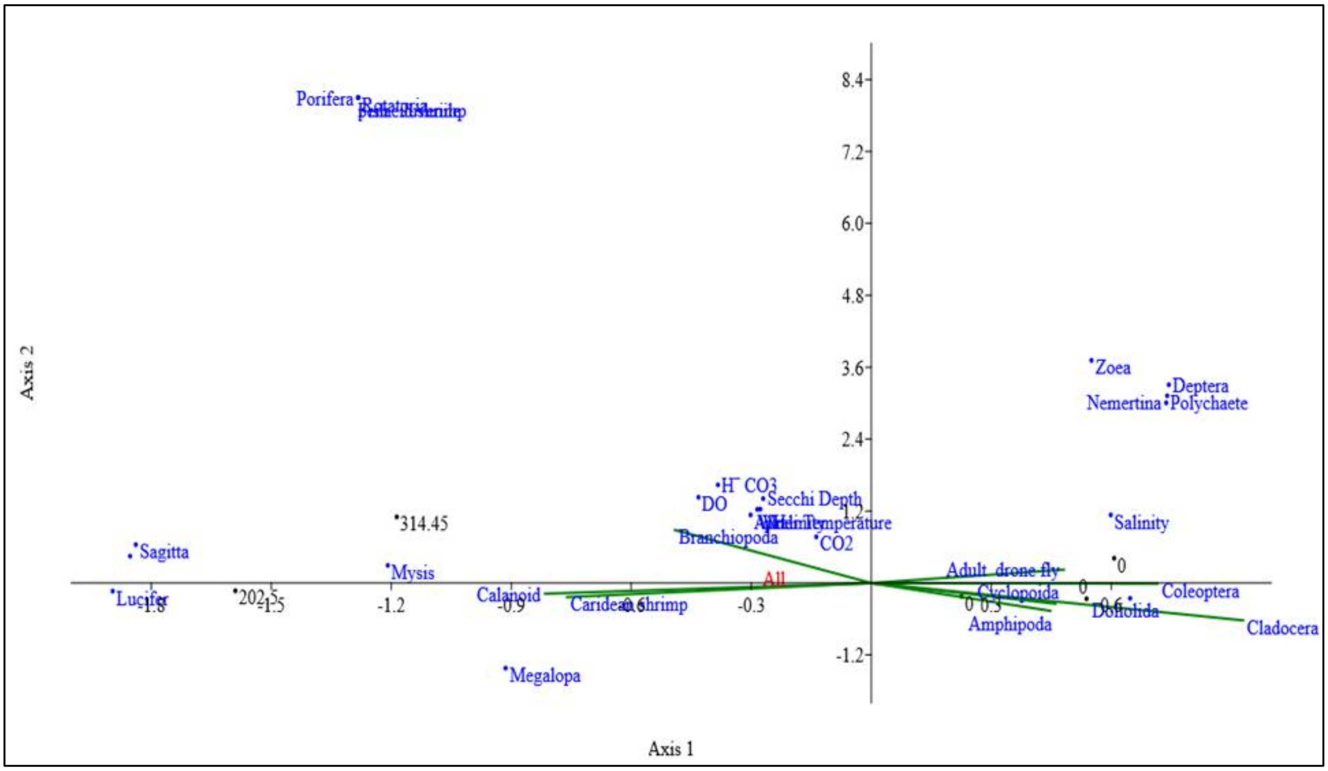
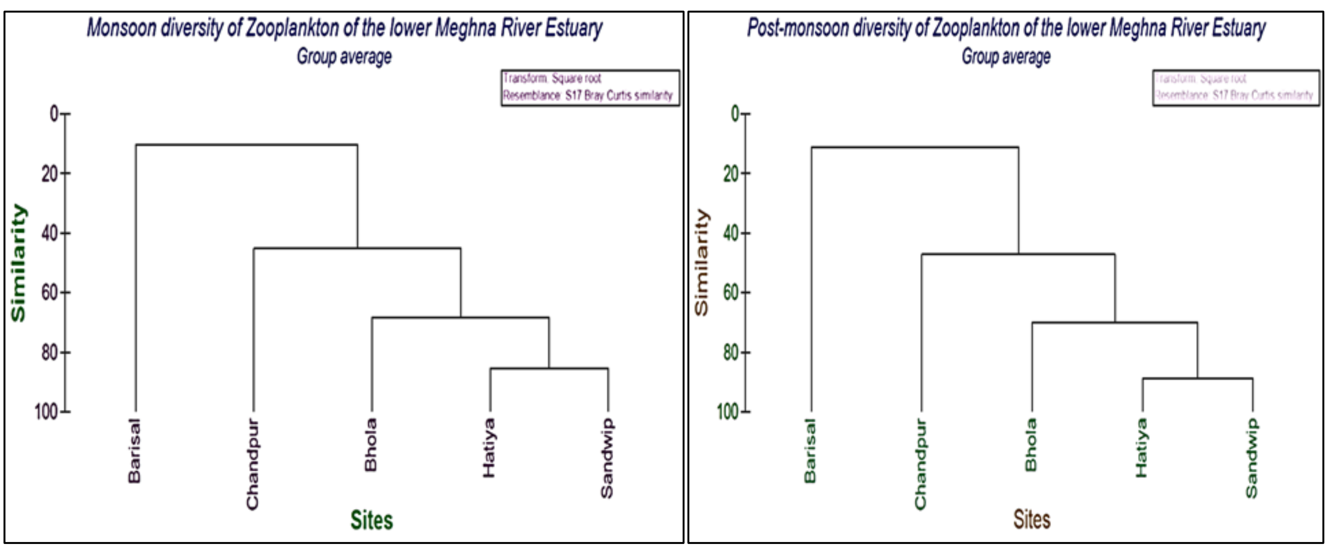


Fig 3. The RDA triplot showing inter-relation between physicochemical parameters and zooplankton during post-monsoon season.

Cluster Analysis

Cluster analyses (CA) were executed using square root and Bray Curtis Similarity to show the similarity among the sites in terms of zooplankton occurrence. The dendogram of the zooplankton, based on their abundance pattern along with different seasons, helped extensively in understanding the similarity in their distribution in the estuary. During the monsoon and post-monsoon season, Hatiya and Sandwip from a cluster, that means they are almost similar in case of zooplankton abundance (Fig. 4a & 4b). Bhola, Chandpur and Barisal formed single cluster both in monsoon and post-monsoon season (Fig. 4a & 4b).

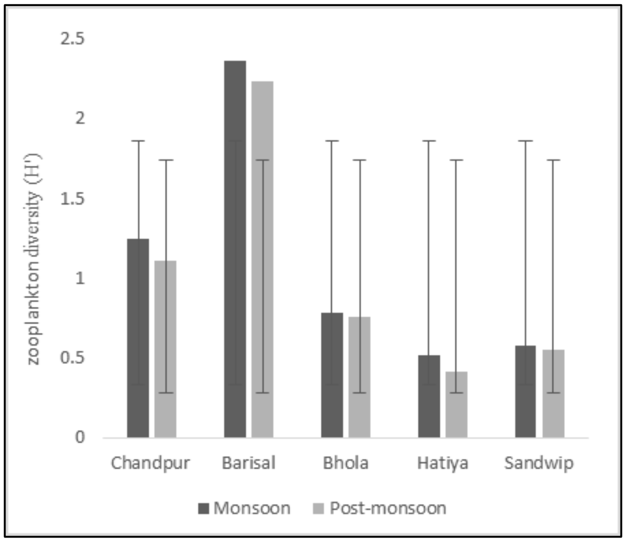


(a) (b)

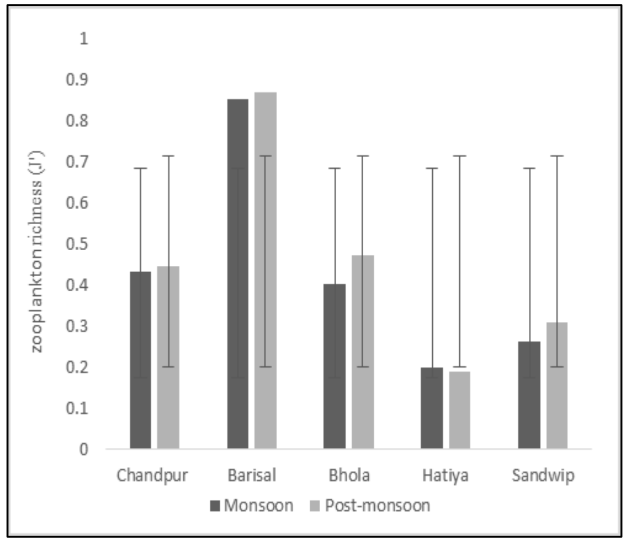
Fig 4. Bray-Curtis similarity-based hierarchical clustering of zooplankton during the (a) monsoon and (b) post-monsoon periods at 5 different sites.

Diversity Indices

Generally, species diversity is a function of species richness and evenness with which the individuals are distributed in these species [83]. Zooplankton diversity (H') and evenness (J') did not show much variation in the present study spatially and temporally (Fig. 5a). Temporally Zooplankton diversity (H') were 1.10±0.77 and 1.01±0.73 during monsoon and post-monsoon respectively. The highest diversity (H') was at Barisal (2.37) in monsoon and the lowest was at Hatiya (0.41) during the post-monsoon (Fig. 5a). Again the maximum evenness was at Barisal (0.8704) during post-monsoon and the minimum value was at Hatiya (0.1999) during the monsoon season (Fig. 5b).



(a)



(b)

Fig 5. Diversity indices zooplankton (a) diversity and (b) evenness, along two seasons. The vertical line on the bar diagram indicates the standard deviation.

4. Conclusion

The findings of the present study are preliminary information of the effects of environmental variables on the diversity, occurrence, distribution and abundance of zooplankton in the lower Meghna River and its estuary. A total of 37 major zooplankton taxonomic group were identified of which 32 and 23 were recorded during monsoon and post-monsoon season. During monsoon highest number of zooplankton were at Sandwip (2419.60 indivs/m^3) and lowest at Bhola (29.90 indivs/m^3). On the other hand during post-monsoon highest (49670.30 indivs/m^3) and lowest (19913.70 indivs/m^3) were recorded at Bhola and Hatiya respectively. Copepoda (Calanoida and Cyclopoida) were common in all sites and seasons. But *Lucifer* and *Sagitta* were restricted in Sandwip and Hatiya only in post-monsoon. Water in the Study area was slightly acidic with very low salinity in major part of the estuary (accept Sandwip 15ppt and Hatiya 10ppt in post-monsoon). The water temperature, secchi depth, H^-CO_3, CO_2, DO, alkalinity, salinity and pH showed significantly liable for the variations in zooplankton community structure ($p<0.05$). Canonical Corresponding Analysis (CCA) revealed that most of the zooplankton showed close affinity with ecological parameters; such as Archiogestropoda and Calanoida showed a positive relation with salinity while Crab larvae, Adult sea wage, Bivalvia, Branchiopoda, Amphipoda, Ephemeroptera, Caridean shrimp, Coleoptera and Diptera showed close affinity to secchi depth, CO_2 and DO during monsoon. Moreover, Adult drone fly, Nemertea, Polychaeta, Diptera and Zoea showed positive affinity to salinity. Archiogestropoda, Branchiopoda and Mysis exhibited positive relation with H^-CO_3, CO_2, water temperature, DO and secchi depth during post-monsoon. Temporally the zooplankton diversity (H') did not show much variation (1.10±0.77 and 1.01±0.73 for monsoon and post-monsoon seasons respectively). Bray-Curtis similarity-based hierarchical clustering of zooplankton for sites showed Hatiya and Sandwip from a cluster whereas Bhola, Barisal and Chandpur formed single cluster in the both season.

5. Limitations

In the present study the sampling sights covered an area of about 172 km and samples were collected from passenger ship. So it was difficult to take sample at a time from all sites as well as to maintain tidal cycle or tide log. Again as samples were collected from passenger ship on board samples have to collect where the ship anchored for disembarkation of passengers and goods

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