Seasonal occurrence and community structure of gastropod molluscs with environmental variables at Cox's Bazar sandy sea beach, Bangladesh

[1]Mohammad A. Baten Bhuyain, [1]Md. Ayenuddin Haque, [1]Md. A. Sayed Jewel, [2]Jakia Hasan, [1]Alok K. Paul, [3]Md. Selim Reza, [4,5]Simon K. Das

[1] Department of Fisheries, Faculty of Agriculture, University of Rajshahi, Rajshahi-6205, Bangladesh; [2] Bangladesh Fisheries Research Institute, Marine Fisheries & Technology Station, Cox's Bazar-4700, Bangladesh; [3] Program Officer (Fisheries), Palli Karma Sahayak Foundation (PKSF), Bangladesh; [4] Department of Earth Sciences and Environment, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia; [5] Marine Ecosystem Research Centre (EKOMAR), Faculty of Science and Technology, Universiti Kebangsaan, Malaysia, Malaysia. Corresponding author: S. K. Das, simon@ukm.edu.my

Abstract. An observation on the seasonal distribution of gastropod molluscs in relation to some environmental variables was made in the intertidal seashore water of Cox's Bazar, Bangladesh. A total of 8253 individuals of gastropods representing 34 species under 21 families and 4 orders were identified. The Shannon-Weaver diversity, Pielou's evenness and Margalef's richness index were found to vary from 2.22 (monsoon) to 2.68 (winter), 0.60 (pre-monsoon) to 0.73 (post-monsoon) and 2.04 (post-monsoon) to 3.21 (winter), respectively that displayed moderate pollution status of the beach. The number of species was varied seasonally with the higher number of individuals being recorded during post-monsoon and the lower during monsoon season. *Turritella acutangula* was the most important species responsible for dissimilarity among the seasons and the distribution of gastropod's community was found best explained by the salinity of water.

Key Words: gastropods, seasonal variations, environmental parameters, Cox's Bazar, Bangladesh.

Introduction. All over the world, sandy shores are most vulnerable to environmental variables including tidal changes, wind, erosion and disposal of nutrients which affects the organisms living within this habitat (Rodriguez et al 2003; McLachlan & Brown 2006; Shanmugam & Vairamani 2015). Wave, sediments and substrates are known as the three basic factors for shore habitat. However, in sandy sea beach, physical factors are through to influence the composition, diversity, and abundance of macrofaunal organisms more strongly rather than biological factors (McLachlan & Brown 2006). Therefore, assessing the interaction between physical factors and species assemblage is considered important for determining the damage of aquatic ecosystem and to take necessary steps towards the conservation and restoration of aquatic organisms (Valiela et al 2001; Mason et al 2005; Cadotte et al 2011).

Molluscs, particularly gastropods and bivalves were among the earliest taxa of marine macrofauna. Gastropods are macrobenthic organisms that can be a good model to find out pollution status of marine environment because of their tolerance and adaptability to various ecological parameters (Primost et al 2016). Moreover, they can serve as an effective indicator to evaluate the overall ecosystem health and species diversity (Rittschof & McClellan-Green 2005) and their study can provide useful tool to know the past, current and future habitat conditions of marine environment (Şahin 2012).

Bangladesh is blessed with a vast marine water resource in the Bay of Bengal which is a part up in the largest malacological and conchological province of the world, the Indo-Pacific region (Ahmed 1990). The longest sandy sea beach of the world is situated here at Cox's Bazar. Nowadays, Cox's Bazar is attracted by tropical cyclones and tornados, tidal surges and floods, erosion, heavy silt, and pollution especially from the mega-cities and ports, shrimp hatchery and shrimp farms. The pollution in the form of organic enrichment changes the sedimentary composition that results in unstable assemblages of populations of many species.

Although, the environment of Cox's Bazar sea beach was favourable for molluscan diversity compared to the other sandy sea beaches of the world (Jumawan et al 2015; Das et al 2016; Raveendran et al 2016), to date, there was no study analyzing the diversity pattern of gastropods present at the sandy sea beach of Cox's Bazar and the key environmental factors structuring the distribution of these species. Therefore, the present study was performed to investigate diversity pattern of the gastropods and some physico-chemical parameters based upon seasons (monsoon, post-monsoon, winter and pre-monsoon).

Material and Method

Study area. The area selected for the sample collection was between 21°26'18.52''N-91°57'25.88''E to 21°23'40.84''N-91°59'50.11"E (Figure 1). Cox's Bazar coast is characterized by the monsoon wind as the equatorial line has passed through the nearly northern side. The seasonal wind in this reason undergoes a complete reversal between January and July, resulting in the northeast monsoon (winter) and southwest monsoon (summer).

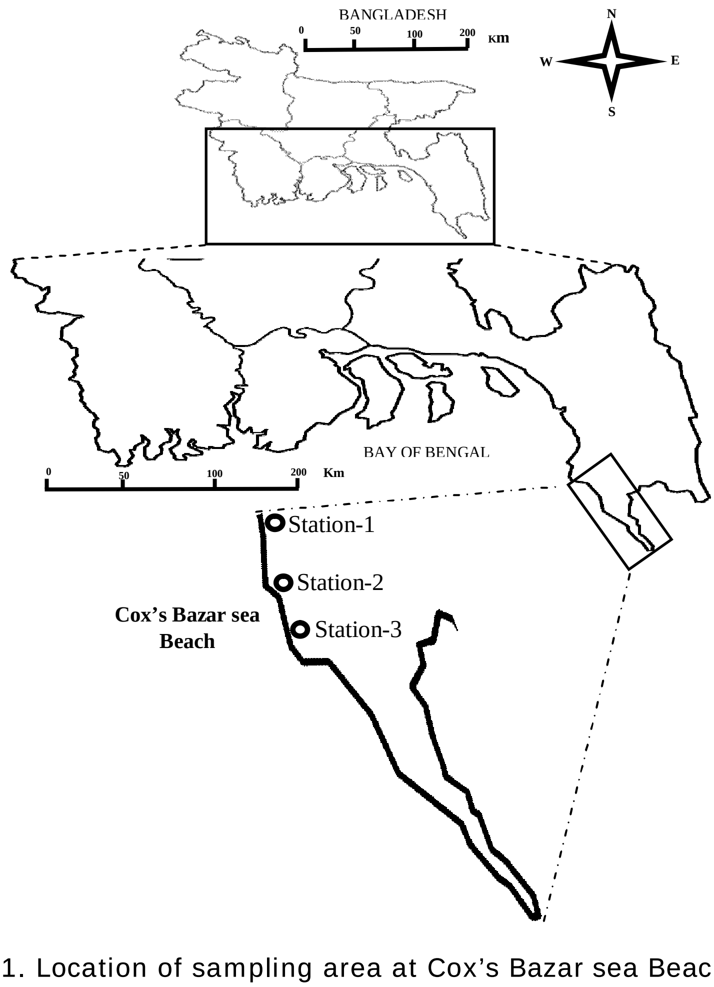

Figure 1. Location of sampling area at Cox's Bazar sea Beach, Bangladesh.

Sampling procedure of gastropods and laboratory analysis. The study was conducted for 12 months from July 2016 to June 2017. Three sampling sites were assigned at a distance of 1 km to generate a uniform data. For the sake of interpretation, the data collected in each station was averaged and pooled together based on the seasons. The whole study period was divided into 4 distinct seasons *viz*., monsoon (June-August), post-monsoon (September-November), winter (December-February) and pre-monsoon (March-May). Sampling spots were determined by a measuring tape and the area of a sampling spot was fixed at 80 x 30 m^2. Samples were collected from each station in every month of the study period by hand picking and dredging during low tide as mentioned by Arumugam et al (2010). Both living and dead shells were taken in polyethylene bags and the bags were marked. The collected samples were washed with tap water for cleaning the sands then living and dead shells were separated. The living samples were kept in 10% alcohol solution for further study. In the laboratory, samples were first sorted and enumerated by enumeration method. Identification was carried out using different authors' key such as Morton (1976), George & George (1979), Gupta & Malik (1977), Ahmed (1990), Ramakrishna & Dey (2003), and Rao (2003) based on the colour pattern of the shell, shape, number of whorls and operculum.

Gastropods diversity analysis. Diversity indices of gastropods such as Shannon diversity index (H'), Pielou's evenness index (J) and Margalef's species richness (S) were calculated based on the following formulae:

The Shannon diversity index: $H = -\sum i \frac{n_i}{N} \ln \frac{n_i}{N}$ (Shannon & Weaver 1949)

Where, H = the diversity index, n_i = the relative abundance (S/N), S = the number of individuals for each species, N = total number of individuals.

Evenness index (J): $e = \frac{H}{L_n S}$ [L_n = the natural logarithm] (Pielou 1969)

Where, H = is the Shannon-Weaver's diversity index and S = is the number of different species in the sample.

Species richness (S): $D = \frac{S-1}{\ln N}$ (Margalef 1969)

Where, D = Margalef's richness index, S = number of different species in the sample, N = total number of individual species in the sample.

Physico-chemical parameters analysis. Water samples were collected monthly from each station and averaged for season. Water temperature was measured using a thermometer; pH and dissolved oxygen using an electronic pH meter (Jenwary 3020) and DO meter (Lutron DO-5509), respectively. Salinity was measured using a hand Refractometer (Model no-211. HANNA instruments). Alkalinity (mg L^{-1}) was determined by the help of a HACH kit (FF2, USA).

Statistical analysis. Multivariate analysis of variance (MANOVA) at 5% level of significance was used to test for the seasonal variation in overall gastropods composition, whereas analysis of variance (ANOVA) was used to test significant difference ($p < 0.05$) of environmental parameters using SPSS (Statistical Package for Social Sciences, version 20.0, IBM Corporation, Armonk, NY, USA) software. Duncan's post hoc tests were employed to check for difference in the abundance of individual species and physico-chemical parameters among the seasons. Analysis of Similarities (ANOSIM) (Clarke & Warwick 1994) was performed to test the significant difference of gastropod species among the seasons. Similarity percentages analysis (SIMPER) was performed to observe the percentage of similarity and percentage of major contributing species among the seasons. Non-metric multi-dimensional scaling (nMDS) was also performed at $\log_{10}(1+x)$ transformed data to allocate the similarity among the seasons in terms of gastropods abundance. The multivariate analyses were conducted using PAST 3 (Paleontological Statistics). For the assessment of the environment influence on gastropod community structure, the Biota and Environment matching routine (BIOENV) package was used to determine the best match between multivariate gastropod abundance pattern and environmental parameters. Environmental parameters were square-root transformed and standardized before analysis. The best matches of biological and environmental parameters were measured using the Spearman rank correlation coefficient (ρ_w). To investigate individual influence of each physico-chemical parameter on gastropod distribution pattern, a distance-based liner model (DistLM) was performed with 95% confidence intervals using 1,000 permutations and at the statistical significance level of 1% in the program PRIMER v7 + PERMANOVA (Clarke & Gorley 2006). Canonical Correspondence Analysis (CCA) was calculated to find out the association between species and physico-chemical parameters using the software PAST 3 (Paleontological Statistics) (Simon et al 2010).

Results

Environmental variables. During the study period, the environmental variables showed significant differences ($p < 0.05$) among the seasons (Figure 2). Water temperature, pH and alkalinity were high during pre-monsoon season. However, temperature decreased subsequently during winter season, whereas pH and alkalinity were decreased during monsoon season. Salinity and dissolved oxygen concentrations showed their higher value during pre-monsoon and winter season, respectively, whereas lower in monsoon and pre-monsoon season (Figure 2).

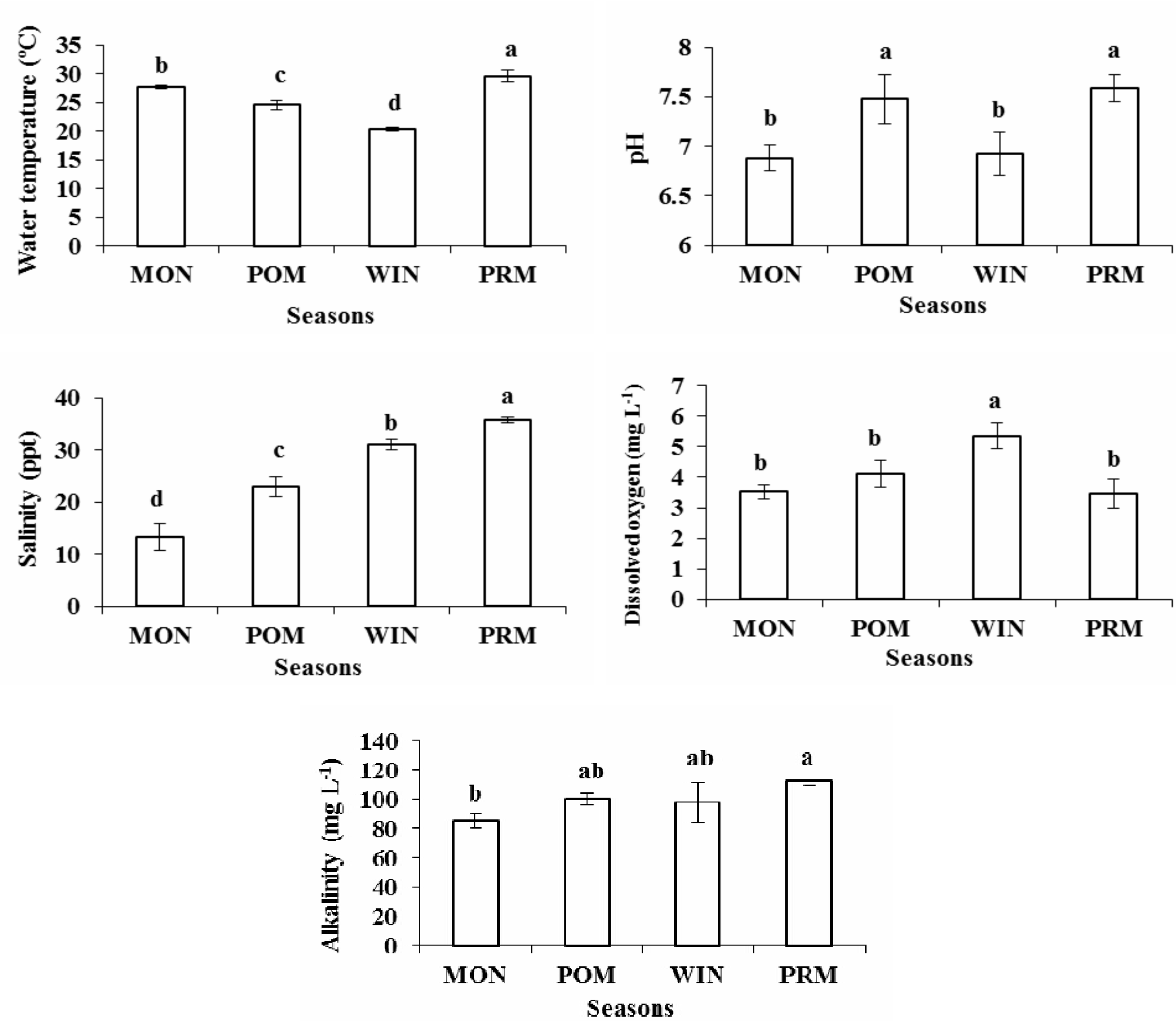

Figure 2. Seasonal variations in mean water temperature, pH, salinity, dissolved oxygen and alkalinity of the intertidal seashore water of Cox's Bazar. Mean values of the environmental parameters with different superscript are significantly ($p < 0.05$) different. Mon = Monsoon, POM = Post-monsoon, WIN = Winter and PRM = Pre-monsoon.

Community structure of gastropods. A total of 8253 individuals of gastropods representing 34 species under 21 families and 4 orders were identified during the study period (Table 1). Number of species found in the samples ranges between 12 and 26 (Figure 3). The highest number of individuals per samples was 956 and the lowest was 266, but in most of the samples the number of individuals was higher than 500. Multivariate ANOVA (MANOVA) test showed significant seasonal variation in individual species abundance (F = 14.452, p = 0.015, according to Wilk's Lamda) with higher number of individuals were recorded during post-monsoon and the lowest during monsoon season. During the study period, the most abundant species was *Umbonium vestiarium* with a relative abundance of 17.75%. However, four species, *viz*. *Polinices* spp. (19.31%), *Nerita ziczac* (11.23%) and *Trochus radiatus* (10.25%) were found abundantly in monsoon season. During the post-monsoon season, the dominant species were *Turritella acutangula* (20.71%), *U. vestiarium* (18.26%) and *Agaronia nebulosa* (11.03%). Moreover, species like *U. vestiarium* (14.90 and 15.06%), *Umbonium giganteum* (11.31 and 14.10%) and *Turritella duplicata* (11.79 and 11.14%) were found dominant during the both winter and pre-monsoon season, respectively. The subsequent univariate component of MANOVA test revealed that 50% of the species (17 out of 34) showed significant differences in the abundance pattern among seasons (p < 0.05) (Table 1). Species such as *U. vestiarium*, *U. giganteum*, *T. acutangula*, *T. duplicata*, *Turritella* spp., *Telescopium telescopium*, *Cerithideopsilla cingulata*, *Thais mancinella*, *Thais* spp. 1 and *Surcula javana* were found to occur in all the studied seasons. Only one species (*Oliva* spp.) was found in the sample of winter season.

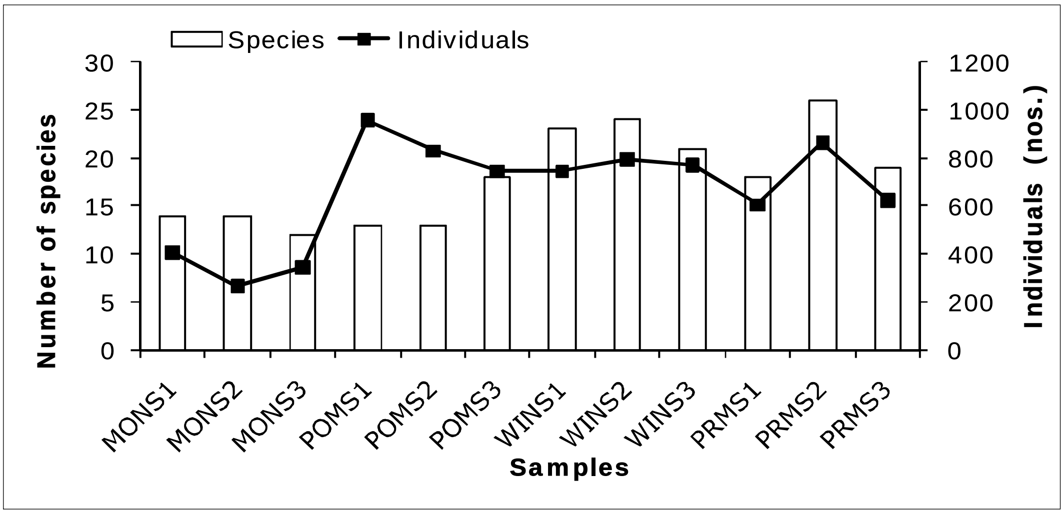

Figure 3. Number of species and individuals of gastropods of different samples. MON = Monsoon, POM = Post-monsoon, WIN = Winter and PRM = Pre-monsoon; S1, S2 and S3 were sampling locations.

Seasonal variation among the species assemblage was also confirmed by one-way ANOSIM (Global R = 0.7623; p = 0.0002). According to the similarity percentage (SIMPER) analysis, dissimilarity among the seasons was 54.68%, where the major contributing species were *T. acutangula* (5.39%), *U. vestiarium* (4.22%), *A. nebulosa* (3.58%) and *U. giganteum* (3.00%) at a percentage dissimilarity of >3%. The results of the SIMPER analysis also indicated *T. acutangula* as the major discriminating species between monsoon to post-monsoon (8.62%), post-monsoon to winter (8.97%) and post-monsoon to pre-monsoon (6.26%). *U. vestiarium*, *U. giganteum* and *T. duplicata* were the major discrimination species between monsoon to winter, monsoon to pre-monsoon and winter to pre-monsoon with percentage dissimilarity of 4.12, 4.79 and 3.75%, respectively.

The result of the one-way ANOSIM was also consistent with the outcome of nMDS (Figure 4). Affinity of the gastropod species occurring both in winter and pre-monsoonal season is evident from the result of nMDS (2D stress 0.17), where separation was observed between monsoonal and post-monsoonal species assemblage.

Table 1

List of gastropod species collected from Cox's Bazar sandy sea beach of Bangladesh during each season with their individual code (used in Figure 5)

Order	*Family*	*Species name*	*Code*	*RA (%)*	*MON*	*POM*	*WIN*	*PRM*	*F-value*	*P-value*
Archeogastropoda	Fissurellaidae	*Diodora variegata*	DV	0.09	-b	+a	+b	+b	102.49	0.00
	Nerritidae	*Nerita ziczac*	NZ	1.72	+	-	-	+	1.81	0.22
	Trochidae	*Trochus radiatus*	TR	0.59	+b	-b	+a	+b	7.02	0.01
	Turbinidae	*Astraea semicostata*	AS	0.75	-b	-b	+b	+a	15.60	0.00
		Umbonium vestiarium	UV	17.75	+	+	+	+	1.65	0.25
		Umbonium giganteum	UG	10.65	+b	+b	+a	+a	7.19	0.01
Mesogastropoda	Architectonicidae	*Architectonica laevigata*	AL	2.47	+ab	-b	+a	+ab	3.01	0.09
		Architectonica spp.	Ar	1.56	-	+	+	+	0.82	0.52
	Crepidulidae	*Crucibulum spp.*	CE	1.06	-b	+a	+b	+b	10.38	0.00
	Cymatiidae	*Gyrineum gyrinum*	GG	4.16	+	+	+	+	0.40	0.76
	Cypraeidae	*Cypraea spp.*	Cy	0.09	-b	+ab	+ab	+a	3.12	0.09
	Naticidae	*Natica elenae*	NE	0.09	-b	-b	+a	+ab	2.87	0.10
		Natica lineata	NL	0.70	-	+	-	+	1.44	0.30
		Polinices spp.	Po	1.24	+	-	+	-	1.83	0.22
		Synum spp.	SN	1.06	-	-	+	+	1.00	0.44
	Potamididae	*Cerithideopsilla cingulata*	CC	2.05	+b	+a	+b	+b	28.81	0.00
		Telescopium telescopium	TT	0.40	+	+	+	+	0.78	0.54
	Tonnidae	*Tonna dolium*	TD	2.00	+b	-b	+a	+b	4.72	0.04
	Turritellidae	*Turritella acutangula*	TA	15.62	+b	+a	+b	+b	10.68	0.00
		Turritella duplicata	TD	8.97	+	+	+	+	1.85	0.22
		Turritella spp.	Tu	5.00	+	+	+	+	1.95	0.20
Neogastropoda	Buccinidae	*Babylonia formosae*	BF	2.02	+	-	+	+	2.13	0.18
		Babylonia spirata	BS	1.90	+b	-b	+ab	+a	3.47	0.06
	Conidae	*Conus* spp.	Co	0.40	+	+	-	-	0.90	0.48
	Marginellidae	*Marginella* spp.	Ma	1.08	-b	-b	+a	+b	8.70	0.01
	Melongonidae	*Pugilina* spp.	Pu	0.11	-	-	+	+	0.91	0.48
	Nassariidae	*Bullia vittata*	BV	0.21	-	+	+	-	0.68	0.59
	Olividae	*Agaronia nebulosa*	AN	4.04	-b	+a	+b	+b	7.97	0.01
		Oliva spp.	Ol	0.21	-b	-b	+a	-b	4.89	0.03
	Thaididae	*Thais mancinella*	TM	2.59	+	+	+	+	0.68	0.59
		Thais spp. 1	Th1	5.33	+	+	+	+	1.27	0.35
		Thais spp. 2	Th2	1.81	-	+	+	-	2.98	0.10
	Turridae	*Surcula javana*	SJ	2.23	+b	+ab	+a	+b	3.35	0.08
Stylommatophora	Claumiliidae	*Clausilia bidentata*	CB	0.04	-b	-b	+a	+ab	3.15	0.09

F-value indicates the test values and P-value indicates the significance (P) of the univariate component of MANOVA. Mean values of the abundance followed by the different lowercase letter in each row indicates significant difference ($p < 0.05$). RA = relative abundance, MON = monsoon, POM = post-monsoon, WIN = winter, PRM = pre-monsoon, + = present of species, - = absent of species.

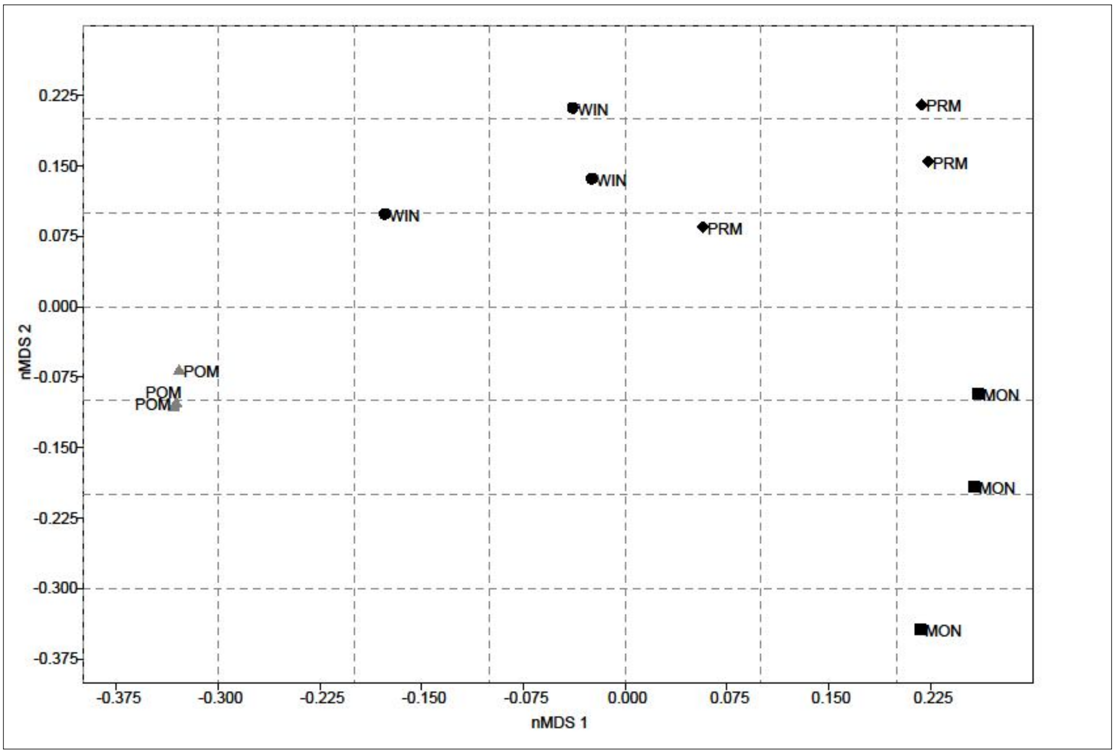

Figure 4. Non-multi-dimensional scaling (MDS) ordination depicting gastropods assemblages among the seasons. MON = Monsoon, POM = Post-monsoon, WIN = Winter and PRM = Pre-monsoon.

Diversity indices. The Shannon-Weaver diversity index varied between 2.22 (monsoon) to 2.68 (winter), evenness 0.60 (pre-monsoon) to 0.73 (post-monsoon) and Margalef's richness between 2.04 (post-monsoon) to 3.21 (winter) (Table 2). The results showed an average diversity, evenness and richness index of 2.45, 0.66 and 2.62, respectively.

Table 2

Ecological indices of gastropod species

Indices	*Monsoon*	*Post-monsoon*	*Winter*	*Pre-monsoon*	*Average*
Shannon-Wiener diversity	2.22	2.36	2.68	2.52	2.45
Poulie's evenness	0.66	0.73	0.65	0.60	0.66
Marglaf's richness	2.16	2.04	3.21	3.05	2.62

Interaction with environmental variables. The triplot of canonical correspondence analysis (CCA) for physico-chemical parameters and gastropod species in relation to the seasons is presented in Figure 5. The first three CCA axes explained 90.36% of the cumulative variance of the gastropod species and water quality relationship. Axis 1 was positively correlated with temperature (R = 0.67) and negatively with dissolved oxygen (R = -0.50). Axis 2 was highly correlated with salinity and alkalinity (R = 0.93, R = 0.79, respectively). However, for axis 3, the best correlations were found for pH (R = 0.69). Gastropods species such as *Clausilia bidentata*, *Natica elenae*, *Marginella* spp., *Cypraea* spp., *Astraea semicostata*, *Synum* spp. and *Pugilina* spp. were found mostly influenced by increased salinity and alkalinity of the water. *Architectonica laevigata*, *Tonna dolium*, *Babylonia formosae* and *N. ziczac* were found sensitive to increase water temperature and species like *C. cingulata*, *Architectonica* spp. and *S. javana* by dissolved oxygen. However, species like *T. acutangula*, *U. vestiarium* and *U. giganteum* were showed their common appearance in all the studied seasons.

BIOENV test (Biota and Environment matching test) identified salinity as the main determining factor that significantly ($p < 0.001$, according to the marginal test conducting trough distance-based liner model (DistLM)) influenced the gastropod community pattern in the present study with a ρ_w of 0.473. However, together with salinity and alkalinity, the ρ_w was 0.384. The model was also found to describe 80% of the variation in the gastropod community data if included five physico-chemical parameters.

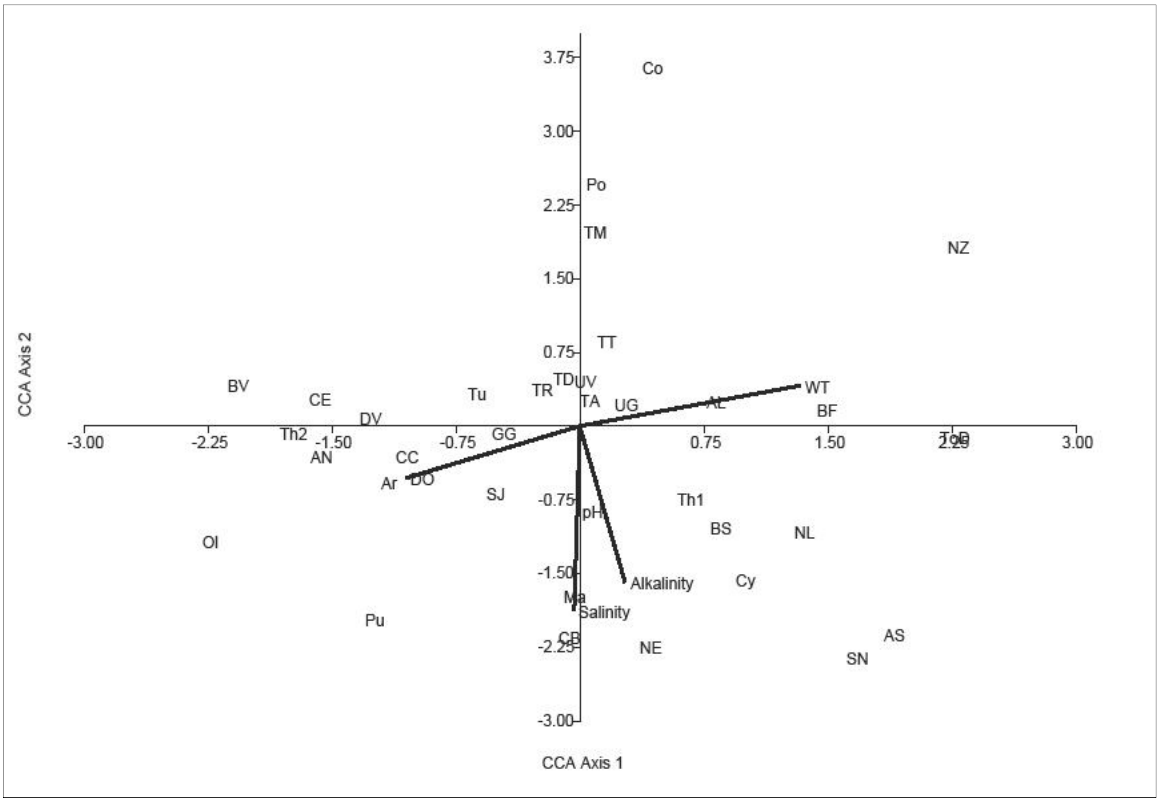

Figure 5. Canonical correspondence analyses (CCA) of gastropods species-environment relationship. WT = water temperature, DO = dissolved oxygen. Species code is given in Table 1.

Discussion. The number of gastropod species (34) recorded during the study period was higher than the findings of Vanmali & Jadhav (2015) in Dativare Coast of Vaitarna Estuary, India and lower than the findings of Khade & Mane (2012) in Raigad district, west coast of India, where they reported 17 and 49 gastropod species respectively. During the study period, the highest abundance of gastropod molluscs was observed during post-monsoon season and the lowest during monsoon season. In general, diversity of taxa indicated moderate pollution of the beach environment during monsoon season according to the environmental classification of Wilhm & Dorris (1966). According to the classification of Akaahan et al (2014) even distribution of the species was observed during post-monsoon season, whereas richness index indicated clean water condition during winter season according to the classification of Lenat et al (1980).

In monsoon season, self-dilution of the body fluid makes the molluscs more sensitive and unable them to adjust the fluctuating osmotic balance quickly and are responsible for much mortality (Patole 2010). However, after that period, the mortality rate of molluscs decreased gradually as soon as they develop the adaptation capability to the prevailing unlikely environment. It was also found that during monsoon season the temperature, pH, salinity and alkalinity dropped down and had made the condition adverse for the gastropod species. The lower value of these environmental parameters was most likely due to the influence of fresh water intrusion that reduced salinity and ultimately hampered the decomposition of organic matter (Nedumaran & Manokaran 2009). The steady increase in population abundance after the monsoon period was noted during the study period and therefore, the maximum number of species was occurred during post-monsoon season. Similar observation was also made by Raju et al (2015) and Paul et al (2014), where they reported that stable dissolved oxygen and temperature might be a reason for higher abundance of gastropod molluscs during post-monsoon season. The variation might also be due to the stable environment factors. However, winter and pre-monsoon season were found mostly similar (52.92%) while monsoon and post-monsoon were the most dissimilar (73.86%) among all seasons with respect to gastropod diversity.

As indicated by BIOENV test and DistLM model, salinity was the main environmental factor which affected the structure of gastropod during the present study. CCA analysis revealed that species like *A. laevigata, T. dolium, B. formosae* and *N. ziczac* were more sensitive to increased water temperature and these species were most abundant during pre-monsoon season. Rumahlatu & Leiwakabessy (2017) also showed that the gastropods are very fond of relatively high temperatures. Sokolova & Portner (2003) also explained that gastropods were more favourable to water with a temperature of 28-30°C. On the contrary, low temperatures caused the osmotic stress in cells responsible for intracellular damage of molluscan species (Matsukura et al 2009). Low temperature (15°C) could also affect the digestive, respiratory and excretion of gastropods (Zhang et al 2016). Therefore, it can be assumed that the temperature (20.31±0.36 to 29.59±0.99ºC) recorded during the study period was not so harmful for gastropod species. Although pH was not found so important to influence the gastropods distribution among seasons during the study period, various researchers have found that acidic water can reduce the thickness of shell and increase metabolism (hyper-metabolism) at low pH (Bibby et al 2007). According to Gallordo et al (1994) and Dillon (2000), pH is the most important factor for development of molluscs and a pH value lower than 6 can be fatal to them (Hart & Fuller 1974). Therefore, pH value noted during the study period was not harmful at all. Together with the temperature, the two other most important factors, salinity and alkalinity which determined the distribution of *C. bidentata, N. elenae, Marginella* spp., *Cypraea* spp., *A. semicostata, Synum* spp. and *Pugilina* spp. influenced the diversity of gastropods during the present study period. Salinity recorded in the present study was fluctuated between 13.34 to 35.79 ppt during monsoon and pre-monsoon season that could disturb the physiological activity of gastropods to some extent (Koprivnikar & Poulin 2009).

Based on CCA result, species that was most affected by dissolved oxygen were *C. cingulata*, *Architectinica* spp. and *S. javana* which formed the dominant number in winter season. Significance of dissolved oxygen in gastropods distribution was also revealed by Ekau et al (2010) and Weisberg et al (2008) who found out a significant adverse impact of hypoxic condition of the water environment on aquatic organisms.

Conclusions. The seasonal variations in abundance of gastropods in Cox's Bazar sandy sea beach were surveyed and it showed that the abundance of identified 34 species of gastropods was varied seasonally. The lowest abundance was recorded during monsoon season and the highest during post-monsoon season. The diversity index ($2 < H < 4$) showed a moderate pollution status of the beach. Although, salinity was the most important factor structuring the community abundance of gastropods in the Cox's Bazar sandy sea beach, overall diversity pattern could be explained by the influence of temperature, pH, dissolved oxygen and alkalinity.

Acknowledgements. Thanks to Universiti Kebangsaan Malaysia for the publication fee of this article through "GP-2019-K019059".

References

Ahmed A. T. A., 1990 Studies on the identity and abundance of molluscan fauna of the Bay of Bengal. Bangladesh Agricultural Research Council, Dhaka, 86 pp.

Akaahan T. J. A., Araoye P. A., Adikwu I. A., 2014 Benthic fauna community structure in river Benue at Makurdi, Benue state, Nigeria. International Journal of Fisheries and Aquatic Studies 1(6):32-39.

Arumugam M., Shanmugam A., Balasubramanian T., Kannan L., Ajmalkhan S., 2010 Studies on molluscan diversity of great Nicobar Island: a pre tsunami scenario. In: Recent trends in biodiversity of Andaman and Nicobar Islands. Sivaperuman C., Ra-Gunathan C., Venketraman R. (eds), Zoological Survey of India, Kolkatta, pp. 275-282.

Bibby R., Cleall-Harding P., Rundle S., Widdicombe S., Spice J., 2007 Ocean acidification disrupts induced defenses in the intertidal gastropod *Littorina littorea*. Biology Letters 3(6):699-701.

Cadotte M. W., Carscadden K., Mirotchnick N., 2011 Beyond species: functional diversity and the maintenance of ecological processes and services. Journal of Applied Ecology 48(5):1079-1087.

Clarke K. R., Warwick R. M., 1994 Change in marine communities: an approach to statistical analysis and interpretation. Plymouth Marine Laboratory, Natural Environmental Research Council, Plymouth.

Clarke K. R., Gorley R. N., 2006 Primer v6: User manual - tutorial. Plymouth Marine Laboratory, United Kingdom, 190 pp.

Das M., Maity D. J., Samanta B., 2016 Marine molluscan fauna found at Digha coast, West Bengal, India. International Journal of Fisheries and Aquatic Studies 4(5):670-674.

Dillon R. T., 2000 The ecology of freshwater mussels. Cambridge University Press, Cambridge, 509 pp.

Ekau W., Auel H., Pörtner H. O., Gilbert D., 2010 Impacts of hypoxia on the structure and processes in pelagic communities (zooplankton, macro-invertebrates and fish). Biogeosciences 7:1669-1699.

Gallordo A., Prenda J., Pujante A., 1994 Influence of some environmental factors on the freshwater macroinvertebrates distribution in two adjacent river basins under Mediterranean climate. II. Molluscs. Archiv fur Hydrobiologie 131:449-463.

George J. D., George J. J., 1979 Marine life: an illustrated encyclopedia of invertebrates in the sea. Douglas & McIntyre, pp. 84-106.

Gupta R. K., Malik B. S., 1977 A treatise on Mollusca. Pragati Prakashan, Meerut, 204 pp.

Hart C. W., Fuller S. L. H., 1974 Pollution ecology of freshwater invertebrates. Academic Press, New York, 389 pp.

Jumawan J. H., Tripoli F. F. D., Boquia E. E. S., Niez K. L. M., Veronilla J. A. H., Dellomes S. A., Udtie R. M., Seit N. K., Hasim N. A., Gatinao M. J. O., 2015 Species diversity and spatial structure of intertidal molluscs in Padada, Davao del Sur, Philippines. AACL Bioflux 8(3):301-309.

Khade S. N., Mane U. H., 2012 Diversity of bivalve and gastropod, molluscs of some localities from Raigad district, Maharashtra, west coast of India. Recent Research in Science and Technology 4(10):43-48.

Koprivnikar J., Poulin R., 2009 Effects of temperature, salinity, and water level on the emergence of marine cercariae. Journal of Parasitology Research 105:957-965.

Lenat D. R., Smock L. A., Penrose D. L., 1980 Biological monitoring for environmental effects. In: Biological monitoring for environmental effects. Worf D. L. (ed), Lexington Books Publishers Toronto, pp. 97-112.

Margalef R., 1969 Diversity and stability: a practical proposal and a model of interdependence. Brookhaven Symposium on Biology 22:25-37.

Mason N. W. H., Mouillot D., Lee W. G., Wilson J. B., 2005 Functional richness, functional evenness and functional divergence: the primary components of functional diversity. Oikos 111:112-118.

Matsukura K., Tsumuki H., Izumi Y., Wada T., 2009 Physiological response to low temperature in the freshwater apple snail, *Pomacea canaliculata* (Gastropoda: Ampullariidae). Journal of Experimental Biology 212:2558-2563.

McLachlan A., Brown A. C., 2006 The ecology of sandy shores. 2nd edition, Academic Press, Amsterdam, 392 pp.

Morton J. E., 1976 Molluscs. 5th edition, Hutchinson & Co. ltd., pp. 11-71.

Nedumaran T., Manokaran S., 2009 Seasonal variations and distribution of sea grass associated macrofauna in Uppanar estuary, Southeast coast of India. Journal of Phytology 1(3):172-176.

Patole V. M., 2010 Ecology and biodiversity mangroves in Mochemad Estuary of Vengurla, South Konkan, Maharashtra. PhD Thesis, University of Mumbai.

Paul P., Panigrahi A. K., Tripathy B., 2014 A study of marine molluscs with respect to their diversity, relative abundance and species richness in North-East Coast of India. Indian Journal of Applied Research 4(12):538-541.

Pielou E. C., 1969 An introduction to mathematical ecology. John Wiley, New York, 286 pp.

Primost M., Bigatti G., Marquez F. M., 2016 Shell shape as indicator of pollution in marine gastropods affected by imposex. Marine and Freshwater Research 67(12):1948-1954.

Raju C., Gowthami S., Sridharan G., 2015 Diversity of molluscs in Vellaiyar estuarine from Vellankanni coast, Nagappattinam district. International Journal of Zoological Research 5(2):29-32.

Ramakrishna, Dey A., 2003 Annotated checklist of Indian marine molluscs (Cephalopoda, Bivalvia and Scaphopoda) Part-1. Records of Zoological Survey of India, Occasional Paper No. 320:1-357.

Rao S. N. V., 2003 Indian seashells (Part-1). Polyplacophora and Gastropoda. Records of Zoological Survey of India, Occasional Paper No. 192:416 pp.

Raveendran S., Sathick O., Muthukumaravel K., Rajakumar R., Ramu S., 2016 Molluscan diversity in Keezhathottam of Thanjavur District, Tamil Nadu, India with special reference to gastropods and bivalves. International Journal of Zoology and Applied Biosciences 1(3):141-143.

Rittschof D., McClellan-Green P., 2005 Molluscs as multidisciplinary models in environmental toxicology. Marine Pollution Bulletin 50(4):369-373.

Rodriguez J. G., Lastra M., Lopez J., 2003 Meiofauna distribution along a gradient of sandy beaches in northern Spain. Estuarine, Coastal and Shelf Science 58(S):63-69.

Rumahlatu D., Leiwakabessy F., 2017 Biodiversity of gastropoda in the coastal waters of Ambon Island, Indonesia. AACL Bioflux 10(2):285-296.

Sahin S. K., 2012 Gastropod species distribution and its relation with some physico-chemical parameters of the Malatya's streams (East Anatolia, Turkey). Acta Zoologica Bulgarica 64(2):129-134.

Shanmugam A., Vairamani S., 2015 Molluscs in mangroves: a case study. Centre of Advanced Study in Marine Biology, Annamalai University, pp. 371-382.

Simon K. D., Bakar Y., Temple S. E., Mazlan A. G., 2010 Morphometric and meristic variation in two congeneric archer fishes *Toxotes chatareus* (Hamilton 1822) and *Toxotes jaculatrix* (Pallas 1767) inhabiting Malaysian coastal waters. Journal of Zhejiang University-Science B 11(11):871-879.

Shannon C. E., Weaver W., 1949 The mathematical theory of communication. University of Illinois Press, Urbana, 125 pp.

Sokolova I. M., Pörtner H. O., 2003 Metabolic plasticity and critical temperatures for aerobic scope in a eurythermal marine invertebrate (*Littorina saxatilis*, Gastropoda: Littorinidae) from different latitudes. Journal of Experimental Biology 206:195-207.

Valiela I., Bowen J. L., York J. K., 2001 Mangrove forests: one of the world's threatened major tropical environments. BioScience 51(10):807-815.

Vanmali H. S., Jadhav R. N., 2015 Assessment of molluscan diversity of dativare coast of Vaitarna Estuary, Dist.-Palghar, Maharashtra (India). Research Inventy: International Journal of Engineering and Science 5(9):1-6.

Weisberg S. B., Thompson B., Ranasinghe J. A., et al, 2008 The level of agreement among experts applying best professional judgment to assess the condition of benthic infaunal communities. Ecological Indicators 8(4):389-394.

Wilhm J. L., Dorris T. C., 1966 Species diversity of benthic macroinvertebrates in a stream receiving domestic and oil refinery effluents. The American Midland Naturalist 76(2):427-449.

Zhang H., Shin P. K. S., Cheung S. G., 2016 Physiological responses and scope for growth in a marine scavenging gastropod, *Nassarius festivus* (Powys, 1835), are affected by salinity and temperature but not by ocean acidification. Journal of Marine Science 73(3):814-824.

Received: 10 February 2020. Accepted: 31 March 2020. Published online: 30 April 2020.
Authors:
Mohammad Abdul Baten Bhuyain, Department of Fisheries, Faculty of Agriculture, University of Rajshahi, Rajshahi-6205, Bangladesh, e-mail: baten_bhuyain@yahoo.com
Md. Ayenuddin Haque, Department of Fisheries, Faculty of Agriculture, University of Rajshahi, Rajshahi-6205, Bangladesh, e-mail: ayenuddin41@gmail.com
Md. Abu Sayed Jewel, Department of Fisheries, Faculty of Agriculture, University of Rajshahi, Rajshahi-6205, Bangladesh, e-mail: jewelru75@yahoo.com
Jakia Hasan[2], Bangladesh Fisheries Research Institute, Marine Fisheries & Technology Station, Cox's Bazar-4700, Bangladesh, e-mail: jakiabfri@gmail.com
Alok Kumar Paul, Department of Fisheries, Faculty of Agriculture, University of Rajshahi, Rajshahi-6205 Bangladesh, e-mail:paulalok.rubd@gmail.com
Md. Selim Reza, Program Officer (Fisheries), Palli Karma Sahayak Foundation (PKSF), Bangladesh, e-mail: selim0624@gmail.com
Simon Kumar Das, Department of Earth Sciences and Environment, Faculty of Science and Technology, University Kebangsaan Malaysia, 43600 UKM Bangi Selangor, D.E., Malaysia; Marine Ecosystem Research Centre, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor D.E., Malaysia, e-mail: skdas_maa@yahoo.com; simon@ukm.edu.my

How to cite this article:
Bhuyain M. A. B., Haque M. A., Jewel M. A. S., Hasan J., Paul A. K., Reza M. S., Das S. K., 2020 Seasonal occurrence and community structure of gastropod molluscs with environmental variables at Cox's Bazar sandy sea beach, Bangladesh. AACL Bioflux 13(2):1126-1137.