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Response of *Villorita cyprinoides* and *Magallana bilineata* (Bivalvia) to Environmental Variables in Munroe Island, Kerala, India

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Abstract The present investigation was aimed at examining the effects of environmental variables on two bivalve species *Villorita cyprinoides* and *Magallana bilineata* in the five stations of Munroe Island, Kerala, India during the pre-monsoon period of 2022. The impacts of various anthropogenic activities were noted. Spatial abundance and distribution of these two species were recorded. Moreover, 12 hydrographical parameters were analyzed during the study period. Spatial dynamics of these two species showed that *Villorita cyprinoides* ranged from 140.25 ind/m^2 (S1) to 185.45 ind/m^2 (S3) and the abundance *Magallana bilineata* was between 139.12 ind/m^2 (S1) and 175.21 ind/m^2 (S3). Environmental variables like temperature, TDS, EC, salinity, hardness, alkalinity and pH were highest at S3 whereas the BOD and COD were highest at S4. The dissolved oxygen and nutrient parameters were highest at S1. The results of water quality analysis specified the moderate levels of anthropogenic activities in Munroe Island. To ascertain the association between bivalve species and water quality variables, the observed variables were measured through the multivariate statistical tools. The response of bivalves still reflected the moderate pollution status of Munroe Island and also revealed that the bivalves can tolerate adverse environmental conditions. The distribution pattern of bivalves in the present investigation also signified the same. Moreover the influences of both the Ashtamudi estuary and the Kallada River were clearly reflected in the hydrographical and biological variations.

Keywords Water Quality, Abundance, Anthropogenic Activities, Bivalves, Munroe Island

1. Introduction

Benthic macroinvertebrate communities primarily consisting of polychaetes, molluscs, and crustaceans, control the health and functioning of estuarine environments [1]. They are a significant component of estuarine food webs, occupying various trophic levels. They are prey for many aquatic organisms and are integral in energy flow through the ecosystem [2]. Through their burrowing and feeding activities, known as bioturbation, benthic macroinvertebrates play a pivotal role in nutrient cycling within estuarine systems. This process enhances the nutrient exchange contributing to the overall nutrient dynamics of the ecosystem [3]. While eutrophic estuaries may have lower species diversity of benthic macroinvertebrates, they often exhibit higher population densities due to increased nutrient availability. This can influence ecosystem dynamics and interactions [4]. Benthic macroinvertebrates aid in the degradation of organic content and this decomposition process releases nutrients back into the ecosystem, making them available for uptake by plants and other organisms [5].

The activities of benthic macroinvertebrates, such as burrowing, lead to the translocation of materials within sediments. This movement has implications for sediment structure, nutrient distribution, and other sediment-related processes [6]. Their abundance and availability influence the health and productivity of higher trophic levels. They are integral to the functioning of estuarine ecosystems, contributing to nutrient cycling, energy flow, and sediment dynamics, and acting as a critical link in the food chain. Their activities and interactions have far-reaching effects on the overall health and sustainability of estuarine environments [7].

Bivalves are a class of molluscs characterized by having two hinged shells that encase and protect their soft, vulnerable body parts. Clams, mussels, oysters, and scallops are well- known examples of bivalves [8]. They primarily inhabit coastal marine environments, including estuarine tidal flats and mudflats. These areas provide suitable conditions for their growth and reproduction [9]. All known species of bivalves, totaling around 15,000, are aquatic organisms. Approximately 80% of these species inhabit marine (saltwater) environments [10]. Bivalves hold significant economic and dietary importance as they are rich in protein and are harvested for consumption. Due to their high stocking density and nutritional value, they play a major role in artisanal fisheries worldwide [11]. They contribute to the enhancement of microphytobenthic productivity in estuaries. Moreover, they govern the energy transfer between microalgae and various predators, including fish, birds, crabs, and humans [12]. They are an essential food source for these predators.

Global climate change and extreme climatological events, such as droughts or heavy rainfall, can influence coastal salinity levels. Estuaries are considered as one of the most threatened ecosystems due to the detrimental activities by humans. Such degradation largely affects macrobenthic community [13]. The present investigation is revealing the relationship between the selected bivalve species and environmental variables.

2. Materials and Methods

2.1. Study Area

Munroe Island (8 °59' 25.296" N and 76 °36' 54.792" E) is situated in Kerala, India, at the confluence of Ashtamudi Lake and Kallada River extending a total area of about 13.4 km^2.

The island is named after Resident Colonel John Munroe, who played a significant role in overseeing restoration efforts in the region where the river meets estuary. The major environmental challenges in Munroe Island are sinking, shrinking, flooding, and waste disposal. Both primary and secondary data have been used to analyze the environmental issues on Munroe Island.

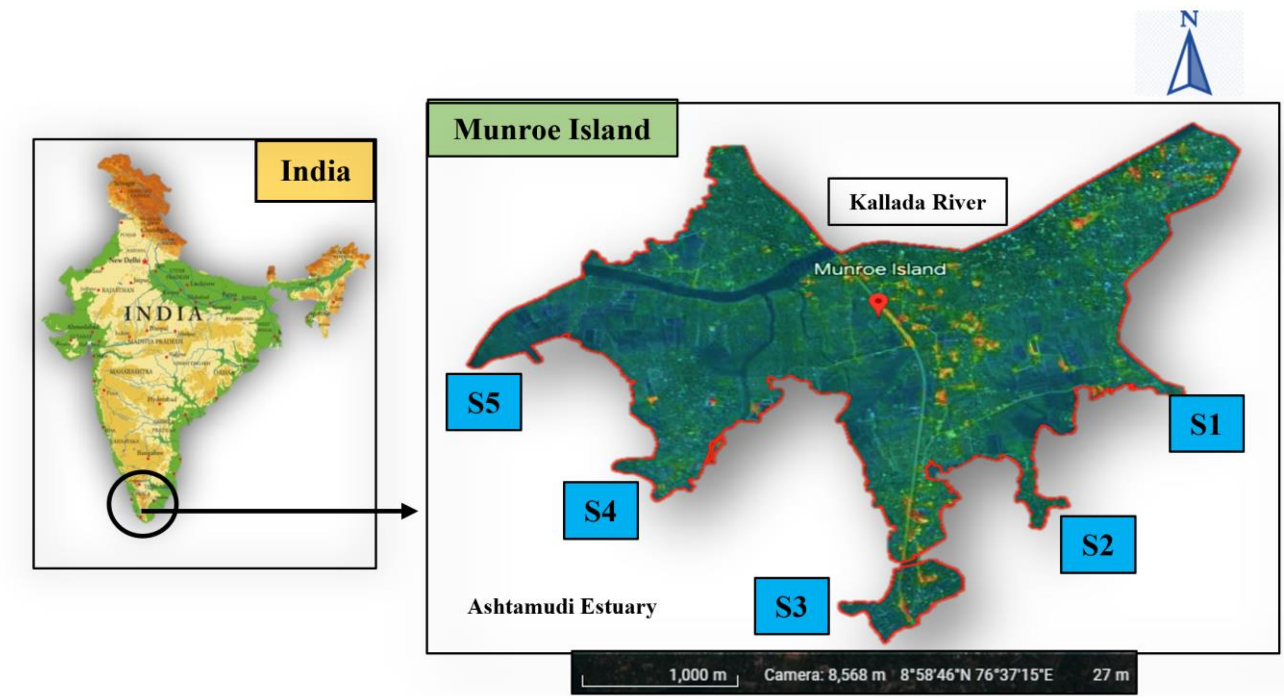

Figure 1. Location map of the study area with GPS coordinates - S1: Nenmeny 8 °59'09.3"/76 °37'35.6", S2: Neettumthuruthu 8 °59'10.5"/76 °37'16.0", S3: Pattamthuruthu 8 °59'05.5"/76 °37'03.4"", S4: Peringalam 8 °59'19.0"/76 °36'00.6", S5: Kidapram 8 °59'55.3"/ 76 °35'15.9".

2.2. Sampling and Laboratory Assessments

Organized fieldwork has been conducted in the study area before selecting sampling stations. Water samples were collected from 5 stations (Figure 1) from Munroe Island during the period of pre-monsoon of 2022.

Clean acid-washed polyethylene bottles were used for water sample collection and placed in a cooler with ice packs and transported to the laboratory. Environmental variables were analyzed based on standard procedures [14].

The benthic macroinvertebrates were monthly sampled from the selected stations of Munroe Island. A total of 1741 individual specimens were collected using a Van Veen grab. Specimens were carefully washed through a sieve (0.2 mm) and were preserved in a 10% formaldehyde solution in a plastic vial. Further, preserved specimens were washed and sorted out into various taxa, enumerated, and identified. The collected specimens were identified using [15, 16, 17, 18].

3. Results and Discussion

3.1. Water Quality Parameters

The outcomes of the hydrological analysis are given in Table 1. The highest temperature was observed in S2 (29.45 ℃) and the lowest in S5 (24.45 ℃). Temperature is one of the significant physical aspects that play a dynamic role in biochemical reactions. Water temperature is a significant variable that regulates an array of ecological processes in an estuarine system. Temperature influences the growth and reproduction of various aquatic communities in an estuary [19]. The water temperature was found to be higher at Neettumthuruthu (S2) which is 29.45 ℃ and lowest in Kidapram (S5) with 24.45 ℃. The increase in water temperature occurs possibly due to the less rainfall and humid weather during the pre-monsoon period [20, 21]. Salinity is critical variable that determines various characteristics of estuarine biodiversity. From the current study salinity was found to be highest in Pattamthuruth (S3) which was 21.64 ppt and lowest in Kidapram which was 6.18 ppt.

However, pre-monsoon is characterized by dry periods with higher evaporation, lower rainfall and higher temperature that significantly increase salinity [22]. The electrical conductivity was found to be highest in pre-monsoon at Pattamthuruthu (S3) which is 5553.51 μS/cm and lowest at Kidapram (S5) which is 1577.5 μS/cm. EC examines the ionic content of water samples [23]. Various ions adjacent to the shoreline increase EC. Total dissolved solids (TDS) are referred to as the dissolved content of all organic and inorganic matters in the water bodies [24, 25].

The total dissolved solids were found to be highest in Pattamthuruthu (S3) with 3345.45 mg/L and lowest at Kidapram (S5) which was 922.84 mg/L. TDS follows the mode of EC in all seasons, as TDS is directly proportional to EC [26]. The high amount of dissolved, suspended and total solids harmfully affects the quality of water [27]. The pH was found to be higher in Pattamthuruthu (S3) and lowest in Kidapram (S5). pH is a significant environmental variable and is defined as a measure employed to indicate the acidic or basic nature of an aqueous solution at a given temperature. The highest pH was attributed to the uptake of CO_2 by photosynthesis. The lowest pH might be due to the fresh water influence [28]. The dissolved oxygen was found to be higher in Kidapram (S5) which is 4.86 and lowest in Nenmeny (S1) which is 4.44 mg/L. The mutual activity of oxygen dissolution and photosynthetic activity upholds the level of DO in water bodies. Increased human activities and sewage from various sources result in low dissolved oxygen. The lowest DO during pre- monsoon was attributed to the high temperature [29]. BOD indicates the quantity of oxygen consumed by bacteria from the decomposition of organic matter [30]. BOD was found to be highest in Peringalam (S4) with 3.81 mg/L and lowest at Kidapram (S5) which was 2.81 mg/L. 70% of the pollution in water bodies is from untreated sewage, which results in low DO and high BOD. In the present study, influx of sewage increased the BOD level. Similar findings were reported by [31], from Ashtamudi estuary.

COD is the quantity of oxygen to oxidize the organic and inorganic content in water [32]. The COD was found to be highest in Peringalam (S4) which was 48 mg/L and lowest in Kidapram (S5) which was 39 mg/L. A high level of COD indicates the extent of chemical pollution mainly from civic effluents [33]. Total hardness is the mineral content in a water sample. It is due to the natural as well as anthropogenic activities. The total hardness was found to be highest in Pattamthuruthu (S3) with 9700 mg/L and lowest in Kidapram (S5) which was 2850 mg/L. Similar findings were reported by [34], from the Ashtamudi estuary. The total alkalinity was found to be highest in Pattamthuruthu (S3) which was 121 mg/L and lowest in Kidapram (S5) which was 67 mg/L. Alkalinity estimated the ability to neutralize acidic contamination in wastewater and the similar observation was reported by [35]. The alkalinity differs based on the changes in the pollutants [36].

The nitrate was found to be highest in Villimangalam (S1) with 0.689 mg/L and lowest in Peringalam (S4) which was 0.365 mg/L. Highest nitrate levels might be attributed to the influence of organic pollutants, and reduced quantity of freshwater inflow [37]. The phosphate was found to be highest in Nenmeny (S1) with 0.21 mg/L and lowest in Peringalam (S4) which was 0.12 mg/L. Phosphate in large quantities in as estuary displays contamination due to sewage effluents [38]. The Silicate was found to be highest in Kidapram (S5) which was 2.86 mg/L and lowest in Pattamthuruthu (S3) which was 0.9 mg/L. The major source of silicate may be due to the minerals and inflow of water from drainage. Similar seasonal fluctuations were reported in Chilika lagoon [39].

3.2. Abundance of Bivalves

During the study period the abundance of the species *Villoriata cyprinoides* was obtained in the range of 140.25 to 185.45 ind/m^2 and abundance of the species *Magallana bilineata* was obtained in the range of 139.12 to 175.21 ind/m^2 (Table 2). In the case of *Villorita cyprinoides*, Pattamthuruth (S3) showed maximum abundance and Kidapram (S5) showed minimum abundance. In case of *Magallana bilineata*, Pattamthuruth (S3) showed maximum abundance and Kidapram (S5) showed minimum abundance.

In the present investigation, the bivalve species *Villorita cyprinoides* abundance ranged from 140.25 ind/m^2 (Kidapram) to 185.45 ind/m^2 (Pattamthuruthu) and the abundance of the species *Magallana bilineata* ranged from 139.12 ind/m^2 (Kidapram) to 175.21 ind/m^2 (Pattamthuruthu). The increase in abundance of the species in Pattamthuruthu (S3) during the study period might be due to favorable conditions in the area. Moderate level of salinity is found to be an optimum condition for the abundance of *Villorita cyprinoides*. Ashtamudi estuary has been used for cage and rope culture of *Magallana bilineata*.

Table 1. Mean values of environmental variables during the study period

	Stations				
Parameters	**S1**	**S2**	**S3**	**S4**	**S5**
Water Temperature (°C)	27.25	29.45	28.45	25.55	24.45
E. conductivity (mg/L)	4873.5	5410	5553.51	3828	1577.5
TDS (mg/L)	2924.1	3002.2	3345.45	2239.2	922.84
pH	7.02	7.39	7.88	7.56	6.77
Dissolved oxygen (mg/L)	5.44	4.78	4.81	4.55	4.86
Total hardness (mg/L)	4500	8850	9700	4300	2850
Total alkalinity (mg/L)	93	111	121	116	67
Salinity (ppt)	7.54	20.28	21.64	17.3	6.18
BOD (mg/L)	3.6	2.87	3.29	3.81	2.81
COD (mg/L)	41	45	43	48	39
Nitrate (mg/L)	0.619	0.589	0.407	0.365	0.491
Phosphate (mg/L)	0.21	0.18	0.16	0.12	0.18
Silicate (mg/L)	2.95	1.05	0.9	2.05	2.06

Table 2. Abundance (ind/m^2) of bivalves during study period

Stations	*Villorita cyprinoides*	*Magallana bilineata*
S1	165.45	141.21
S2	180.45	151.25
S3	185.45	175.21
S4	184.45	171.52
S5	140.25	139.12

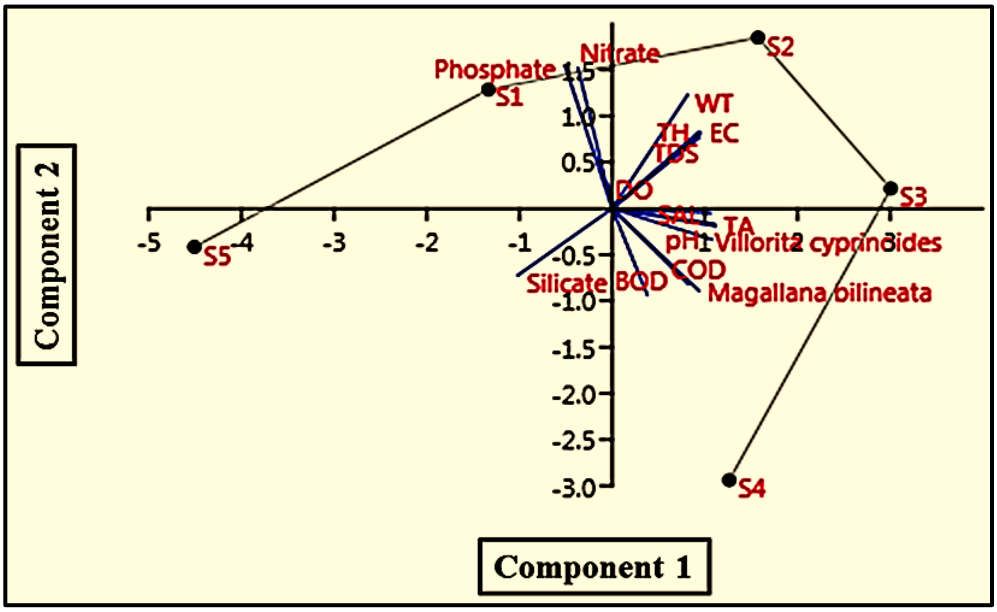

Figure 2. Biplot diagram of Principal Component Analysis

3.3. Principal Component Analysis

PCA was conducted on selected water quality parameters and two biological components; a similar approach based on PCA has been used to identify the relation between biotic variables and water quality [40]. The results of PCA are depicted in Figure 2. The axis PC1 (eigenvalue 8.33), examined for 55.57%, while the second axis PC2 explained 26.21% (eigenvalue: 3.93) in the dataset.

Table 3. Component of indicators of variables in PCA inMunroe Island during the study period

Variables	PC1	PC2
WT (℃)	0.56	0.821
EC (μS/cm)	0.738	0.573
TDS (mg/L)	0.738	0.532
pH	0.972	0.026
DO (mg/L)	-0.109	0.276
TH (mg/L)	0.699	0.656
TA (mg/L)	0.991	0.097
Salinity (ppt)	0.914	0.23
BOD (mg/L)	0.461	-0.556
COD (mg/L)	0.803	-0.261
NO_3- (mg/L)	-0.271	0.822
PO_4t^- (mg/L)	-0.606	0.676
SiO_2 (mg/L)	-0.917	0.332
Villorita cyprinoides	0.987	-0.15
Magallana bilineata	0.741	-0.654

Two axes explained 81.78% of total variation. Thus, only these two PCs were selected. Bi-plot (Figure 2) showed that FI had significant association (0.90) on pH, TA, and salinity. High loadings on alkalinity and salinity were attributed to the tidal water intrusion from the estuary. The PC2 that explained the total variance negatively correlated to BOD, COD and two biotic variables and passively correlated with the remnant variables (Table 3). The various aquaculture practices chiefly contributed to the nutrient levels and the increased sewage altered the water quality [41]. Both the species are positively correlated with water temperature, electrical conductivity, TDS, pH, total hardness, alkalinity, salinity and negatively correlated with DO, COD, nitrate, phosphate, silicate. *Villorita cyprinoides* is positively correlated with water temperature, electrical conductivity, TDS, pH, total hardness, alkalinity, salinity and negatively associated with DO, COD, nitrate, phosphate, silicate.

The negative relationship of water temperature, nitrate, and magnesium with the species exposed that the variables had no effects on the density and they could withstand the adverse conditions. *Magallana bilineata* was positively correlated with water temperature, electrical conductivity, TDS, pH, total hardness, alkalinity, salinity and negatively correlated with DO, COD, nitrate, phosphate, silicate. The presence of total dissolved solids and other contaminants may result in water hardness and salinity, and affects the water balance in the cells of aquatic organisms. The negative relation to nitrate and silicate showed that they limit their distribution. The abundance of bivalves still reflects the moderate pollution status of Munroe Island. The present study exposed that the environmental variables had little effects on bivalve abundance. The PCA findings were also reflected in the correlation analysis (Table 4). This analysis underlined the effects of anthropogenic stresses in the Munroe Island.

Table 4. Pearson correlation analysis on water quality and biological variable (B1- *Villorita cyprinoides*, B2- *Magallana bilineata*)

Variables	WT	EC	TDS	pH	DO	TH	TA	SAL	COD	NO3-	PO_4^{3-}	SiO_2	B1	B2
WT	1													
EC	0.02	1												
TDS	0.04	0.01	1											
pH	0.36	0.18	0.18	1										
DO	**-0.91**	**-0.74**	-0.72	-0.94	1									
TH	0.07	0.06	0.08	0.18	-0.48	1								
TA	0.26	0.08	0.09	0.01	-0.79	0.15	1							
SAL	0.25	0.17	0.21	0.04	-0.61	0.12	0.03	1						
BOD	**0.78**	**0.74**	**0.65**	**0.52**	-0.13	**0.66**	0.42	**0.88**						
COD	0.67	0.5	0.53	0.21	-0.64	0.61	0.1	0.23	1					
NO3-	0.36	**0.68**	**0.78**	**0.63**	**0.78**	**0.67**	**0.76**	**0.54**	**0.77**	1				
PO_4^{3-}	**0.72**	**0.89**	**0.86**	0.27	**0.94**	**0.97**	0.41	0.4	0.16	0.24	1			
SiO_2	**0.66**	**0.51**	0.41	0.03	0.46	0.37	0.06	0.14	0.16	0.32	-0.98	1		
B1	0.46	0.28	0.25	0.04	-0.82	0.26	0.02	0.08	-0.12	-0.27	-0.14	-0.91	1	
B2	**0.84**	**0.8**	**0.8**	0.19	**-0.78**	**0.81**	0.24	0.29	-0.17	-0.53	-0.19	-0.35	-0.38	1

Values in bold are different from 0 with a significance level alpha=0.05

4. Conclusions

In the present study, the physico-chemical properties and abundance of bivalves revealed a number of factors that contributed to the survival of the bivalves in the estuary. The high percentage of two bivalve species in S3 indicates the favorable conditions that serve as an ideal habitat, and dissolved oxygen that is moderate in the study area. Decreased abundance in S5 was due to pollution, anthropogenic activities such as discharge of sewage effluents. The present study revealed that water quality had little impact on bivalve abundance.

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