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Distribution of meiofauna in the sublittoral sediments of the tropical island ecosystem, off Port Blair, Andaman Sea

T K A Arunima*, N M Afnan, V Swathi, N S Heera, K Shah & P M Mohan

Department of Ocean Studies and Marine Biology, Pondicherry University off Campus, Brookshabad, Port Blair, Andaman and Nicobar Islands – 744 112, India

*[E-mail: arunimasivanandtk@gmail.com]

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Meiofaunal studies from offshore sediments of the Andaman Sea were conducted during the South-West Monsoon Season (SWMS), North-East Monsoon Season (NEMS) and Non-Rainy Season (NRS) of the year 2019. The study focused on identifying the meiofauna and its distribution from the sub-littoral sediments of South Andaman Islands. Altogether ten meiofaunal groups *viz*., foraminifera, nematodes, copepods, pteropods, diatoms, polychaetes, kinorhyncha, ostracods, halacarids and gastrotricha were reported in the present study. Foraminifera dominated throughout the study period (24 %), followed by nematodes (22 %), while gastrotrichs (0.94 %) were found to be the least abundant group. NEMS was observed to have the highest meiofaunal density among all three seasons. Cluster analysis represented foraminifera and nematodes as a single cluster with the highest similarity percentage (97 %). Shannon-Weiner diversity index was highest in North Bay during Non-Rainy Season (NBNRS) and lowest in Corbyn's Cove during South-West Monsoon Season (CCSWMS). Principal Component Analysis (PCA) results indicated that sediment composition, Dissolved Oxygen (DO) and Organic Carbon (OC) content were the most important factors influencing the meiofaunal distribution in these areas. The study revealed marked differences in the meiofaunal population dynamics compared to the mainland India and have also reported additional meiofaunal groups from the studied regions.

[**Keywords**: Benthos, Diversity, Meiofauna, Offshore sediments, South Andaman]

Introduction

The marine environment harbours several microscopic benthic invertebrate groups collectively known as meiofauna. Andaman & Nicobar Islands (ANI) were formed around 65 million years ago in the Cretaceous period. Subsequently, it underwent several periods of partial submergence and elevation, making it sufficiently aged to support a variety of fauna and flora. The maturity and complexity of the ecosystem that a submerged landform sustains can vary depending on its age. As they have had more time to experience biological succession and create stable habitats, the older submerged areas are more likely to have well-established ecosystems with greater biodiversity.

The earliest studies on taxonomy, diversity and zoogeography of marine benthic groups from this Archipelago were performed by Rao[1-6] providing an insight about the different interstitial meiofaunal taxa inhabiting in the intertidal sediments. Subsequent study by Ansari & Ingole[7], made clear that the meiofaunal groups were found to be plentiful in top layers of the sediments due to increased concentration of oxygen and nutrients in the upper surface than the deeper parts of the sediments. The sharp changes in geochemical factors, hydrodynamic conditions, depth, nutrition availability, and predation are further responsible for controlling the population density and diversity of benthic animals[8]. Their distribution pattern mainly depends on biotic interactions like competition and predation and abiotic factors such as salinity, temperature, Dissolved Oxygen (DO), carbon content, sediment size, etc.[9-11]. Even though meiofauna are generally found in oxygen-rich environments, they can also thrive in anoxic, sulphur-rich environments by behaving as facultative anaerobic metazoans capable of migrating between anoxic and oxygenated environments[12]. They also serve as biological indicators and are abundantly available in all marine environments, making them a perfect group for ecological studies[13-15]. They are essential in benthic nutrient cycling and energy conversion. Eco-physiological responses are prominent in some meiobenthic groups like pteropods, foraminifera, ostracods and copepods which help to identify the changes occurring in oceans due to ocean acidification and global warming[16]. The faunal distribution along

India's coastline is significantly shaped by regional variations and climatic circumstances, which results in diverse ecosystems and species compositions in various coastal locations[17-19]. Species or communities that are particularly vulnerable to environmental changes can be identified through distributional studies, allowing scientists to monitor and manage ecosystems[20]. These studies also aid in taxonomic research by identifying and characterizing available meiofaunal species in selected study areas[21].

Studies reported from Andaman in the last decade incorporate nematodes, gastrotricha, kinorhyncha, foraminifera, polychaetes, copepod, isopod, pteropods, ostracods, pycnogonids, turbellaria and tardigrada[22-25]. Seasonal changes in wind patterns and precipitation are observed during monsoons, and these changes have an impact on water flow, salinity, and the movement of sediment[26]. These hydrological modifications may have a direct effect on meiofaunal distribution. Overall, distributional studies of meiofauna allegedly provide valuable information on biodiversity, ecological interactions, biogeography, and taxonomic research[26-27]. The present study aims to understand the distribution and diversity of meiofauna in the sub-littoral sediments of South Andaman Island. Further, data of the meiofaunal groups represented in the current study weren't found available in the IUCN list.

Materials and Methods

Study area

The study was carried out in four near-shore stations of Andaman Islands: North Bay - NB (Lat: 11°41'49.67" N; Long: 92°45'01.55" E), Marina Park - MP (Lat: 11°40'15.39" N; Long: 92°45'39.16" E), Corbyn's Cove - CC (Lat: 11°38'18.72" N; Long: 92°45'34.43" E), Kodiyaghat - KO (Lat: 11°31'51.76" N; Long: 92°43'58.56" E) (Fig. 1). The sediment

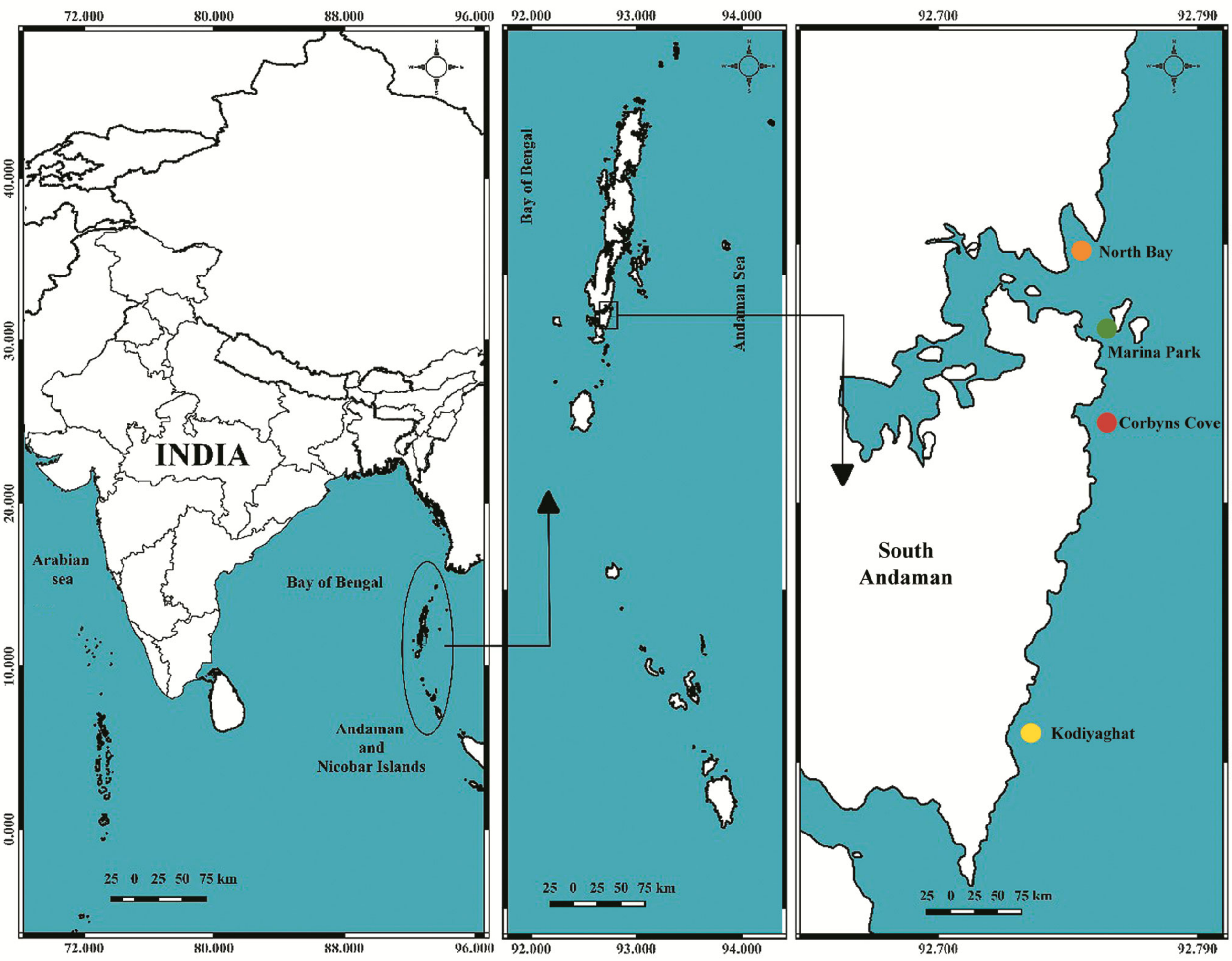

Fig. 1 — Map representing sampling locations of the current study

samples collected from these sampling sites were composed of silty-sand and clayey-sand. Station CC had clayey-sand composition during all the seasons, while Kodiyaghat and Marina Park had silty sand. Station NB only had silty-sand in the North-East Monsoon Season (NEMS), while Non-Rainy Season (NRS) and South-West Monsoon Season (SWMS) had clayey sand.

Methodology

Offshore sediment samples were collected throughout the year 2019 from January to December, during the SWMS, NEMS and NRS. A Van Veen grab of 25 cm^2 was used to collect the sub-surface sediments *in-situ* at 15 m water depth. Samples (15 cm from surface) were collected monthly in triplicate by employing a PVC corer of 10 cm diameter from each station and were then transferred into plastic zip lock bags, followed by the addition of 10 % $MgCl_2$ solution to anaesthetise the meiofaunal organisms. A total of 144 core samples were collected during the one-year sampling period and whole of the each core sample was sieved and analysed. Temperature, Dissolved Oxygen (DO), salinity and pH were recorded on-site using EXO - a multiparameter water quality sonde. Samples were stained with rose Bengal solution for 8 h and kept in the laboratory before further processing. Fauna was extracted from sediment samples using the decantation technique involving a 63 µm mesh-sized sieve[1] and collected into 100 ml plastic sample containers and fixed with 4 % formalin. Individual groups were sorted and counted using a Leica M205C stereo microscope. Sorted specimen groups were preserved in 90 % ethanol. Slides were prepared using glycerol, and further identifications were carried out using Olympus BX50 microscope equipped with differential interference contrast microscopy and Carl-Zeiss inverted a1 microscope equipped with Axiocam.

Foraminifera[28-31], nematodes[32-34], polychaetes[35], diatoms[36-38], ostracods[39-41], gastrotricha[42], kinorhynchs[43-44], and pteropods[45-47] were identified up to the lowest possible taxonomical level using the published identification keys and journals.

Sediment analyses were performed after the removal of salts present in the sediments. Hundred grams of the collected sediment samples were transferred to distilled water in separate glass beakers and left undisturbed for the finer sediments to settle. This step was repeated with minimal disturbance till the fine sediment suspension was attained as per Stokes law. The sediment samples were then dehydrated at 40 °C in a hot air oven and the pipette analysis was conducted thereafter. The sand, silt and clay percentages were estimated and plotted on the triangle graph as suggested by Lindholm[48]. Fifty grams of sediment was dried and powdered using mortar and pestle for the estimation of organic carbon and carbonate[49]. The estimation of carbonate content was carried out using HCl on 2.5 g powdered sediment followed by titration against Sodium hydroxide solution[49]. Wet oxidation method using potassium dichromate was performed on 0.5 g powdered sediment for Organic Carbon (OC) analysis[50].

Statistical analysis

Statistical analysis was performed using Microsoft excel and PRIMER 6 software. The abundance of meiofaunal groups and their relationship with different environmental parameters were compared using multivariate analysis methods. Margalef's Species Richness (SR) index, Shannon-Weiner diversity index (H′), Simpsons Dominance index (D), Pielou's Evenness index (J′), Principal Component Analysis (PCA) and cluster analysis were executed based on a similarity matrix built using Bray-Curtis similarity measure after square root transformation of the data with PRIMER 6.0 software.

Results

Among the NRS, NEMS and SWMS, the highest density of meiofaunal taxa was shown in the NEMS. The maximum individual density obtained in NEMS is 222±65 ind./10 cm^2. The minimum animal density was observed in Corbyn's Cove (144±30 ind./10 cm^2) during the NRS (Table 1). The abundant taxa observed in the study region were foraminifera (24 %) followed by nematodes (22 %), copepods (17 %), pteropods (14 %), diatoms (11 %), polychaetes (7 %), kinorhyncha (2 %), ostracods (2 %), halacarids (1 %) and the least was gastrotricha (0.92 %) (Plate 1, Fig. 2).

Maximum abundance was observed in foraminifera with 20 identified families, comprising 34 species belonging to 29 genera (Table 2). Among those species, *Bolivina striatula*, *Spiroculina* sp. and *Elphidium* sp. were dominant. Nematode density was recorded to be the second highest. Twenty-six species under 23 genera and 14 families were identified. The noticeable abundance was observed in the family Chromadoridae. *Cobbia* sp. had the maximum density

Table 1 — Density (ind/10 cm^2) and Standard Deviation (SD) of meiofauna observed during Non-Rainy Season (NRS), South-West Monsoon Season (SWMS) and North-East Monsoon Season (NEMS) at North Bay (NB), Marina Park (MP), Corbyn's Cove (CC), and Kodiyaghat (KO)

Seasons/ Faunal groups	Foraminifera	Nematodes	Copepods	Pteropod	Diatoms	Polychaetes	Kinorhyncha	Ostracods	Sea mites	Gastrotricha	Average
NBNRS	42.75±12.15	37.5± 9.29	26.5±6.56	22±0.82	16±4.24	10.5±1.73	2.75±2.22	2.75±1.89	2.75±1.71	0.0.525±	163.75 ±41.11
MPNRS	40.75±11.47	36.5±12.23	28.7±7.8	23±6.16	19±1.41	8.75±4.79	1.75±1.71	2.25±2.06	1±0.82	0.5±1	162.25 ±49.45
CCNRS	35.25±8.42	35.75±4.03	26.25±5.19	18±4.32	12.5± 1.73	7±2.16	2.25±1.71	2.75±2.63	5±0	0	144.75±30.19
KONRS	42±11.4	36.25±13.18	28.25±11.87	31.5±13.03	26.5±12.45	13.25±7.18	1.75±0.96	2±4	3±2.94	1.75±1.26	186.25±78.27
NBSWMS	45.4±6.31	39±4.9	34.6±4.93	31±3.74	19.8±2.28	11.8±3.49	4.2±3.11	2.6±2.3	2.2±1.48	0.4±0.55	191±33.09
MPSWMS	46±8.54	37.6±6.07	33.4±8.26	24.4±6.99	18.8±7.19	12.6±2.88	3.6±2.3	4.6±3.85	2.6±2.61	0.8±1.1	184.4±49.79
CCSWMS	46±10.42	33.6±6.07	28±5.34	20.4±3.58	16.4±3.91	10.4±3.78	2±0.0	2±2.55	0.4±0.89	0.4±0.55	159.6±87.45
KOSWMS	45±11.53	43.6±13.07	33±19.9	25.4±15.47	19.2±5.36	12.8±3.03	3.2±2.95	0.8±0.84	1.6±1.95	4.4±1.52	189±75.62
NBNEMS	42.33±2.52	40.67±3.06	34.67±5.03	24±2.65	20.33±1.53	12.33±3.79	5.33±2.89	5.67±3.79	3.33±1.53	2.33±4.04	190.99±30.83
MPNEMS	42±5.29	36.67±8.5	30.67±11.02	21.33±2.08	19.67±2.89	15.33±5.69	4±3.61	5.33±2.31	3±2.65	1±1.73	179±45.77
CCNEMS	40.33±2.52	41.67±2.52	29.33±6.51	26±8.72	17.33±5.51	17±8.72	4±1	4±2.65	3±2.65	2.33±4.04	184.99±44.84
KONEMS	45.33±7.57	49.67±14.57	42±5.29	33.33±13.05	25.33±12.86	14±2.65	3.67± 2.52	2.67±1.53	1±1	5.67±4.04	222.67±65.08

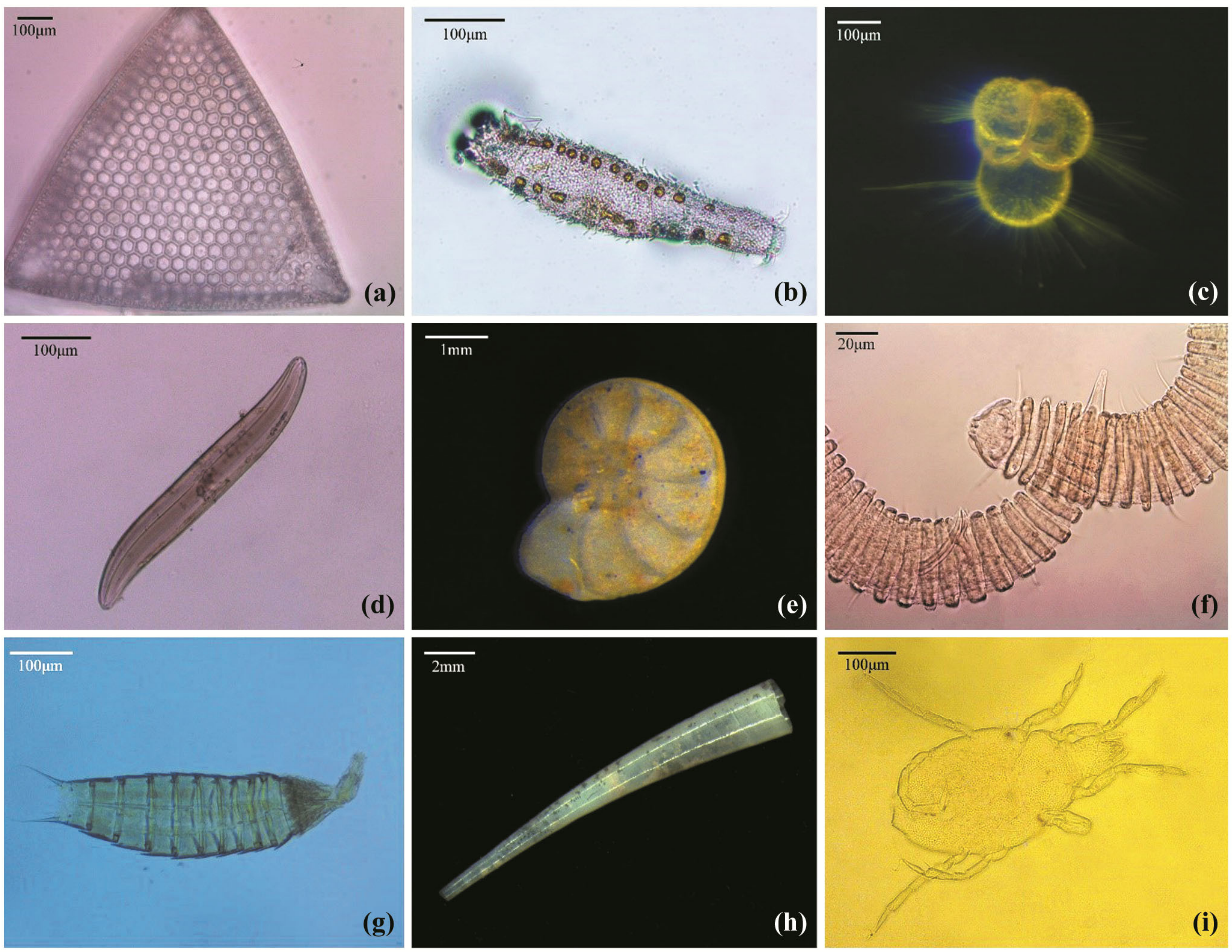

Plate 1 — a) *Triceratium* sp., b) *Tetranchyroderma* sp., c) *Globigerinoides ruber*, d) *Gyrosigma* sp., e) *Operculina ammoinoides*, f) *Tricoma* sp., g) *Echinoderes bengalensis*, h) *Creseis Acicula*, and i) *Copidognathus* sp.

followed by *Desmodora* sp. and *Sabatieria* sp. The least abundant genera were *Ceramonema* and *Dracograllus*. *Bolbolaimus* sp., *Desmoscolex* sp. 1, *Halalaimus* sp., and *Tricoma* sp. were particularly abundant during the SWMS and NEMS period. A total of 11 species of copepod belonging to 7 families were identified. *Stenhalia* sp. belonging to the family Miraciidae had the leading abundance. Family Dactylopusiidae had the lowest density. Throughout the NRS, their total numbers were less when

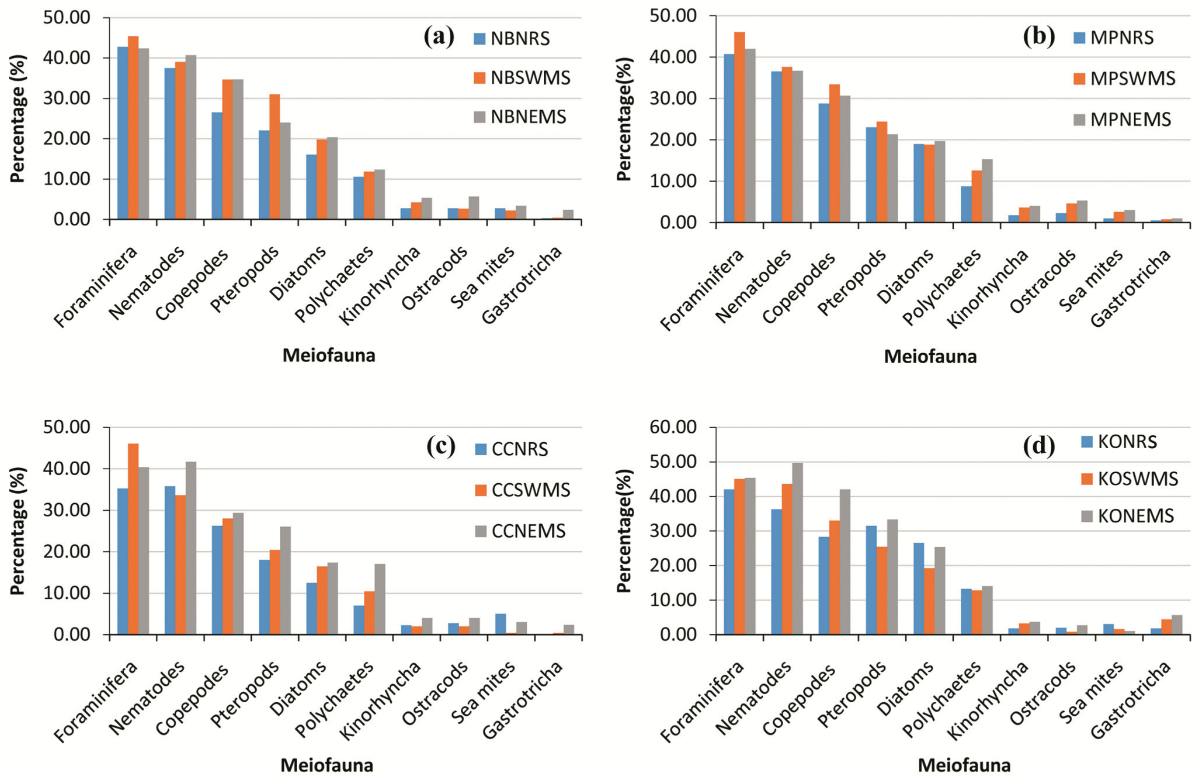

Fig. 2 — Distribution of meiofaunal groups: a) North Bay (NB), b) Marina Park (MP), c) Corbyn's Cove (CC), and d) Kodiyaghat stations (KO). NBNRS: North Bay Non-Rainy Season; NBSWMS: North Bay South-West Monsoon Season; NBNEMS: North Bay North-East Monsoon Season; MPNRS: Marina Park Non-Rainy Season; MPSWMS: Marina Park South-West Monsoon Season; MPNEMS: Marina Park North-East Monsoon Season; CCNRS: Corbyn's Cove Non-Rainy Season; CCSWMS: Corbyn's Cove South-West Monsoon Season; CCNEMS: Corbyn's Cove North-East Monsoon Season; KONRS: Kodiyaghat Non-Rainy Season; KOSWMS: Kodiyaghat South-West Monsoon Season; and KONEMS: Kodiyaghat North-East Monsoon Season

Table 2 — Total meiofaunal occurrence during the study period. '+': presence; '-': absence; NRS: Non-Rainy Season, SWMS: South-West Monsoon Season, NEMS: North-East Monsoon Season, MP: Marina Park, NB: North Bay, CC: Corbyn's Cove, and KO: Kodiyaghat

Species	Family	NRS				SWMS				NEMS			
		MP	NB	CC	KO	MP	NB	CC	KO	MP	NB	CC	KO
		Foraminifera											
Ammodiscus sp.	Ammodiscidae	+	+	+	-	-	+	+	+	+	+	+	+
Bolivina compacta	Bolivinitidae	+	+	-	+	+	+	+	-	+	+	-	+
Bolivina sp. 1	Bolivinitidae	-	-	-	+	-	+	+	+	+	-	+	+
Bolivina striatula	Bolivinitidae	+	+	-	+	-	+	+	+	+	+	+	+
Bolivinita quadilatera	Bolivinitidae	+	-	+	-	+	+	+	-	-	-	+	+
Bulimina sp.	Buliminidae	+	+	-	+	-	-	+	-	+	-	+	-
Calcarnia sp.	Calcarinidae	+	-	-	+	-	+	+	+	-	+	-	+
Elphidium sp.	Elphidiidae	-	+	-	-	+	-	+	+	+	+	+	+
Eponides repandus	Eponididae	-	+	+	+	-	+	+	-	-	+	+	+
Globuligerina bathoniana	Globigerinidae	+	-	+	+	+	+	-	+	+	+	+	-
Globigerina calida	Globigerinidae	-	+	-	-	-	+	+	-	+	-	-	+
Globerigenella adamsi	Globigerinidae	+	-	+	+	+	+	+	-	+	+	+	+
Globerigerinata glutinata	Globigerinidae	+	+	+	-	+	-	+	+	-	+	-	-
Globigerinoides ruber	Globigerinidae	+	-	-	+	+	+	-	+	-	+	-	+
Globerotalia menardi	Globorotaliidae	+	+	+	+	-	+	+	+	+	+	+	+
Globorotaloides sp.	Globorotaliidae	-	+	+	-	+	+	-	+	+	+	+	+
Lagena sp.	Lagenidae	+	+	-	+	+	+	-	+	+	-	+	-

(*Contd.*)

Table 2 — Total meiofaunal occurrence during the study period. '+': presence; '-': absence; NRS: Non-Rainy Season, SWMS: South-West Monsoon Season, NEMS: North-East Monsoon Season, MP: Marina Park, NB: North Bay, CC: Corbyn's Cove, and KO: Kodiyaghat (*Contd.*)

Species	Family	NRS				SWMS				NEMS			
		MP	NB	CC	KO	MP	NB	CC	KO	MP	NB	CC	KO
Micrometula sp.	Allogromiidae	+	-	+	+	+	-	+	+	+	+	+	+
Miliammina sp.	Miliamminidae	-	+	+	+	+	+	+	+	-	+	-	+
Monalysidium acicularis	Peneroplidae	+	-	+	+	+	-	-	+	+	+	+	+
Neorotalia calcar	Calcarinidae	+	-	+	+	-	+	+	+	+	+	+	-
Nonionella hantkeni	Nonionidae	-	+	+	-	+	+	+	+	+	+	+	+
Operculina ammoinoides	Nummulitidae	+	+	-	+	+	-	-	+	-	-	+	-
Orbulina universa	Globigerinidae	-	-	+	-	+	+	+	+	+	+	+	+
Peneroplis planatus	Peneroplidae	+	+	+	-	-	+	+	+	+	+	+	+
Psammophaga sp.	Saccamminidae	+	+	+	+	+	-	-	+	+	+	+	+
Quinqueloculina oblonga	Hauerinidae	-	+	+	+	+	+	+	-	-	+	-	-
Quinqueloculina sp. 1	Hauerinidae	+	+	+	+	+	+	+	+	+	+	+	+
Quinqueloculina tropicalis	Hauerinidae	+	-	-	+	-	-	+	+	+	+	+	+
Resigella sp.	Allogromiidae	+	+	+	+	+	+	+	+	+	-	+	+
Rosalina globularis	Rosalinidae	+	+	+	+	-	+	+	-	+	+	+	+
Saccamminis sp.	Saccamminidae	-	-	+	+	+	+	+	+	+	+	+	-
Spirolina sp.	Peneroplidae	+	+	-	-	+	+	-	+	+	+	+	-
Spiroculina sp.	Spiroculinidae	+	+	-	+	+	+	+	+	+	+	-	+
Spiroloculina corrugata	Spiroculinidae	+	+	+	+	-	+	+	-	+	+	+	-
Textularia sp.	Textulariidae	+	-	+	+	+	+	+	+	-	+	+	+
		Nematodes											
Anticoma sp.	Anticomidae	-	-	+	-	+	-	-	-	-	+	+	-
Bathyepsilonema sp.	Epsilonematidae	+	+	+	-	-	-	+	+	+	-	-	-
Bolbolaimus sp.	Microlaimidae	-	+	-	+	+	-	-	-	+	+	+	+
Ceramonema sp.	Ceramonematidae	+	-	-	+	-	-	-	-	+	-	-	-
Chromadora sp.	Chromadoridae	-	+	-	+	+	+	+	+	-	-	-	-
Cobbia sp.	Xyalidae	-	+	+	+	+	-	+	-	+	+	+	-
Daptonema sp.	Xyalidae	+	-	-	+	-	+	+	-	+	+	-	-
Desmodora sp.	Desmodoridae	-	+	+	+	-	+	+	-	-	+	-	-
Desmoscolex sp. 1	Desmoscolecidae	+	+	+	+	+	-	-	+	+	+	+	+
Desmoscolex sp. 2	Desmoscolecidae	+	-	-	+	-	+	+	+	-	-	-	+
Dichromadora sp.	Chromadoridae	-	+	+	-	-	-	-	-	+	-	-	-
Dorylaimopsis sp.	Comesomatidae	-	-	-	+	-	+	-	+	-	+	-	+
Dracograllus sp.	Draconematidae	+	-	-	+	+	-	-	-	+	-	+	+
Draconema sp.	Draconematidae	+	+	-	+	+	-	-	+	+	+	-	+
Halalaimus sp.	Oxystominidae	-	+	+	-	-	-	+	-	-	+	-	+
Halichoanolaimus sp.	Selachinematidae	-	-	-	-	+	-	-	+	+	-	-	-
Paracomesoma sp.	Comesomatidae	+	+	+	+	+	+	-	+	-	+	-	-
Pselionema sp.	Ceramonematidae	-	-	+	+	-	-	-	-	-	-	-	-
Ptycholaimellus sp.	Chromadoridae	+	-	-	-	+	-	-	-	+	-	-	-
Sabatieria sp.	Comesomatidae	+	+	+	+	-	-	+	+	-	+	+	+
Sphaerolaimus sp.	Sphaerolaimidae	+	-	+	+	+	+	+	+	+	-	-	+
Spirinia sp.	Desmodoridae	-	+	-	+	-	+	-	-	-	-	-	+
Terschellingia sp.	Linhomoeidae	+	-	-	+	-	+	+	+	+	-	-	+
Tricoma sp. 1	Desmoscolecidae	+	+	+	+	+	-	-	+	+	+	-	+
Tricoma sp. 2	Desmoscolecidae	-	+	-	+	-	-	+	+	-	-	-	+
Tricoma sp. 3	Desmoscolecidae	+	-	-	-	+	-	-	-	+	-	-	-
		Copepods											
Canuellina nicobaris	Canuellidae	+	-	+	-	+	+	+	+	+	-	+	+
Diarthrodes sp.	Dactylopusiidae	-	+	+	+	+	-	+	-	+	+	-	+
Longipedia weberi	Longipedidae	+	-	+	+	-	+	+	-	+	-	+	-
Noodtiella ornamentalis	Ectinosomatidae	+	+	+	-	+	+	-	+	+	-	+	+

(*Contd.*)

Table 2 — Total meiofaunal occurrence during the study period. '+': presence; '-': absence; NRS: Non-Rainy Season, SWMS: South-West Monsoon Season, NEMS: North-East Monsoon Season, MP: Marina Park, NB: North Bay, CC: Corbyn's Cove, and KO: Kodiyaghat (*Contd.*)

Species	Family	NRS				SWM				NEM			
		MP	NB	CC	KO	MP	NB	CC	KO	MP	NB	CC	KO
Parastenhelia hornelli	Parastenheliidae	-	+	+	+	+	+	+	+	+	+	+	-
Scottolana longipes	Canuellidae	+	-	+	+	-	-	+	+	-	+	+	-
Stenhalia sp.	Miraciidae	+	-	+	+	-	+	-	+	+	-	+	-
Unidentified sp.	unknown	-	+	+	+	+	-	+	+	-	+	+	-
		Pteropods											
Creseis acicula	Creseidae	+	+	+	+	+	+	+	+	+	+	+	+
Creseis conica	Creseidae	+	+	+	+	+	+	+	+	+	-	+	+
Creseis virgula	Creseidae	-	-	+	+	+	+	+	+	-	-	-	-
Heleconoides inflatus	Heliconoididae	+	+	+	+	+	+	+	+	+	+	-	-
Limacina bulimoides	Limacinoidea	+	-	-	-	+	+	+	+	-	-	-	-
Limacina helicina	Limacinoidea	+	+	+	+	+	+	+	+	+	-	-	-
		Diatoms											
Actinocylus sp.	Actinocyclidae	+	+	-	+	+	-	+	+	+	-	-	+
Amphipluera sp.	Amphipleuraceae	-	+	-	+	-	+	+	+	+	+	+	+
Amphora sp.	Catenulaceae	-	+	-	-	+	+	+	-	+	+	-	+
Biddulphia bidulphiana	Biddulphiaceae	+	-	-	-	+	-	+	+	-	-	+	+
Caloneis sp. 1	Naviculaceae	+	-	-	+	-	+	-	+	+	-	-	+
Cocconeis distans	Cocconeidaceae	+	-	+	-	+	-	+	-	+	-	-	+
Cocconeis scutellum	Cocconeidaceae	+	+	-	-	+	+	-	-	+	+	-	+
Cyclotella litoralii	Stephanodiscaceae	-	+	+	+	-	+	+	-	+	+	-	+
Cyclotella meneghiniana	Stephanodiscaceae	+	+	-	+	-	+	+	-	-	-	+	-
Cylindrotheca closterium	Bacillariaceae	+	+	-	+	-	+	+	-	+	-	+	+
Diploneis gabro	Diploneidaceae	-	+	+	-	+	-	-	+	+	-	+	+
Diplonoeis sp.	Diploneidaceae	+	-	-	+	+	-	+	+	+	+	-	+
Encyonopsis montana	Cymbellaceae	+	+	+	+	-	+	+	+	-	+	+	-
Flagilaria sp. 1	Flagilariaceae	-	-	+	+	-	+	+	+	-	-	+	+
Flagilaria sp. 2	Flagilariaceae	+	-	+	+	+	+	-	+	-	+	+	+
Frustulia sp.	Bacillariophycanae	-	-	+	-	-	+	+	+	+	+	+	+
Grammatophora marina	Striatellaceae	+	+	+	+	+	+	+	-	+	-	-	+
Grammatophora oceanica	Striatellaceae	+	+	+	+	-	+	-	+	-	+	+	-
Gyrosigma sp.	Bacillariophycanae	+	+	-	+	+	+	+	+	+	+	+	+
Leptocylindricus sp.	Leptocylindraceae	-	-	+	+	+	-	-	+	+	+	+	-
Lindavia sp.	Stephanodiscaceae	+	+	+	-	+	+	+	+	+	+	-	+
Lyrella clavata	Lyrellaceae	+	+	+	+	+	-	-	+	-	+	+	+
Melosira nummuloides	Melosiraceae	+	+	-	+	+	+	+	+	+	+	+	+
Melosira sp.	Melosiraceae	+	+	+	+	+	-	+	+	-	+	+	+
Navicula hennedey	Naviculaceae	-	-	+	-	+	+	+	+	+	+	-	+
Navicula sp. 1	Naviculaceae	-	+	+	+	+	-	-	+	+	-	+	+
Navicula sp. 2	Naviculaceae	+	+	+	+	+	+	+	+	+	-	+	-
Nitzchia sigma	Bacillariaceae	+	-	+	-	+	-	+	-	+	+	+	+
Paralia sulcata	Paraliaceae	-	-	+	+	+	+	+	+	+	+	+	-
Pluerosigma sp.	Pluerosigmataceae	+	-	+	-	-	+	-	+	+	+	-	+
Psammothidium sp.	Achnanthidiaceae	-	+	+	+	+	+	+	+	+	-	+	+
Skeletonema sp.	Skeletonemaceae	+	+	-	+	+	+	+	+	+	+	+	+
Stenopterobia sp.	Surirellaceae	+	+	+	-	-	+	+	+	+	+	+	+
Stephanodiscus yellowstonensis	Stephanodiscaceae	-	-	+	+	-	+	+	+	+	+	+	+
Surirella fastuosa	Surirellaceae	+	+	+	+	+	-	-	+	+	+	+	-
Synedra sp.	Fragilariaceae	+	-	+	+	+	+	+	+	+	-	-	+
Thalassiosira punctigera	Thalassiosiraceae	-	+	+	-	+	+	+	-	-	+	+	+
Triceratium favus	Triceratiaceae	+	+	-	+	-	+	+	+	+	+	+	+
Trigonium sp.	Biddulphiaceae	-	+	+	+	+	-	+	-	-	+	+	-

(*Contd.*)

Table 2 — Total meiofaunal occurrence during the study period. '+': presence; '-': absence; NRS: Non-Rainy Season, SWMS: South-West Monsoon Season, NEMS: North-East Monsoon Season, MP: Marina Park, NB: North Bay, CC: Corbyn's Cove, and KO: Kodiyaghat (*Contd.*)

Species	Family	NRS				SWM				NEM			
		MP	NB	CC	KO	MP	NB	CC	KO	MP	NB	CC	KO
		Polychaete											
Species 1	Polynoidae	-	-	-	+	-	-	-	+	-	+	-	+
Species 2	Sabellidae	+	+	+	+	+	+	+	+	+	-	+	+
Species 3	Syllidae	+	-	+	-	-	-	+	+	+	+	+	-
Species 4	Phyllocillidae	-	+	+	+	+	-	+	-	+	+	-	+
Polychaete larvae	unidenified	+	+	+	-	+	+	+	-	+	+	+	+
		Kinorhyncha											
Cateria sp.	Cateriidae	+	-	-	-	+	+	+	+	-	-	+	+
Condyloderes sp.	Condyloderidae	-	-	-	-	-	+	-	-	-	-	+	-
Echinoderes andamanensis	Echinodereidae	+	+	-	-	-	-	-	-	+	+	-	-
Echinoderes bengalensis	Echinodereidae	+	+	+	+	+	+	+	+	+	+	+	+
Echinoderes coulli	Echinodereidae	+	+	-	+	+	-	+	-	+	+	-	-
Echinoderes horni	Echinodereidae	+	+	+	+	+	+	+	+	+	-	+	+
Echinoderes hwiiza	Echinodereidae	+	+	+	+	-	-	-	-	-	+	+	-
Echinoderes sp. 1	Echinodereidae	+	-	+	-	+	-	+	+	+	+	+	+
Neocentrophyes sp.	Neocentrophyidae	-	-	-	-	-	-	-	-	-	-	+	-
Pycnophyes sp. 1	Pycnophyidae	-	+	-	-	+	+	-	-	-	+	+	+
Pycnophyes sp. 2	Pycnophyidae	-	-	-	-	-	-	-	-	+	+	-	+
		Ostracods											
Bradleya andamanae	Thaerocytheridae	+	-	-	+	+	+	+	-	-	-	+	+
Actinocythereis sp.	Trachyleberididae	+	+	-	+	-	+	-	-	+	+	-	+
Argilloecia sp.	Pontocyprididae	-	-	-	+	-	-	-	-	-	-	+	-
Keijella sp.	Trachyleberididae	-	-	+	-	-	-	-	+	-	-	-	+
Heterocypris sp.	cyprididae	+	+	-	-	+	+	+	+	-	+	+	-
Unidentified sp.	Trachyleberididae	-	-	+	-	+	-	-	-	+	-	+	
		Halacarid mites/Sea mites											
Copidognathus sp. 1	Halacaridae	-	-	-	-	+	+	-	+	-	-	-	-
Arhodeoporus sp. 1	Halacaridae	-	-	-	-	+	-	-	+	-	-	-	-
Arhodeoporus sp. 2	Halacaridae	-	-	-	-	-	-	-	+	-	-	-	-
Copidognathus sp. 2	Halacaridae	-	-	-	-	-	-	-	+	-	-	-	-
Halacarellus sp.	Halacaridae	-	-	-	-	-	+	-	+	-	-	-	-
		Gastrotricha											
Macrodasys andamanensis	Macrodasyidae	+	-	-	+	+	-	-	+	-	-	-	+
Pseudostomella sp.	Thaumastodermatidae	+	-	-	+	-	-	-	+	-	-	-	+
Tetranchyroderma sp.	Thaumastodermatidae	-	-	-	+	-	-	-	+	+	-	-	-
Unidentified sp.	Thaumastodermatidae	+	-	-	+	+	-	-	+	-	-	-	+
Urodasys viviparus	Macrodasyidae	-	-	-	+	-	-	-	+	+	-	-	+

compared to the monsoon time. Six pteropods belonging to 3 families were identified at the species level. *Creseis acicula* of the family Cresidae and *Limacina helicina* of the family Limacinoidea had the highest density among the pteropods recorded from this study. The third species *Heliconoides inflatus* had the least abundance and distribution. They were spotted from all the stations during all seasons. Benthic diatoms were the most diverse group observed with a total of 39 species belonging to 24 families and 29 genera. Family Naviculaceae was identified as the most abundant and had the highest number of species. The diatom species with highest abundance included *Navicula* sp., *Flagilaria* sp., and *Cocconeis distans*.

Family Polynoidae, Sabellidae, Syllidae, Shyllocidae, etc., were the polychaete families observed from the sediments. Among the polychaete families maximum density was found in family Syllidae. Kinorhynchs from 5 families belonging to 5 genera and 10 species were reported. The abundant species observed was *Echinoderes bengalensis.* The least abundant was *Pycnophyes* sp. 1, belonging to the family Pycnophyidae. Family Trachyleberididae was the most abundant Ostracod family in this study. *Bradleya andamanae* was the leading member of this group and *Propontocypris* sp. under the family Pontocyprinidae was the least abundant species. Halacarid seamite *viz*., *Copidognathus* sp. and *Arhodeporous* sp. 1 were the dominant ones found during all the three seasons. *Halacarellus* sp. was the least abundant one and was observed only during the monsoon seasons. Gastrotrichs were found to be the least abundant among all the groups throughout all the seasons. Species *Macrodasys andamanensis*, *Pseudostomella* sp., *Tetranchyroderma* sp., and *Urodasys viviparus* were seen in the sediments. Among these *M. andamanensis* was reported as the dominant species.

The parameters recorded include temperature, pH, salinity, DO, sediment composition (sand, silt, clay), Organic Carbon (OC) and carbonate content (Table 3). The average temperature during the study period varied between 28.06 °C to 33.8°C, pH from 7.4 to 8.5, salinity from 29.8 PSU to 34.37 PSU, DO from 4.08 to 5.284 ml/L, OC from 0.42 – 1.65 % and carbonate from 2.2 – 4.8 %, etc. The temperature was found to be the highest during the NRS and lowest was found during the SWMS. Highest average pH, salinity values were obtained during the SWMS and lowest during the NEMS. DO values peaked during the NEMS and was least during NRS. Out of all the stations, carbonate content in sediments was found to be most significant in Marina Park station during the SWMS, and OC was highest in Kodiyaghat during the NRS.

From Table 4, it can be seen that Margalef's species richness (SR) was maximum (2.56) in Corbyn’s Cove during SWMS and minimum (2.41) in Kodiyaghat during the NEMS time. Shannon-Wiener diversity index (H′) was highest in North Bay NEMS (3.16) and lowest in Corbyn’s Cove SWMS (3.0). NRS in CC and NB and NEMS in CC showed the highest Pielou's Evenness Index (J′). Lowest eveness index (J′) was observed during SWM at CC. Simpson's dominance Index (D) was maximum in NEMS at NB and CC and in SWMS at Marina Park. In the Bray-Curtis dendrogram (Fig. 3), two major clusters were formed. Cluster one with 88.54 % similarity and cluster two with 81.88 % similarity. Foraminifera and nematodes were found to be most similar in abundance (97 %) as they were the most abundant groups found in all the three seasons.

PCA was used to understand the distribution of environmental parameters and their effect on the meiofaunal distribution of the selected locations at different seasons (Fig. 4). PC1 accounts for a

Table 3 — Temperature, pH, salinity and DO observations during the three sampling seasons at North Bay (NB), Marina Park (MP), Corbyn’s Cove (CC) and Kodiyaghat (KO)

Seasons/ Parameters	NBNRS	NBSWMS	NBNEMS	MPNRS	MPSWMS	MPNEMS	CCNRS	CCSWMS	CCNEMS	KONRS	KOSWMS	KONEMS
Temp (ºC)	28.9	29.3	29.2	28.8	29.2	29.2	28.7	29.0	29.1	28.8	28.6	33.8
pH (H^+)	8.3	8.3	8.4	8.3	8.3	8.4	8.3	8.3	8.4	8.3	8.4	7.1
Salinity (PSU)	32.8	33.8	30.0	33.3	34.4	30.5	34.0	34.1	30.6	33.1	33.0	29.8
DO (ml/L)	4.1	4.4	5.2	4.1	4.6	4.7	4.1	4.6	4.5	4.1	4.7	4.7

*NBNRS: North Bay Non-Rainy Season; NBSWMS: North Bay South-West Monsoon Season; NBNEMS: North Bay North-East Monsoon Season; MPNRS: Marina Park Non-Rainy Season; MPSWMS: Marina Park South-West Monsoon Season; MPNEMS: Marina Park North-East Monsoon Season; CCNRS: Corbyn’s Cove Non-Rainy Season; CCSWMS: Corbyn’s Cove South-West Monsoon Season; CCNEMS: Corbyn’s Cove North-East Monsoon Season; KONRS: Kodiyaghat Non-Rainy Season; KOSWMS: Kodiyaghat South-West Monsoon Season; and KONEMS: Kodiyaghat North-East Monsoon Season

Table 4 — Univariate diversity indices. Number of Species (S), Margalef's species richness (SR), Shannon-Wiener diversity index (H′), Pielou's Evenness Index (J′), Simpson's dominance Index (D)

Seasons/ Diversity indices	NBNRS	NBSWMS	NBNEMS	MPNRS	MPSWMS	MPNEMS	CCNRS	CCSWMS	CCNEMS	KONRS	KOSWMS	KONEMS
S	10	10	10	10	10	10	9	10	10	10	10	10
SR	164	191	191	162	184	179	145	160	185	186	189	223
H′	1.77	1.71	1.71	1.77	1.73	1.74	1.61	1.77	1.72	1.72	1.72	1.67
J'	0.81	0.82	0.86	0.80	0.83	0.85	0.85	0.78	0.85	0.83	0.82	0.83
D	1.87	1.88	1.98	1.83	1.92	1.96	1.87	1.81	1.97	1.91	1.89	1.92

*NBNRS: North Bay Non-Rainy Season; NBSWMS: North Bay South-West Monsoon Season; NBNEMS: North Bay North-East Monsoon Season; MPNRS: Marina Park Non-Rainy Season; MPSWMS: Marina Park South-West Monsoon Season; MPNEMS: Marina Park North-East Monsoon Season; CCNRS: Corbyn’s Cove Non-Rainy Season; CCSWMS: Corbyn’s Cove South-West Monsoon Season; CCNEMS: Corbyn’s Cove North-East Monsoon Season; KONRS: Kodiyaghat Non-Rainy Season; KOSWMS: Kodiyaghat South-West Monsoon Season; and KONEMS: Kodiyaghat North-East Monsoon Season

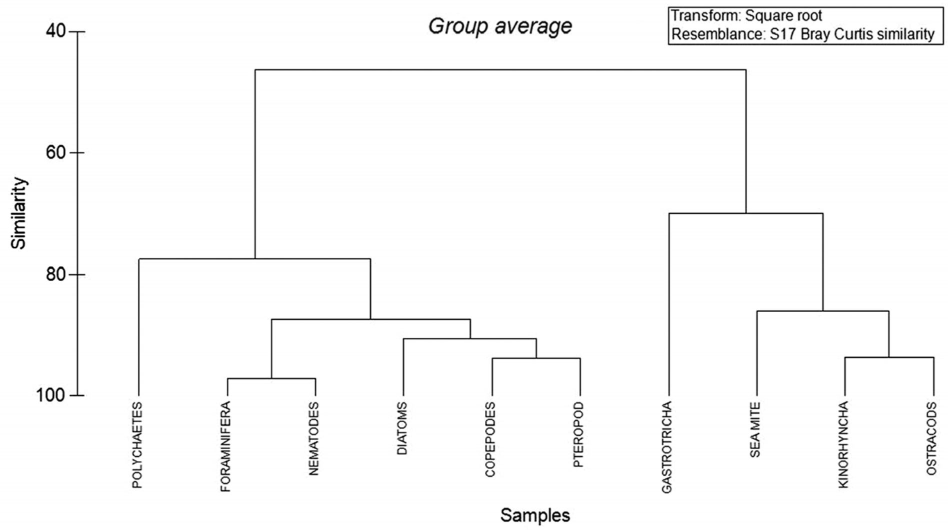

Fig. 3 — Bray-Curtis similarity dendrogram formed after square root transformation of the data showing grouping of meiofaunal groups available throughout the study period

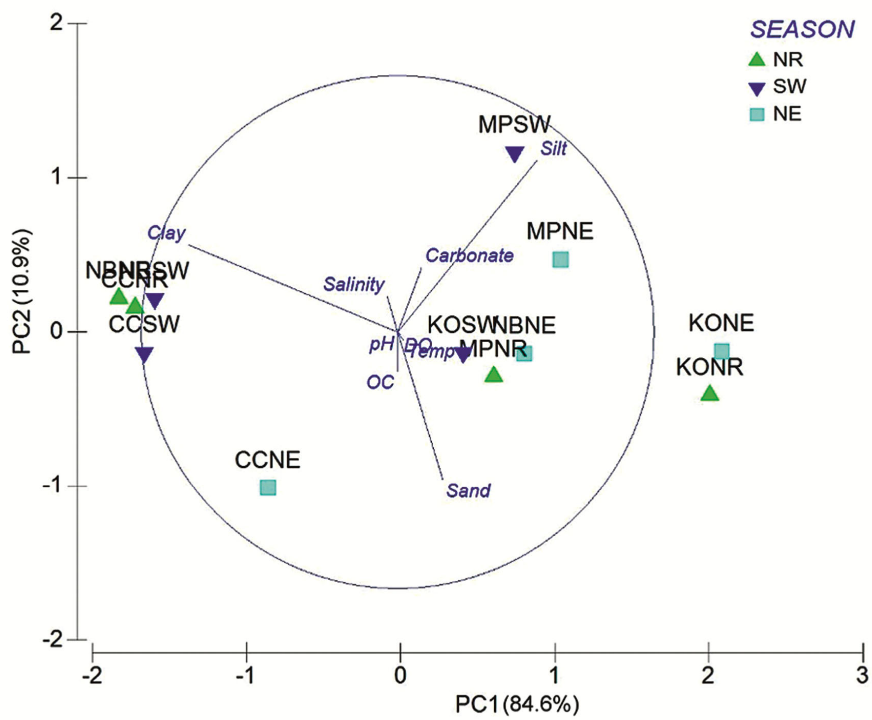

Fig. 4 — PCA plot depicting relationship of station-wise seasonal physico-chemical parameters. NR: Non-Rainy season; SW: South-West monsoon season; NE: North-East monsoon season; NBNR: North Bay Non-Rainy season; NBSW: North Bay South-West monsoon season; NBNE: North Bay North-East monsoon season; MPNR: Marina Park Non-Rainy season; MPSW: Marina Park South-West monsoon season; MPNE: Marina Park North-East monsoon season; CCNR: Corbyn's Cove Non-Rainy season; CCSW: Corbyn's Cove South-West monsoon season; CCNE: Corbyn's Cove North-East monsoon season; KONR: Kodiyaghat Non-Rainy season; KOSW: Kodiyaghat South-West monsoon season; and KONE: Kodiyaghat North-East monsoon season

variation of 84.6 % in environmental data, and PC2 accounts for 10.6 % variation. The total variation seen is 95.5 %. PC1 reflected highest loading of clay and silt while in PC2, silt and sand were the most important environmental factors. This suggests that the distribution of meiofaunal taxa in all the study locations was influenced mostly by the sediment composition in the respective areas.

Discussion

Until now, there is no realistic estimate of benthic meiofaunal distribution reported from the offshore sediments of Andaman Islands. However, Dhivya & Mohan[23] reported eleven meiofaunal groups such as foraminifera, nematoda, copepoda, polychaeta, halacaroidea, amphipoda, kinorhyncha, tardigrada, ostracoda, syncarida, and isopoda from the continental shelf sediments off the Nicobar group of islands. Similar results excluding syncarida and isopoda were obtained in the current study. However, additional meiofaunal groups like pteropods and gastrotrichs were also recorded in this study.

In the Kodiyaghat station, maximum abundance and diversity was reported since it harboured the highest number of meiofaunal groups belonging to different phyla (Tables 1 & 4) in contrast to numerous prior studies carried out along India's east and west coast[51-53], where nematodes and copepods were the predominant taxa, the species composition of meiofauna observed in the current study were different. The most abundant meiofaunal groups observed in the current study are foraminifera with an average density of 43.02±8.53 ind/10 cm^2, followed by nematode 38.72±8.78 ind/10 cm^2. Similar results were observed by Langlet *et al.*[54,55] where the foraminifera were reported as the plenteous group. Further, studies have also reported that the foraminiferan species like *Quinqueloculina oblonga*, *Bolivina* sp., *Elphidium* sp., etc. are observed in regions with lower levels of oxygen conditions with good survival rates[28-29]. Gastrotricha, kinorhyncha and halacarid mites were found to be least among other groups, this might be due their sensitive nature towards the amount of oxygen present in the sediments[56-57]. All the studied stations do not have well-oxygenated environments, and earlier studies have reported that the abundance of these minor phyla may be limited if the oxygen concentration is low. Also, gastrotricha and kinorhyncha often inhabits in specific microhabitats within marine sediments, such as the interstitial spaces between sand grains[58-59]. If the conditions in these microhabitats are not optimal, their abundance may be limited as observed in current study locations.

In the dendrogram, foraminifera and nematodes were grouped as single cluster with the highest similarity (97 %). This might be due to the sediment composition, higher amount of fresh organic matter deposition and increased percentage of coarser sediments than clay in North Bay, Kodiyaghat and Marina Park stations. These physical factors reported from the North Bay and Marina Park stations during the monsoon seasons are favoured by nematode families such as Chromadoridae, Comesomatidae and Selachinematidae; and foraminiferan families such as Bolivinitidae, Globigerinidae, Saccamminidae, and Hauerinidae as reported in the previous studies[53,60]. The second highest similarity was seen between copepods and pteropods with 94 % similarity in the cluster. This may be due to the increased concentration of carbonate and sand materials providing the basic need of aragonite and silica as reported by Paula[12].

Total average abundance was high during the NEMS than the SWMS for meiofaunal groups like nematodes, pteropods, diatoms, ostracods, kinorhynchs, and gastrotrichs. Meiofaunal organisms prefer environments with higher DO since they can thrive better in well aerated conditions that promote decomposition of organic matter, which in turn leads to the release of adequate quantity of nutrients such as nitrogen and phosphorous required for their growth and reproduction[61-62]. Present study is supported by the fact that a negative correlation between DO and OC content was observed which has been related to higher meiofaunal abundance[63]. The nematode species found in higher numbers during the NEMS included *Tricoma* sp., *Desmoscolex* sp. and *Bolbolaimus* sp. Earlier studies have also reported that the seasonal changes in temperature and DO values can have a significant impact on the abundance of nematodes since they are sensitive to temperature variations, and their reproductive rates, metabolic activities, and overall population dynamics may be influenced by temperature changes[64]. During the NEMS, highest average temperature was obtained in the present study which can be considered as a contributing factor to their peak abundance during that period. In this study, foraminifera's presence dominated during the SWMS. The species *Globigerina adamsi*, *Sacamminid* sp., *Textularia* sp., *Spiroculina* sp., etc., were found to be distributed with highest abundance in all stations. This increased abundance can be attributed to the OC content and carbonate influx from the inland sources as highlighted by the studies of Gupta[65], Schonfeld *et al.*[66], and Natalia *et al.*[67].

Gastrotrich and Kinorhyncha were found to have lower densities during the whole study period. These findings correlate with the other studies in which their

Table 5 — Reported average temperature, pH, salinity, and DO of Eastern and Western coast of India, and present study (NE: North-East coast, SE: South-East coast, SW: South-West coast)

Place/Parameters	Temperature (°C)	pH	Salinity (ppt)	DO (ml/L)	References
			East coast		
NE coast, Sundarbans	32.26	7.42	16.53	6.41	Ghosh[17]
Digha coast	28.05	8.50	28.31	4.63	Sayan *et al.*[76]
SE coast, Tamil Nadu	31.37	7.97	28.20	3.90	Varadharajan & Sourapandian[19]
East coast, Muthupettai	27.65	7.85	29.00	4.59	Thilagavathi *et al.*[77]
			West coast		
SW coast Kerala	25.85	7.84	29.37	5.42	Priyalakshmi & Menon[18]
West coast Arabian sea	27.60	NA	34.89	3.40	Sajan *et al.*[78]
SW coast Poonthura	27.53	7.92	32.74	5.31	Anila[79]
Mumbai coast	27.50	NA	31.80	5.80	Sahoo *et al.*[80]
			Present study		
Andaman Sea	32.00	8.30	32.80	4.50	Present Study

recorded densities were lesser than the other meiofaunal groups[68]. Another reason to see a decline in the gastrotrich population could be the dormancy of their eggs due to stress and other environmental variations[69-70]. Gastrotrichs were seen more abundant in Kodiyaghat station during NEMS. Here, coarser sediments with more amounts of silt and sand were present. Similar results have been found in the studies conducted on gastrotrichs from other geographic locations[71-72].

From the Table 5, it could be understood that the values of pH (8.3), salinity (32.8 ppt), temperature (29 °C), and DO (4.5 ml/L) in Andaman Sea fluctuated from other studied areas of the Eastern and Western coast of India. The average temperature, salinity and pH levels of Andaman Sea were higher than east and west coast regions. These changes in the environmental parameters may cause alterations in abundance and diversity but also lead to morphological and biological variations, thereby contributing to the distinctiveness of the benthic meiofauna in a region as reported by Balsamo *et al.*[72].

Even though foraminifera and pteropod exoskeletons are composed of the same material ($CaCO_3$), foraminifera are found in more significant numbers than the pteropod. This is because foraminifera tests have the calcite form of $CaCO_3$, which is the most stable polymorph of $CaCO_3$ and the pteropod shell has aragonite which is a less stable polymorphic form of $CaCO_3$ that dissolves faster in seawater. Therefore, pteropod disintegrate faster than foraminifera, which makes their counts lesser than foraminifera[73-74]. Among pteropods and foraminiferans sorted in this study, some of the pteropod shells had already started to disintegrate and their shells were degraded. But the foraminiferan tests mostly remained intact and dissolution of their tests wasn't observed. Additionally lesser numbers of pteropods found in sediments than foraminifera might be because of their planktonic nature and also because of the presence of ocean currents which causes less amount of their shell deposition in the near shore sub-littoral sediments[75].

Moreover, changes in physiological parameters such as temperature, pH, DO, and OC, and in ecological conditions and assemblage modifications leads to the alteration in the abundance and diversity of the benthic meiofauna and its distinctiveness at the selected study area. This was also revealed through the distinct group formations observed in the cluster analysis suggesting that variations in environmental parameters are impacting the meiofaunal distribution in the study area.

This peculiar distribution of meiofaunal groups in the Andaman Sea is relatively different from other areas, making Andaman an inimitable environment. The fine substrata of clay and silt retain higher organic matter content, whereas sandy substrata hold lower organic matter content[76-78]. Dispersal ability and taxon-specific traits, which can change with changes in physico-chemical parameters, depth, sediment grain size gradient, and organic content, aids in the complex interaction of elements that contribute to taxon-specific traits and the different environmental variations[79]. Hence, it is essential for the ecologists and conservationists to comprehend these relationships in order to forecast how ecosystems may react to environmental changes and how various taxa may be impacted[80].

Conclusion

The present study conducted to explore the meiofaunal distribution in the near shore regions of South Andaman region revealed differences in meiofaunal diversity and abundance in comparison to reported meiofaunal population dynamics from the Eastern and Western coast of India. Here, the study noted foraminiferans and nematodes as the most abundant meiofaunal groups, against the reported leading groups like copepods and nematodes. Similarly, Gastrotrichs and Kinorhynchs were found to be more abundant in the current study area compared to the other Indian coastal regions. The sub-littoral sediments were found to be providing a likely environment for the survival of all meiofaunal taxa identified. In NRS the meiofaunal abundance was seen to be lowest, while NEMS showed highest abundance and diversity. The physico-chemical parameters recorded during the NEMS was found to have more influence on the meiofaunal population compared to the other two seasons, since the average temperature and DO values observed here were the highest than the other two seasons.

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Conflict of Interest

The authors declare no conflict of interest.

Ethical Statement

The authors declare that no live organisms were harmed during the study.

Author Contributions

TKAA designed the study and prepared the manuscript; TKAA, NMA, NSH, VS & KS helped with identification and laboratory work. PMM supervised the study and helped in manuscript editing.

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