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Benthic meiofaunal diversity and distribution in Nagapattinam coastal waters, India

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ABSTRACT

In the present study, benthic meiofaunal diversity and distribution in Nagapattinam coastal waters was studied. A total of 40 meiobenthic species belonging to four meio-faunal taxa foraminiferans, nematodes, ostracods and harpacticoids were recorded with maximum density of meiofauna (428Nos/10cm^2) in offshore station and minimum in estuarine station. Among the four meio-faunal taxa, foraminiferans topped the list with 24 species followed by nematodes (7 species), ostracods (6 species) and harpacticoids (3 species). Seasonally, the maximum number of meiofaunal species (31 species) was recorded at offshore stations during postmonsoon and minimum (19 species) was recorded at inshore stations during monsoon. CCA and BIO-ENV (Biota-Environmental matching) analysis showed that the environmental parameters such as DO, W. pH, salinity, sand, clay and TOC manifested as best match ($\varrho\omega$ = 0.948) in determining meiofaunal distribution in the surveyed stations. The maximum species diversity (3.447) and evenness (0.995) was recorded at offshore station and similarly the maximum species richness (7.362) was recorded at inshore station. The results of present study helps to develop an understanding on the meiofaunal distribution based on physico-chemical parameters, which will form a reliable tool in bio-monitoring studies.

KEYWORDS: Meiofauna, density, diversity, Nagapattinam coast, India

1.INTRODUCTION

The ocean covers 71% of the Planet Earth and holds 97% of the Earth's water. It is a key ecosystem that encompasses most of the living space on Earth and plays several crucial roles that support the health of the planet and the livelihood of humans [1]. The environmental parameters such as temperature, salinity, dissolved oxygen and nutrients are of profound biological significance and are used as population indicators [2]. Benthic system regulates energy flow in aquatic ecosystems and therefore studies have been made in order to better understand the mechanisms of the benthic ecosystem. Benthic faunal groups plays important role in benthic community processes such as bioturbation (organic decomposition, nutrient cycling, redistribution of organic material, oxygenation of the sediment) and also form an effective link in food web [3]. However, their large abundance attracts a large number of fin-fishes and shell fishes who visit the coastal belts at regular intervals in order to gain energy from the benthic habitats, mostly in the intertidal and sub tidal zones.

Meiofauna are generally, the interstitial benthic invertebrates are distinguished from macro benthos by their smaller sizes and shares tremendous amount of total benthic biomass in marine habitats [4]. Meiofauna include both small metazoans (e.g., nematodes, ostracods, and harpacticoids) and ecologically relevant protists (e.g., foraminifera and ciliates) that inhabit all sediment types in all climatic zones [5, 6]. Physical factors such as tidal elevation and amplitude regulate various abiotic factors, such as temperature, salinity, dissolved oxygen, hydrodynamics, and sedimentary processes, which, in turn influence the diversity and distributions of meiofauna [7, 8]. Meiofauna are very important in marine ecosystems, since they facilitate bio-mineralization, support various higher trophic levels and show a high sensitivity to anthropogenic pressures, making them excellent group for pollution bio-monitoring studies [9].

In this backdrop, taking cognizance of the facts elaborated above, the present study has been made to investigate the spatial distribution of benthic meiofauna with special emphasis on the seasonal changes in environmental entities in Nagapattinam coastal waters, Southeast coast of India.

2.MATERIALS AND METHODS

Study area

In the present study, the seasonal sampling was carried out in Nagapattinam coastal waters (10°45′16.43"N and 79°52′27.86"E) for a period of one year from April 2017 (Summer) to March 2018 (Post monsoon). Six sampling sites were selected based on the depth (Table 1, Fig. 1). The monthly data were amalgamated to seasons and the results are presented seasonally. The details of sampling stations are given below:

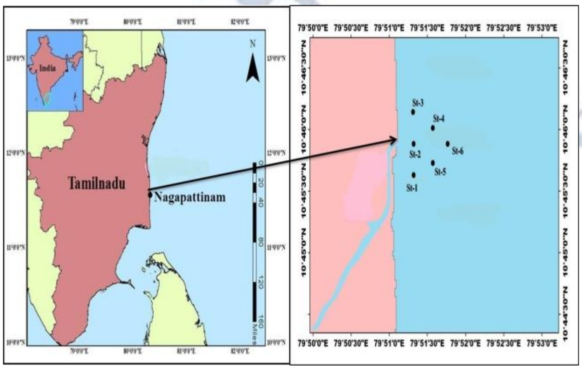

Fig. 1. Map showing the sampling stations in Nagapattinam coast water

Table 1. Geographical locations of sampling stations in Nagapattinam coast waters

Sl. No	Stations Code	Latitude	Longitude
1.	St-1	10°45'16.43"N	79°51'32.26"E
2.	St-2	10°45'49.55"N	79°51'32.84"E
3.	St-3	10°46'24.45"N	79°51'32.61"E
4.	St-4	10°46'14.45"N	79°52'30.53"E
5.	St-5	10°45'30.30"N	79°52'50.70"E
6.	St-6	10°45'57.05"N	79°52'27.86"E

Water and sediment analysis

Measurements of temperature (hand-held mercury thermometer), salinity (Refractometer, ATAGO, Japan) and pH (pH pen, model LI-120, Eutech Instrument, Singapore) were recorded during each sampling event. Bottom water dissolved oxygen (DO) was estimated by using Winkler's method [10]. Undisturbed surface-sediment subsamples were shade dried for estimation of Petroleum Hydrocarbon (PHC), Total Organic Carbon (TOC) and sediment texture. The sediment grain-size analysis (i.e., sediment texture) was done by following pipette method of [11]. TOC estimation was done by following [12] and the level of heavy metals was detected by using Inductively Coupled Plasma Mass Spectrophotometer (AGILENT -7700x ICP-MS). Total petroleum hydrocarbon analysis in sediment sample was done by using the methods suggested by Laboratory Analytical Work Instruction, 2011.

Benthic meiofauna analyses

For faunal analysis, a total of six surface three replicate sediment samples were collected using a Van Veen grab with a sampling area of $0.1m^2$ in a depth ranging between 8.0 and 12.0 m (Fig. 1 & Table 1). Sub-sampling the top layer of each grab (~1 cm thick) taken and samples were then stored in cold box in sealed plastic bags. Sediment sub-samples (~100 g) for meiofauna analysis were placed in labeled plastic bags, immediately fixed in 4% buffered formalin in distilled water, and brought to the laboratory. The sediments were washed with tap water through a set of 0.5 mm and 0.063 mm sieves. The sediment retained on the 0.063 mm sieve was decanted to extract meiofauna following the methodology of [13]. Sorting of metazoan meiofauna (foraminiferans, nematode, harpacticoids, and ostracods) from sediment was done by flotation and decantation using a sieve with 0.040 mm mesh size as the efficiency of this technique has been reported as 95% by various researchers [14, 15, 16]. The organisms retained on the sieve were placed into Petri dishes for sorting and preserved in 70% ethyl alcohol with 5% glycerol [17]. A few drops of Rose Bengal (1 g/l) were also added to this solution to facilitate the counting process. Subsequently, the sorted meiobenthic organisms were counted and identified to species level under a stereomicroscope (EISCO Stereo Binocular Microscope) by consulting the standard works of [18, 19, 20, 21, 22, 23, 24, 25] for foraminifera; [26, 27, 28, 29, 30, 31] for nematodes; [32, 33, 34] for ostracods; and [35, 36, 37] for harpacticoids. The numerical abundance of the meiofauna was expressed in individuals per 10 cm^2 [38].

Statistical analysis

Environmental and meiofauna data were statistically treated using univariate, graphical/distributional and multivariate methods available in the statistical software PRIMER (Ver. 7.0) [39]. The diversity index (H') [40], richness index (d) [41], evenness (J') [42], and dominance (D) [43] were calculated using benthic meifaunal species abundance. To determine the correlation between the biological variables and environment, BIO-ENV matching (ϱω) was used [44]. The statistical package 'R' (v. 3.4.4; [45]) was used for Principal component analysis (PCA) to visualize correlation between the physico-chemical parameters and sampling stations and similarly, Canonical Correspondence Analysis (CCA) was also done to relate the abundance of meiofaunal taxa with linear representations of environmental variables.

3.RESULTS

Physico-chemical characteristics of water and sediment

The values of physico-chemical parameters of water and sediment are summarized. Temperature ranged from 10.0 to 36.5^{0}C and the minimum was recorded at St-3 during monsoon and maximum was at St-5 during summer. Salinity fluctuated between 15 and 35.5 ppt, with the minimum was recorded at St-2 during monsoon and maximum was at St-6 during summer. Water pH varied from 8.35 at St-6 during summer and 8.13 at St-2 during premonsoon. Dissolved Oxygen (DO) ranged from 3.42 mg/l at St-5 during summer to 5.39 mg/l at St-2 during monsoon. In the sediments, the PHC ranged from 0.57µg/g at St-1 during monsoon to 2.51 µg/g at St-2 during post-monsoon. TOC content ranged from 2.41 to 8.26mgC/g with maximum was recorded at St-2 during monsoon and minimum was at St-6 during summer. Sand content ranged between 7.35 and 88.10%, with maximum value was recorded at St-2 during summer and minimum was at St-2 during monsoon; silt content varied from 6.40 to 31.15% with maximum was at St-4 during monsoon and minimum at St-3 in summer and the clay content in the sediment fluctuated between 6.40 and 74.45% with maximum (St-2) was in postmonsoon and minimum (St-6) in summer.

Lead content varied from 0.94 to 3.26 mg/kg with the maximum (St-2) in summer and minimum (St-6) in premonsoon. Copper values ranged between 1.14 and 5.18 mg/kg with the maximum was recorded during summer (St-2) and minimum during pre-monsoon (St-6). Cadmium varied from 2.09 to 4.27 mg/kg with the maximum level was recorded at St-3 during monsoon and minimum at St-5 during pre-monsoon. Chromium level varied from 0.65 ± 0.18 to 3.05 mg/kg and the maximum (St-2) was recorded during monsoon and minimum (St-6) during summer.

Benthic Meiofauna

In the present study, as many as 41 species belonging to four groups of benthic meiofauna namely Foraminiferans, Nematodes, Ostracods and Harpacticoida were recorded in various stations in Nagapattinam coastal waters (Table 2). Among them, foraminiferans topped the list with 24 species; nematodes were found to be the next dominant group with 7 species; ostracods came next with 7 species and Harpacticoida came last with 3 species only.

Among the foraminiferans, *Ammonia beccarii, A. tepida, Bolivina limbata, Elphidium texanum, Rosalina globularis* and *Trochammina adaperta* were found commonly in various stations. With respect to nematodes, *Desmodora cambelli, Halalaimus filum* and *Astomonema jenneri* were found to be the common species in the surveyed stations. The ostracods species such as *Basslerites liebaui, Bairdoppilata scaura, Keijella* *reticulate* and Harpacticoids, *Laophonte thoracica*, *Paramesochra dubia* and *Macrosetella gracilis* were found to be common in the surveyed stations. The maximum abundance was recorded at station St-6 with 428 ind./10 cm^2 during postmonsoon and the minimum was at St-2 with 117 ind/10 cm^2 during monsoon. Seasonally, the maximum number of meiofaunal species (31 species) was recorded at offshore station during post-monsoon and minimum (19 species) was recorded at inshore stations during monsoon.

Percentage contribution

The results of percentage composition of meiofauna revealed that foraminiferans constituted the maximum with 76% of the total meiobenthic organisms. Nematodes, ostracods and harpacticoids contributed with 11%, 9% and 4% respectively to the total meiobenthic samples collected from Nagapattinam coastal waters (Fig. 2).

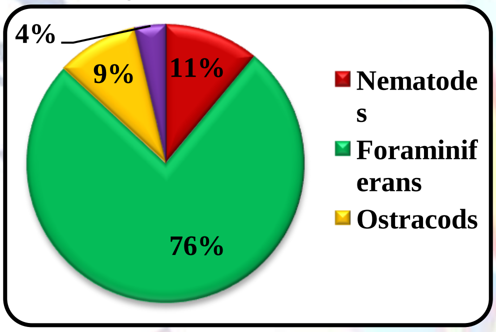

Fig. 2. Percentage contribution of meiofaunal groups recorded in various sampling stations of Nagapattinam coastal waters

Diversity Indices

Shannon diversity (H') index showed minimum (2.815) at St-2 during monsoon and maximum (3.447) was at St-6 during postmonsoon. Margalef species richness (d) showed lowest value (4.726) at St-4 during monsoon and highest (7.362) at St-2 during postmonsoon. Pielou's species evenness (J') varied between 0.528 and 0.874 with the minimum value in St-2 during monsoon and the maximum in St-6 during summer. Simpson dominance index varied from 0.586 to 0.841 with lowest in St-5 during monsoon and the highest in St-2 during postmonsoon (Table 3).

Statistical analyses

The principal component analysis was performed using physico-chemical parameters to set a well-defined distinction between the stations. The PCA plot revealed that St-4, St-5 and St-6 showed high correlation with parameters such as DO, salinity, water pH, sand, evenness (J) and diversity (H'); while St-1, St-2 and St-3 negatively correlated with other parameters such as water silt, PHC and heavy metals (Fig. 3).

Table 3. Diversity indices Shannon diversity (H'); Margalef richness (d), Pielou's evenness (J') and Simpson dominance (D) calculated for Meiobenthos in Nagapattinam coastal waters

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')	Simpson dominance (D)
St-1	3.021	6.839	0.607	0.784
St-2	2.815	7.362	0.528	0.841
St-3	3.050	6.317	0.747	0.769
St-4	3.302	4.726	0.851	0.653
St-5	3.213	5.249	0.836	0.586
St-6	3.447	5.635	0.874	0.596

Statistical analyses

The principal component analysis was performed using physico-chemical parameters to set a well-defined distinction between the stations. The PCA plot revealed that St-4, St-5 and St-6 showed high correlation with parameters such as DO, salinity, water pH, sand, evenness (J) and diversity (H'); while St-1, St-2 and St-3 negatively correlated with other parameters such as water silt, PHC and heavy metals (Fig. 3).

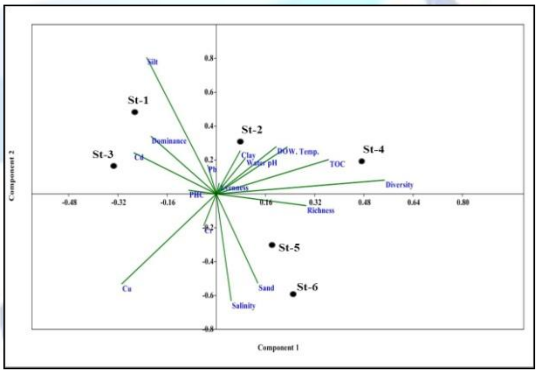

Fig. 3. Principal Component Analysis plot drawn for environmental parameters and meiofaunal diversity in Nagapattinam coastal waters

Table 2. Occurrence of meiofaunal species in various stations of Nagapattinam coastal waters

Name of the species	S. Code	St-1	St-2	St-3	St-4	St-5	St-6
Nematodes							
Daptonema conicum	Dco	+	+	-	+	+	+
Metadasynemallea sp.	Msp	+	+	+	+	+	-
Halalaimus filum	Hfi	+	-	-	+	+	-
Oxystomina clavicauda	Ocl	+	-	+	+	+	+
Enoplolaimus abnormis	Eab	+	+	+	+	+	+
Astomonema jenneri	Aje	-	+	-	+	-	+
Neocamacolaimus parasiticus	Npa	-	+	+	+	+	+
Foraminiferans							
Ammodiscus exsertus	Aex	+	+	-	-	+	+
Ammonia beccarii	Abe	+	+	+	+	+	+
A. tepida	Ate	+	+	+	+	+	+
Bolivina punctuate	Bva	+	+	+	+	+	+
B. vadescens	Bau	+	-	+	+	+	+
Cancris auricula	Cau	+	+	+	-	+	+
Discorbinella bertheloti	Dbe	+	+	-	+	+	+
Edentostomina cultrata	Ecu	-	+	+	-	+	-
Elphidium advenum	Ead	-	+	+	-	+	+
Fissurina marginata	Fma	+	+	+	+	-	-
Globigerina globularis	Ggl	+	+	-	+	+	-
Globorotalia menardii	Gme	+	+	+	-	+	+
Lagena hispida	Lhi	-	+	+	-	-	+
Miliolinella semicostata	Mse	-	+	+	-	+	+
Quinqueloculina debenayi	Qde	+	+	-	-	-	+
Q. seminula	Qse	-	+	+	+	+	-
Q. zhengi	Qzh	+	+	+	+	-	-
Recurvoides trochamminiformis	Rtr	+	+	+	-	-	-
Rosalina globularis	Rgl	+	+	-	+	-	-
Spirillina limbata	Sli	-	-	-	+	-	+
S. tuberculata	Stu	+	+	+	+	+	-
Spiroloculina bradyi	Sbr	+	+	-	+	+	+
S. depressa	Sde	+	+	+	+	+	+
Trichohyalus aguayoi	Tag	+	+	+	+	-	-
Ostracods							
Basslerites liebaui	Bli	-	+	-	-	+	-
Paracytheroma sudaustralis	Psu	+	+	+	-	+	-
Keijella reticulata	Kre	+	+	+	+	+	-
Paracytherideis sp.	Psp	+	+	+	-	-	+
Stenocypris major	Sma	+	+	-	+	+	-
Microcytherura nigrescens	Mni	-	-	+	-	+	-
Tanella gracilis	Tgr	+	-	+	-	-	+
Harpacticoida							
Paramesochra dubia	Pdu	-	+	-	+	+	+
Macrosetella gracilis	Mgr	+	+	+	+	-	+
Tisbe furcata	Tfu	+	-	+	-	+	-

+: Present; -: Absent;

The CCA analysis, which was done to find out the correlation among environmental parameters and species abundance, revealed that the vectors for most environmental parameters were relatively short, indicating their relatively limited variability and individual influence on the assemblages of benthic meiofauna. The total variance of the species-environment relationships and eigenvalues for axes 1 and 2 are 0.397, 0.318, 0.265, and 0.171 respectively. From the CCA plot, it was again evident that species such as *Ammonia beccarii, A. tepida, Bolivina limbata, Elphidium texanum, Quinqueloculina granulocostata, Rosalina globularis, Spirillina lateseptata, Spiroloculina excavate, Desmodora cambelli, Halalaimus filum, Astomonema jenneri, Basslerites liebaui, Neocytherideis senescens, Keijella reticulata, Paijenborchella cymbula, Macrosetella gracilis* got positively correlated with temperature, W. pH, salinity, dissolved oxygen, sand, clay, and total organic carbon at St-4, St-5 and St-6. It was also evident that species such as *Globorotalia hirsute, Lagena lacunata, Neouvigerina hispida, Nonion grateloupi, Orbulina universa, Pararotalia ozawai, Sorites marginalis, Triloculina tricarinata, Trochammina adaperta Oxystomina clavicauda, Enoplolaimus abnormis, Oxystomina clavicauda, Enoplolaimus abnormis, Bairdoppilata scaura, Stenocypris major, Laophonte thoracica, Paramesochra dubia* were negatively correlated to the silt, petroleum hydrocarbon and heavy metals at St-1, St-2 and St-3 (Fig. 4).

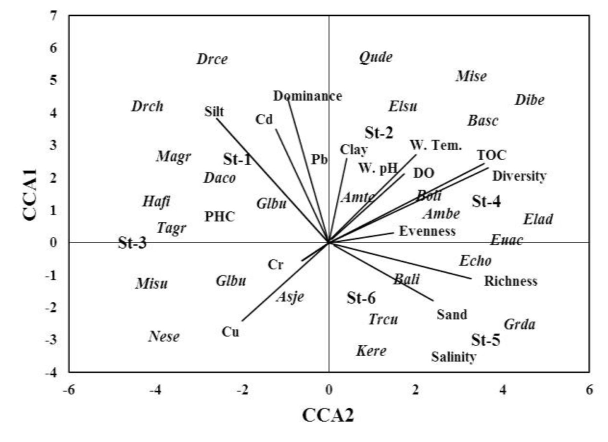

Fig. 4. CCA plot showing inter-relationship between meiofauna species against environmental variables in Nagapattinam coastal waters

Further, to confirm the CCA results, Biota-Environment matching (BIO-ENV) was also employed to measure the agreement between the rank correlations of the biological (Bray-Curtis similarity) and environmental (Euclidean distance) matrices. As observed in CCA, a combination of six environmental parameters, dissolved oxygen, pH, salinity, clay, total organic carbon and sand got manifested as the best match ($\rho\omega$ = 0.948) in determining the distribution of benthic meiofauna. Dissolved oxygen, temperature, salinity, silt, pH and sand were the second best combination to explain meiofauna distributions in Nagapattinam coastal waters (Table 4).

Table 4. Harmonic rank correlations ($\rho\omega$) between benthic meiofaunal abundance against environmental variables in Nagapattinam coastal waters

No. of variables	Best variable combinations	Correlation ($\rho\omega$)
6	Dissolved Oxygen – W. pH - Salinity – Clay - TOC – Sand	0.948
6	Dissolved Oxygen - Temperature – Salinity - Silt – W. pH – Sand	0.856
5	Temperature - Clay – W. pH – Dissolved Oxygen – TOC	0.814
5	Temperature - Salinity - Clay - TOC – Sand	0.765
5	Sand – Clay – W. pH - Dissolved Oxygen – Salinity	0.702

4. DISCUSSION

Worldwide urbanization and industrialization led to widespread contamination of coastal environments. As stated above, the distribution, abundance, diversity, and composition of benthic meiofaunal assemblages in coastal and sub-littoral environments are controlled largely by a combination of physico-chemical parameters (temperature, salinity, currents, substrate, sediment type and vegetation cover), food resources and biotic interactions [46]. In the present study, the high water temperature, salinity and pH values observed in offshore stations St-4, St-5 and St-6 might be due to proximity to the marine zone and lower values were recorded in nearshore stations St-1, St-2 and St-3 receiving freshwater influx. Among the seasons, the maximum values were recorded during summer which might be due to low rain fall and the rise in atmospheric temperature [47, 48].

The dissolved oxygen (DO) was found maximum in offshore stations St-6 during monsoon season and minimum at nearshore stations St-2 during summer season. The relatively minimum DO values observed in the summer/pre monsoon are attributed to fluctuations in temperature and salinity, which in turn affect the dissolution of oxygen. Similar observation was made earlier by [49] in Iranian coast and [50] from Uppanar Estuary, India. TOC content varied from 4.15mgC/g to 11.60mgC/g and the maximum was recorded at nearshore stations St-1 during post monsoon and minimum at offshore station St-5 during monsoon. The maximum TOC in coastal stations might be attributed to clayey nature of sediment (sandy loams, sandy clay, clay loams and clays). Organic matter, as a food source, plays a key role in determining the meiofaunal distributions [51, 52]. Similarly, [53] also opined that the sediment characteristics and the total organic carbon (TOC) contents influence the distribution of meiofauna in Lake Varano, Southern Italy.

Bottom sediments cannot be considered as a permanent sink of pollutants and the metal mobilization in the sediment environment may take place, depending on the physico-chemical changes. In the present study, heavy metal concentration also varied significantly in both the nearshore and offshore stations. The level of Cadmium (Cd), Lead (Pd) and Chromium (Cr) accumulation was found maximum at nearshore stations (St-1, St-2 and St-3) and minimum at offshore stations (St-4, St-5 and St-6). The higher concentration of metals in nearshore stations could be attributed to the heavy rainfall and subsequent river runoff, bringing much industrial and land derived materials along with domestic, municipal, and agricultural wastes, which include residue of heavy metal containing pesticides. [54, 55, 56] also reported similar range of heavy metal distribution in Ennore estuary and [57] in Karaikal coastal waters. The values recorded in the present study are comparable to the reports made by [58, 59, 60] from Uppanar estuary, India.

With respect to faunal entities, a total of 41 meiofaunal species belonging to four groups of meiobenthos organisms namely Foraminiferans, Nematodes, Ostracods and Harpacticoids were recorded. Among them, Foraminiferans topped the list with 24 species. Nematodes were found to be the next dominant group in the order of abundance with 7 species. Ostracods and Harpacticoids came next with 6 and 3 species respectively. Among the foraminiferans, *Ammonia beccarii*, *A. tepida*, *Bolivina limbata*, *Spiroloculina excavate*, *Rosalina orbicularis* and *Spirillina lateseptata* were found commonly in various stations. With respect to nematodes, *Astomonema jenneri* and *Halalaimus filum* were found to be the common species in the samples collected in various stations. The ostracods species such as, *Basslerites liebaui* and *Bairdoppilata scaura* harpacticoids, *Harpacticus chelifer* and *Laophonte thoracica* were found to be common species in the surveyed stations. The lower diversity and density of meiofauna was recorded in nearshore stations, which might be due to the freshwater influx and shallow depth, leading to unfavorable environment for meiofaunal population. Similar range of meio-faunal density was also reported earlier by [61] in East coast of the Yucatan peninsula (Mexico); [62] in Red Sea coast, Sudan.

Species diversity can be an expression of the environmental stress on benthic meiofaunal assemblages, with higher diversity in more stable environments. Species diversity and evenness value was found minimum in nearshore stations during monsoon and maximum in offshore stations during summer season, which might be due to the influence of freshwater influx, temperature and low salinity as reported earlier by [63]. Similar range of meiofaunal diversity values were also reported by [64] from Conero coast, Adriatic. Species richness and dominance showed minimum value at offshore stations during pre-monsoon and higher value in nearshore stations in summer. Similar trend was also observed by [65] from Dongsha Lagoon, China. BIO-ENV and CCA results displayed a good ordination pattern with a combination of temperature, dissolved oxygen, salinity and pH in the distribution and composition of meiofaunal species in the surveyed stations. Similar trend was also observed by [66] from the Moorea, French Polynesia and [67] from Cuddalore coast, India.

5. CONCLUSION

The present study provided base line information about the diversity and distribution of meiofauna along the Nagapattinam coastal waters and further the present findings also contribute additional knowledge on the influence of seasonal variation on the meiofaunal assemblage, since only a minimum studies are available on this aspects in Indian coastal waters. Analysis of data undertaken with conventional tools like univariate and multivariate methods clearly revealed the healthy nature of the coasts and species estimation showed that the sample size of present study is quite adequate for the efforts taken to document all the meiofaunal species occurring in the surveyed coast. Moreover, this study also emphasized that temperature, DO, salinity and pH are the most important factors determining the distribution of meiofauna in Nagapattinam coastal waters.

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Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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