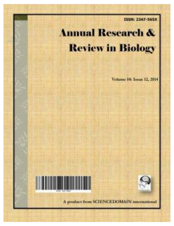

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Distribution and Abundance of Benthic Meiofauna in the Eastern Red Sea Coasts (Jeddah, Saudi Arabia)

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Authors' contributions

This study was achieved in collaboration between all authors. Author AH designed the study, sampling and counting meiofauna and wrote the manuscript. Author MBA performed the statistical analysis and managed the literature searches. Authors AHNED and BA contribute in meiofauna sampling and managed the literature searches. Author MMSH participated in sampling and counting meiofauna and reviewing manuscript. Author TS contribute in meiofauna sampling and sediment analysis. Author FB participated in free-living nematodes identification. All authors read and approved the final manuscript.

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ABSTRACT

An investigative study was conducted during September 2017 along the eastern Red Sea coasts (Jeddah, Saudi Arabia). During this study, 5 stations were prospected and samples of sediment were especially collected in order to study their meiobenthic organisms. Results showed important variations of the environmental factors between stations mainly for salinity measurements that were clearly higher at Shuaiba lagoon (47.70 psu). Meiofauna densities ranged from 218.50 to 485.25

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ind.10 cm^{-2}. Nematodes, Polychaeta, Foraminifera and Ostracoda were the most abundant among the 14 taxa registered. The highest densities of meiofauna were related to high levels of organic matter in Al Saif bay station while the lowest were observed in Shuaiba lagoon station with muddy sediments, low dissolved oxygen and high salinity. Statistical analyses showed that dissolved oxygen rate had a positive effect on Polychaeta, Turbellaria, Gastrotricha and Tardigrada whereas Arachnida, Mollusca and Brachiopoda were respectively affected by organic matter and salinity.

Keywords: Meiofauna; sediment; distribution; abundance; red sea coasts; Saudi Arabia.

1. INTRODUCTION

The increasing impact of human activities on marine and estuarine environments has attracted attention towards the need for monitoring, assessing and managing ecological integrity to promote the long-term sustainability of these systems [1,2]. Meiofauna are the numerically dominant metazoans that occupy sediments of a variety of marine habitats [3,4 and 5]. It has an important ecological role in marine sediments, as they are closely associated with physical and biochemical characteristics of the sediment, which makes them a good bioindicator of anthropogenic disturbance in aquatic ecosystems [6,7 and 8]. In any ecosystem, it is not easy to detect the effect of disturbances on community structure because of the temporal and spatial variability in natural communities; however, a significant contribution of meiofauna in diversity and integrity of stream's benthic communities has been reported by [9]. In fact, due to their short generation time, small size and high density, meiofauna have been considered as precise indicators of all natural and anthropogenic alterations in marine ecosystems [10,11 and 12]. Moreover, the meiofauna can provide food for higher trophic levels, such as fish and marine invertebrates [13]. The spatial patterns of the structure of the meiofaunal community in sandy beaches may be associated with different environmental variables. In fact, the sediment granulometry [14], the organic matter source in coastal sediments [15,16] and anoxic conditions in the interstitial pore space [17,18] have a fundamental role in the richness and abundance of the benthic meiofauna.

In Red sea, a few studies about meiofauna distribution have been done [19]. According to the author, little information was available on the meiofauna distribution neither about their abundance at the eastern coasts of Saudi Arabia (Red Sea). In this study, meiofauna was investigated in five sites along these coasts (Jeddah, Saudi Arabia). Through this pioneer study, we investigate the meiofauna communities from both distribution and abundance in order to provide answers to the basic question on what are different types of meiofaunal metazoans and their spatial variation in these areas.

2. MATERIALS AND METHODS

2.1 Study Site

The study was carried out at the eastern Red Sea coasts of Saudi Arabia during September 2017 (Fig. 1). These areas are characterized by a semi-arid climate with a mean annual precipitation of 63 mm, and a mean daily temperature of 29ºC in winter and 42ºC in summer [20]. Five sites representing five different habitats were sampled for meiofauna (Table 1). Site 1 is Salman bay located 50 km north of Jeddah City, the second is Jeddah harbor (Jeddah City), third site is Al Saif bay located 50 km south of Jeddah City, site 4 is Shuaiba Al Qattan located 50 km south of Al Saif bay and site 5 is Shuaiba lagoon. Distance between each sites is about 50 km, while distance between Shuaiba Al Qattan and Shuaiba lagoon is not far away (12 km). These sites were referred to as: (S1) Salman bay; (S2) Jeddah harbor; (S3) Al Saif bay; (S4) Shuaiba Al Qattan and (S5) Shuaiba lagoon, which is a hypersaline small basin (143 km^2) located 80 km of Jeddah City (Table 1). At all the prospected sites, water depth of sampling was about 1.20 m.

2.2 Sampling Methods and Meiofauna Communities Analysis

For meiofauna analysis, four sediment samples were collected at each station using a hand cylindrical cores (10 cm^2 sampling surface area) to a sediment depth of 5 cm. Sediment with their meiofauna were immediately fixed in 5% neutral formaldehyde filtered seawater solution. In the laboratory, meiofaunal were sieved following the resuspension- decantation methodology [21], stained with Rose-Bengal (0.2 $g.l^{-1}$) and counted and sorted into the major taxa under a stereomicroscope. At each site, 3 additional core samples were taken for sediment and organic

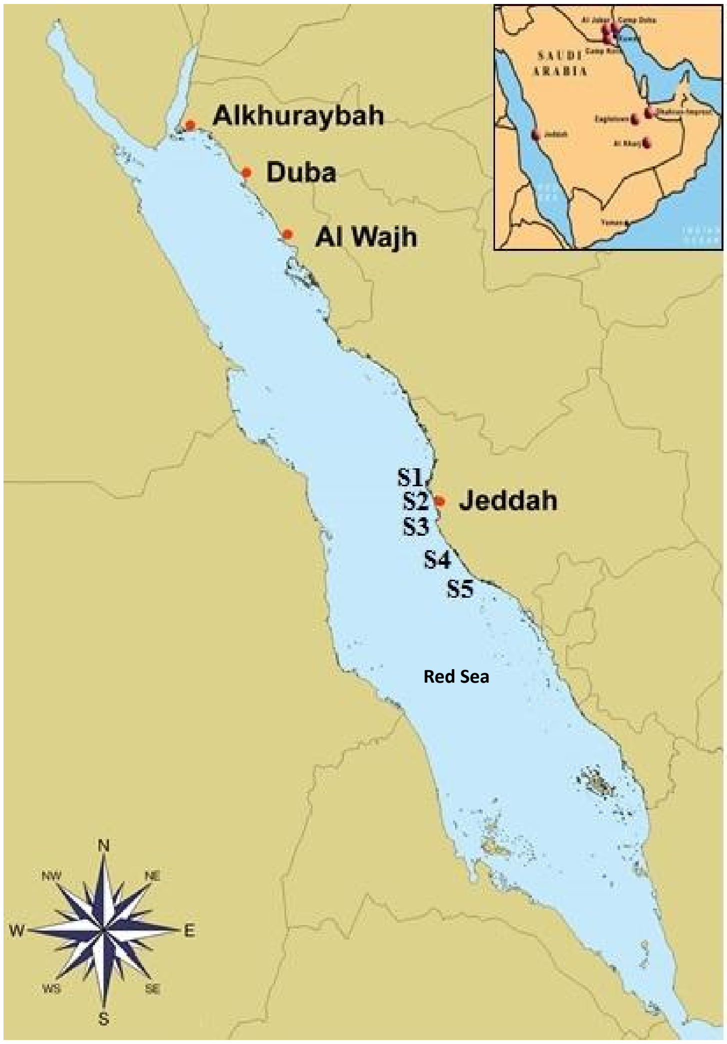

Fig. 1. Location map of sampling sites in Jeddah Coasts (Red sea, Saudi Arabia)

matter analysis. The abundance of meiofauna taxa was determined by counting all specimen in each sample, using a stereomicroscope and converted to abundances per 10 cm². In the present study, only dominant nematodes were identified up to family level.

2.3 Data Analysis

All data analysis followed methods described by [22,23] using the PRIMER 5.0 software package [24]. Multidimensional scaling plot (MDS) derived from Bray-Curtis similarity matrices on square root-transformed data were used to visualize the differences in the structure of meiofauna communities following the procedure described by [22]. Taxa abundance data were presented in k-dominance plots, in which taxa were ranked in decreasing order of dominance, the percentage cumulative abundance (k-dominance) was then plotted against the taxa rank k [25]. Bray-Curtis similarity based on square root-transformed data was used. Pairwise analysis of similarities (ANOSIM) was carried out to determine if there were any significant differences between meiofauna assemblages in different sites. A similarity percentages analysis (SIMPER) was performed to identify the main meiofauna taxa responsible for the observed multivariate community patterns. Univariate indices were computed: Total meiofauna abundance (I), number of taxa (S), diversity [Shannon–Weaver index (H')], taxa richness [Margalef's (d)] and evenness [Pielou's (J')]. Pearson correlation coefficients (r) of log-transformed (X+1) data between the environmental factors and benthic taxa assemblages in different sites was used (Statistica 8.0). The 1-way ANOVA was used to test for overall differences between these indices and the Tukey HSD multiple comparisons test was used in pairwise comparisons of different sites. In all the above statistical significance testing a significant difference was assumed when p<0.05.

3. RESULTS

3.1 Environmental Factors

Salinity varied from 33.44 psu in Salman bay (S1) to 44.90 psu in Shuaiba lagoon (S5) and dissolved oxygen ranged from 3.80 mg/L in S5 to 6.15 mg/L in S3. Surface water pH was the highest (8.8) in Jeddah harbor and showed the lowest values (8.09) in Shuaiba Al Qattan, while temperature showed a spatial variation between stations which increased gradually southwards reaching the highest value (32.8 °C) in the Shuaiba lagoon (Table1).

Sediments of all prospected sites were sandy except Shuaiba lagoon when mud is relatively higher than the others stations (23.74%). In fact, Coarse fraction was more abundant in Jeddah City coasts reaching a maximum value of 29.12% of total dry weight in Jeddah harbor. The minimum value of coarse fraction was observed in Shuaiba lagoon (Table 1). Sand fraction (2-0.063 mm) distribution pattern showed an opposite relationship with those of the gravel fraction. It showed the highest value (~65%) in both S1 and S3; whereas on the southern sides it decreased to 52% of the total dry weight (S4). Fine sediments (mud, 0.063 mm) were more abundant in Shuaiba lagoon (up to 30%), especially in the mangrove area. Organic matter (OM), strongly related to sediment, showed the lowest value (~3%) in the surface sediments of Salman bay and Shuaiba Al Qattan and was higher in Jeddah harbor (S2) and Shuaiba lagoon (respectively 16.78% and 8.34%) (Table 1).

3.2 Meiofaunal Community Composition

Average total meiofauna densities are shown in Table 2. A total of 14 major taxa were found in the five prospected sites, with 14 in Al Saif bay (S3), 12 and 11 respectively in Salman bay (S1) and Shuaiba Al Qattan (S4), 9 meiofauna taxa in S2 (Jeddah harbor) and only 7 taxa counted in Shuaiba lagoon (S5). Nematodes were the dominant taxa at all sampling sites (45-78%) followed by Polychaeta (4-14%), Foraminifera (4-10%), Ostracoda (3-9%), Turbellaria (1-7%), Olighochaeta (1-6%) and Copepoda including nauplii (2-5%) (Table 2). The contribution of both Kinorhyncha and Gastrotricha did not exceed 3% each, whereas the remaining taxa including, Tardigrada, Acarina, Gastrotricha, Mollusca and Brachiopoda represented collectively about 1-2% of the total meiofauna. An unidentified taxa designated as other representing larvae and juvenil forms of some meiofauna taxa were 3 to 8% of total meiofauna abundance.

Results revealed a significant differences on meiofauna communities between site S3 (Al Saif bay) and all prospected sites (P < 0.05). In fact, total abundances of total meiofauna were significantly higher in S3, while the abundance was various at the rest of stations and no significant differences were recorded. In addition, Shuaiba lagoon (S5) meiofauna abundance was the lowest compared to the other habitats. Results indicated also a significant interaction effect on meiofauna composition and taxa richness (d) (P < 0.05). In fact, Meiofauna composition, based on abundance data, was significantly different between stations and taxa richness was significantly lower at Jeddah harbor (S2) and Shuaiba lagoon (S3) (Table 3).

The k-dominance curves (Fig. 2) combined with ANOSIM results (Table 4) indicate that meiofauna communities in Shuaiba lagoon and Jeddah harbor are less diverse than Al Saif bay and Salman bay which are more diversified. In all sites, k-dominance curves were significantly different from each other except S1–S3 (Table. 4). In the MDS ordination, all sites are distinct from Al Saif bay (Fig. 3). Furthermore, S2 and S5 are placed at the end of this ordination; this indicates a clear difference on meiofauna taxa composition between these areas and the rest of sites.

The SIMPER analysis identified the taxa that are responsible for the differences in community structure between and within different sites (Fig. 4). The taxa causing dissimilarities between sites were mainly free- living nematodes, Polychaeta and Turbellaria which were more abundant in S2 and S3. In addition, the average dissimilarity between S3 and S5 was 38.28% while the difference between S2 and S5 was lower (18.83%) (Table 4). Ostracoda and Foraminifera were more abundant in S3, S4 and S5 than in the other two sites (Table 2).

Table 1. Geographic locations and measurements of the environmental factors at the prospected sites

Site	Reference	Latitude N	Longitude E	Temperature (ºC)	Salinity (psu)	pH	Dissolved oxygen (mg/l)	Gravel (%)	Sand (%)	Mud (%)	Organic matter (%)
Salman bay	S1	21º51’38.53’’	38º58’41.16’’	28.70	33.44	8.75	5.88	11.14	65.12	23.74	3.22
Jeddah harbor	S2	21º29’24.66’’	39º10’22.62’’	30.40	36.10	8.85	4.05	29.12	55.80	15.08	16.78
Al Saif bay	S3	21º14’0.07’’	39º8’43.13’’	25.80	34.64	8.17	6.15	11.62	65.20	23.18	5.65
Shuaiba Al Qattan	S4	21º51’35.18’’	39º24’9.33’’	28.80	34.20	8.09	4.70	19.80	52.50	20.20	3.12
Shuaiba Lagoon	S5	20º44’50.90’’	39º28’28.73’’	32.80	44.90	8.41	3.80	5.28	59.30	35.42	8.34

Table 2. Mean ± SD values for meiofauna taxa densities (ind./10 cm^2) at the prospected sites. Taxa frequency (Freq %) is expressed as percentage of occurrence. Each value presented the mean of four replicates

Site	S1		S2		S3		S4		S5	
Taxa	**Mean ± SD**	**Freq (%)**	**Mean ± SD**	**Freq (%)**	**Mean ± SD**	**Freq(%)**	**Mean ± SD**	**Freq(%)**	**Mean ± SD**	**Freq (%)**
Free-living nematodes	109±26.80	45.84	211±20.46	78.58	241.75±43.36	49.81	129±24.36	50.14	159.25±37.06	72.88
Polychaeta	35.25±10.59	14.82	11±6.27	4.09	28.25±10.67	5.82	21±2.92	8.16	10±1.69	4.57
Oligochaeta	14.25±5.31	5.99	3.5±2.20	1.30	12.5±2.44	2.57	11.75±3.95	4.56	5.75±2.05	2.63
Copepoda	10±1.69	4.20	8±2	2.97	27±11.28	5.56	9.5±1.60	3.69	2.25±1.58	1.02
Turbellaria	7.75±0.88	3.25	2.25±1.38	0.83	34.25±12.94	7.05	9.5±1.92	3.69	0±0	0
Kinorhyncha	11±2.26	4.62	2±1.30	0.74	25±12.71	5.15	0±0	0	0±0	0
Gastrotricha	5±2.72	2.10	1.5±1.19	0.55	14.25±3.05	2.93	4.25±1.58	1.65	0±0	0
Tardigrada	1.5±1.19	0.63	0±0	0	7.75±2.76	1.59	0.5±0.53	0.19	0±0	0
Ostracoda	13.25±3.49	5.57	9.5±2.20	3.53	31.25±12.17	6.43	24.25±5.31	9.42	12±1.51	5.49
Foraminifera	18.25±2.31	7.67	11±2	4.09	26.25±10.09	5.40	16±4.95	6.21	20.75±2.18	9.49
Arachnida	1±0.75	0.42	0±0	0	5±2.72	1.03	5.75±2.76	2.23	0±0	0
Mollusca	0±0	0	0±0	0	8±2.39	1.64	0±0	0	0±0	0
Brachiopoda	0±0	0	0±0	0	2±0.75	0.41	3.25±2.43	1.26	0±0	0
Others	11.5±3.74	4.83	8.75±3.57	3.25	22±7.44	4.53	22.5±3.42	8.74	8.5±1.19	3.89
Total Meiofauna	237.75±61.77	100	268.5±42.62	100	485.25±134.85	100	257.25±55.78	100	218.5±47.28	100

Table 3. Means ± SD values of univariate indices for meiofauna assemblages from each site. Abundance (ind./10 cm^2) = I, Number of taxa =S, Taxa richness = Margalef's d, Evenness = Pielou's J' and Shannon-Weaver index H'

Indices	**I**	**S**	**d**	**J'**	**H'**
Site					
S1	237.75±34.19	11.5±0.92	1.92±0.17	0.74±0.04	1.82±0.11
S2	268.50±24.90	9.75±0.46	1.56±0.07	0.40±0.03	0.93±0.09
S3	485.25±68.56	14±1.58	2.10±0.04	0.70±0.04	1.85±0.13
S4	257.25±25.38	11.5±0.53	1.89±0.11	0.71±0.04	1.75±0.11
S5	218.50±34.82	6±0.45	0.928±0.03	0.55±0.07	0.997±0.14

Table 4. Anosim results (*R* statistic and significance level) of pair-wise tests for differences between K-dominance curves of different sites using square-root transformed meiofauna taxa abundance data and Bray-Curtis dissimilarity percentage of total benthic meiofaunal taxa

Sites	***R* values**	**Significance level**	**Average dissimilarity (%)**
S1-S2	1.00	0.03*	35.11
S1-S3	0.21	0.20	23.04
S1-S4	1.00	0.03*	21.21
S1-S5	1.00	0.03*	29.16
S2-S3	1.00	0.03*	29.44
S2-S4	1.00	0.03*	30.36
S2-S5	1.00	0.03*	18.83
S3-S4	1.00	0.03*	30.01
S3-S5	1.00	0.03*	38.28
S4-S5	1.00	0.03*	25.52

** Denotes significant differences when p<0.05*

Table 5. Pearson correlation coefficients (r) between the environmental factors (Temperature salinity, dissolved oxygen, pH, sediment grain size “Gravel, Sand, Mud” and organic matter) and benthic taxa assemblages and diversity indices in the prospected sites. Bold values mark the correlations significant at the $p < 0.05$

Meiofauna taxa	TEMP	SAL	OXYG	PH	GRAVEL	SAND	MUD	OM
Free living nematodes	-0.26	0.13	-0.05	0.21	0.39	-0.46	0.31	0.66
Polychaeta	-0.79	-0.77	**0.95**	-0.41	-0.05	0.49	-0.11	-0.78
Oligochaeta	-0.67	-0.55	0.84	-0.72	-0.40	0.69	-0.23	**-0.94**
Copepoda	**-0.92**	**-0.91**	0.78	-0.03	0.53	0.32	-0.26	-0.28
Turbellaria	**-0.99**	-0.81	**0.88**	-0.38	0.20	0.49	-0.26	-0.51
Kinorhyncha	-0.78	-0.54	0.86	-0.00	0.26	-0.17	0.45	-0.16
Gastrotricha	**-0.99**	-0.82	**0.91**	-0.34	0.21	0.44	-0.19	-0.50
Tardigrada	**-0.91**	-0.49	**0.89**	-0.46	-0.04	0.19	0.17	-0.40
Ostracoda	-0.79	-0.41	0.62	-0.79	-0.26	0.68	-0.39	-0.59
Foraminifera	-0.30	0.266	0.43	-0.77	-0.75	0.12	0.36	-0.42
Arachnida	-0.79	-0.60	0.64	-0.71	-0.14	0.83	-0.60	-0.69
Mollusca	-0.78	-0.23	0.63	-0.38	0.00	0.01	0.24	-0.07
Brachiopoda	-0.62	-0.43	0.36	-0.67	-0.13	0.82	-0.72	-0.51
Others	-0.80	-0.58	0.61	-0.69	-0.11	0.80	-0.59	-0.63
I	-0.85	-0.39	0.62	-0.25	0.21	0.05	0.09	-0.01
S	**-0.94**	**-0.93**	0.83	-0.16	0.41	0.44	-0.31	-0.43
D	**-0.90**	**-0.96**	0.83	-0.14	0.41	0.49	-0.36	-0.48
J’	-0.58	-0.45	0.76	-0.79	-0.51	0.72	-0.25	**-0.96**
H’	-0.81	-0.71	**0.89**	-0.63	-0.19	0.70	-0.32	**-0.89**

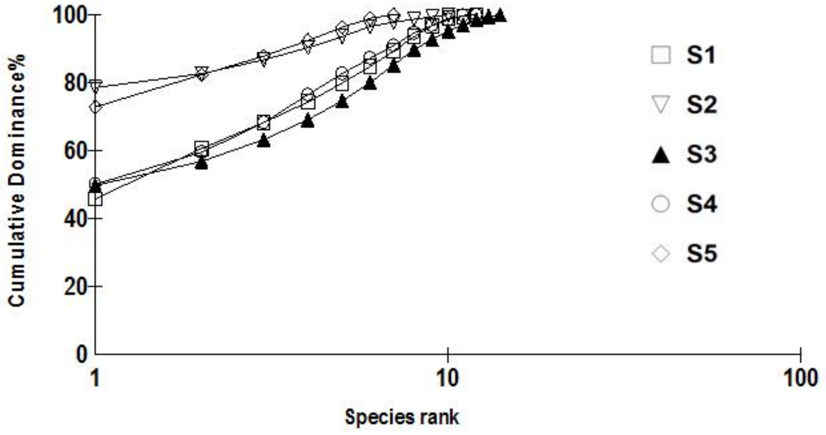

Fig. 2. k-dominance curves for different prospected sites

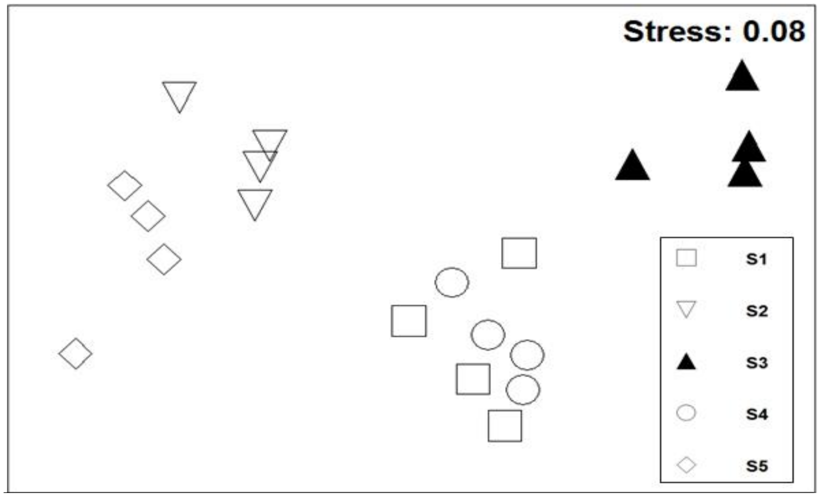

Fig. 3. Non-metric MDS ordination of square-root transformed meiofauna taxa abundance data from different prospected sites

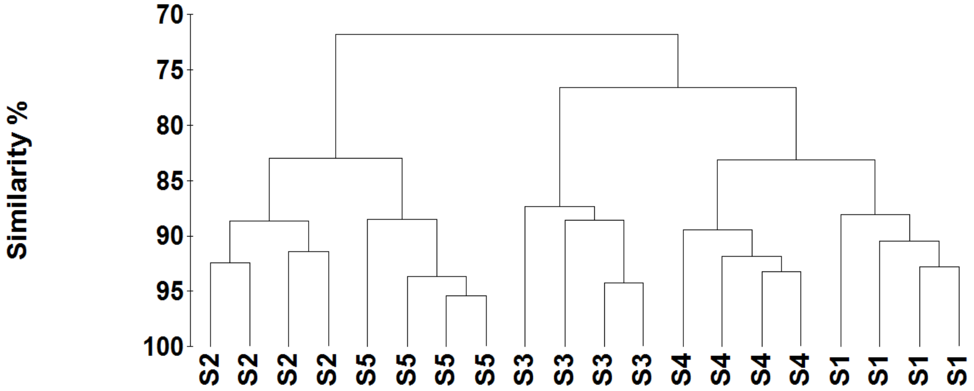

Fig. 4. Hierarchical cluster analysis for the prospected sites using Bray-Curtis similarity percentage of total benthic meiofaunal taxa

Furthermore, Turbellaria and Gastrotricha were absent only in Shuaiba lagoon (S5) while Mollusca was present only in S3. Low abundances of Kinorhyncha, Tardigrada and Arachnida were observed in the prospected sites and were absent in Shuaiba lagoon (S5) (Table 2). According to this distribution, the hierarchical cluster analysis for the prospected sites using Bray-Curtis similarity percentage of total benthic meiofaunal taxa showed two distinct areas. The first includes Jeddah harbor (S2) and Shuaiba lagoon (S5) which are less divers and the second groups the rest of the stations (Fig. 4). Similarly, values of taxon evenness (J') and Shannon-Wiener diversity (H') were in general low in Jeddah harbor (S2) and Shuaiba lagoon (S5) and high in Al Saif bay (S3) and Salman bay (S1) (Table 2). The values of J' and H' were significantly different between S2 and the rest of stations while no significant difference for H' was observed between S2 and S5 ($P \leq 0.05$). Comparing the stations, only S1 and S3 showed significantly higher values of these indices ($P \leq 0.01$).

3.3 Relation between Meiofauna and Environmental Variables

Copepod, Kinorhyncha and Gastrotricha assemblages were negatively correlated with the Salinity in S5 (r respectively -0.94, -0.90 and -0.89); Oligochaeta was negatively correlated with mud fraction and organic matter (r respectively -0.85 and -0.95) (Table 5). A positive correlation with salinity and dissolved oxygen were observed in Turbellaria while free-living nematodes communities show no relationship with the other environmental factors, except with salinity in Shuaiba lagoon, for which an inverse relationship occurs. In addition, no significant differences in total nematode abundances were detected between sites ($P < 0.05$); this can be explained by significantly higher nematode abundances found at the prospected sites, however their abundances were only lower in Salman bay (S1) (Table 2). Results showed also that values for both indices J' and H' were negatively correlated with organic matter (r respectively -0.96 and -0.89) (Table 5).

Through this study, an attempt was made to study the dominant families of free-living nematodes communities. Dominant nematode families were Oncholaimidae, Cyatholaimidae, Xyalidae, Linhomoeidae and chromadoridae represented by several genera of nematodes. In fact, nematode composition in Al Saif bay showed major differences in nematode diversity and community structure compared to the Shuaiba lagoon. In addition, nematode genera were more diverse in Salman bay and Shuaiba Al Qattan compared to Jeddah harbor and Shuaiba lagoon. Furthermore, some genera which occurred in all sites, such as *Oncholaimus*, *Oncholaimellus*, *Terschellingia*, *Trichotheristus* and *Xyala* showed elevated abundances in Shuaiba lagoon.

4. DISCUSSION

The present study indicated that Al Saif bay sediments are dominated by diverse and abundant benthic fauna. High faunal density (485.25 ± 68.56 ind./10cm^2) were recorded in this station and the species evenness (J') and diversity (H') were remarkably high. This means that this ecosystem is dominated by a tolerant species adapted to fluctuating environmental conditions such as tidal changes, temperature, salinity, food and pH. These conditions could promote these species to reproduce very rapidly and to die before attaining large sizes [26,27,28] and [29]. On the contrary, low faunal density (218.50±34.82 ind./10cm^2) accompanied with low faunal evenness and diversity were found in the Shuaiba Lagoon (S5). The difference in meiofauna composition between these sites is attributed to the lower abundance or absence of some meiofaunal groups such as Turbellaria, Kinorhyncha, Gastrotricha, Tardigrada, Acarina, Mollusca and Brachiopoda. This is probably attributed to predominance of a relatively stable environment, so dominant species live longer attaining larger sizes and promoting a faunal diversity. In fact, many authors [30,31] suggested that the intertidal areas are the most stressed environments where a limited number of species can tolerate seasonal variations in their physical and chemical conditions.

These observations suggest also that other environmental factors are strongly associated with the disturbance in meiofauna abundances. Thus, resource availability and quality [32] local biochemical conditions such as oxygen availability [33] organic enrichment associated with a higher silt/clay composition [34] and species interactions such as facilitation or the lack of competition or predation by species from the macrobenthos [35,36] and [37] have a major effect on the ecosystem. Our study suggests also that the lack of interference or competition with the macrofauna and the availability of resources may explain the increased abundances in Al Saif bay. In fact, [38] showed by means of exclusion experiments that, when macrofaunal epifauna was excluded, the abundance of the most common predatory and microalgae-feeding nematodes tended to increase in the surface layers, together with the amount of detritus and pigment concentrations. However, the relatively high meiofaunal abundance at Jeddah harbor can also be explained by the increased availability of high food resources, which is possibly resulting from higher microalgal and cyanobacterial biomass [39].

In general, our results did not confirm the expected positive relationship between sediment grain size and diversity [26,27] and [39], since the communities from the muddy Al Saif bay sediments (23%) were more diverse than those from the other sites. This result support previous observations that other factors that are co-varying with the sediment granulometry such as food and oxygen availability and organic enrichment are also important in structuring meiofauna and nematode communities [28].

5. CONCLUSION

This study illustrates differences in sediment characteristics and associated meiobenthic communities when comparing five adjacent sites. Al Saif bay habitat was characterized by high abundances of meiobenthic communities. However, the hypersaline Shuaiba lagoon contain low abundance benthic meiofauna assemblages. Through this study, a cause-effect relationship between ecological factors and meiofauna populations can be established in detecting the consistent and significant differences in sediment characteristics, and in the structural and functional diversity of these benthic metazoans. Application of functional trait indices combined with taxonomic information may deliver additional ecological information related to the effect of the ecological parameters and thus, to ecosystem biodiversity.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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