Spatial and temporal changes in beach meiofaunal communities of the Ligurian Sea (NW Mediterranean)

Variaciones espaciales y temporales de las comunidades meiofaunales de las playas del Mar Ligure (NW Mediterráneo)

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Abstract.- Abundance and community structure of the intertidal meiofauna were studied in five beaches of the Ligurian Sea (northwestern Mediterranean) in Summer 1994 and Winter 1995 and related to the main environmental variables such as temperature, food availability, hydrodynamic stress and grain size of the sediment. Mean meiofaunal density ranged from 130.7±212.5 ind./10 cm^2 in winter to 230.8±336.6 ind./10 cm^2 in summer. Water temperature, wave action and sediment texture appeared to be the main factors affecting meiofaunal communities while organic matter content appeared to play a minor role, although highest densities were reported from beaches close to the Entella river estuary characterized by large amounts of organic detritus. Meiofaunal community structure in sheltered beaches was characterized by the dominance of nematodes and turbellarians, whereas high-energy beaches showed the dominance of harpacticoid copepods. Meiofaunal density and number of taxa increased with increasing sediment sorting. Meiofaunal community structure displayed clear changes between summer and winter: nematodes were generally the dominant taxon in winter (on average 77.3% of the total meiofaunal density) whilst copepods generally dominated in summer (on average 62.5% of the total meiofaunal density). The results of this study suggest that different parameters might have different roles in meiofaunal characteristics: 1) the very low absolute meiofaunal densities are consistent with the low sedimentary OM content; 2) changes in meiofaunal densities appear characterized by a clear seasonality (related to temperature) and 3) grain size and/or exposure degree might have a preeminent role in affecting community composition and aggregation.

Keywords: Meiofaunal assemblages, beaches, Mediterranean Sea, Italy.

Resumen.- La densidad y la estructura de las comunidades meiofaunales fueron estudiadas en cinco playas del Mar Ligure (Mediterráneo noroeste) durante el verano de 1994 y el invierno de 1995. La densidad de la meiofauna varió, en promedio, entre 130,7 ± 212,5 individuos/10 cm^2 (invierno) y 230,8 ± 336,6 individuos/10 cm^2 (verano). La temperatura, el oleaje y la textura del sedimento influirían en las comunidades meiofaunales. No obstante las más altas densidades hayan sido encontradas en las playas vecinas al estuario del río Entella, caracterizado por la presencia de grandes cantidades de detrito orgánico, el contenido de materia orgánica jugaría un papel menor. La comunidad meiofaunal en las playas protegidas se caracterizó por la dominancia de nemátodos y turbelarios, mientras en las playas expuestas al oleaje se observó un dominio de copépodos harpacticoides. La densidad y la riqueza de taxa crecieron con el aumento del coeficiente de selección del sedimento. La estructura de comunidad de la meiofauna mostró claras diferencias entre verano e invierno: los nemátodos dominaron generalmente durante el invierno (promedio 77,3% de la densidad total) mientras en verano los copépodos dominaron las comunidades estudiadas (promedio 62,5% de la densidad total). Los resultados del presente estudio sugieren que diferentes parámetros tendrían distintos roles en las características de la meiofauna: 1) las bajas densidades absolutas de meiofauna están relacionadas con el bajo contenido de materia orgánica en el sedimento; 2) las variaciones de las densidades parecen caracterizadas por una clara estacionalidad (ligada a la temperatura) y 3) la dimensión de las partículas de sedimento y/o el grado de exposición de las playas jugarían un rol relevante en la composición y agregación de la comunidad.

Palabras clave: Agrupamientos meiofaunales, playas, Mar Mediterráneo, Italia.

Introduction

There is a number of studies on sandy beach fauna, mainly focused on benthic macrofaunal communities inhabiting meso- and megatidal sandy beaches (McLachlan 1983, Brown and McLachlan 1990). Sandy beaches characterize at least 80% of the shoreline along the Mediterranean Sea. But, despite their ecological importance especially in the light of the close interaction with human life, there is a limited information on mesolittoral macrofauna and meiofauna in the Mediterranean (Abbiati *et al.* 1987, Dexter 1989, Hulings 1971a, 1971b, 1974, Villora-Moreno *et al.* 1990, 1991)

The mesolittoral zone in the Mediterranean Sea is characterized by some peculiar environmental features which might have significant ecological implications for beach communities and which can be summarized as: 1) a strong temperature seasonality (ranging from 8-12°C in winter to more than 30°C in summer) and 2) an extremely short tidal range (e.g. 15-25 cm in the Ligurian Sea) so that high water level (HWL), depending on the slope of the beach, covers from a few centimeters to about 1.5 m of the shore.

It is generally recognized that meiofaunal dynamics are controlled by physical factors (temperature, grain size and wave action), food availability and predation. In high-energy environments, such as the meso-infralittoral zone of exposed areas, sediment features may play a predominant role in structuring meiobenthic communities (Hicks & Coull 1983, Heip *et al.* 1985). However, information on beach ecology of microtidal systems, such as the Mediterranean Sea, is practically non existent.

In this paper we report the results of a seasonal study of meiofaunal abundance and community structure at five sandy beaches along the northwestern Mediterranean characterized by different wave exposure. Meiofaunal parameters were related to the main environmental variables such as temperature, food availability, hydrodynamic stress and grain size in order to understand which factors control meiofaunal composition and distribution.

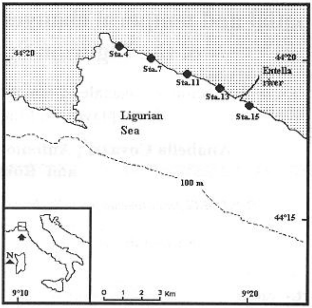

Figure 1

The study area and sampling stations.

Area de estudio y estaciones de muestreo.

Materials and Methods

Study area and sampling

Sediment sampling was carried out at five stations located in the mesolittoral zone of the Gulf of Marconi, Ligurian Sea (Figure 1). All stations (Sta.) look at the south-south west. Stations 4 and 7 were located in coves, exposed to the wave action. Sta. 15 was also exposed to the wave action but located close to the estuary of the river Entella and was characterized, especially in winter, by a large presence of allochthonous (terrestrial) detritus brought from the river. Sta. 11 was located in a semi-sheltered beach. Sta. 13 was located in a sheltered beach protected by an artificial reef. In the study area, water temperature ranged between 26.6°C (August) and 12.2°C (February), whereas salinity ranged from 36.1 (February) to 38.1 (August). Macroalgal covering was absent at all sampling sites. Sta. 7 and particularly Sta. 13 were summertime seaside resorts, Stations 4 and 11 were relatively undisturbed sites accessible only from the seaside. According to the position of the beaches and the geomorphological characteristics of the coast, an exposure degree (ED) to each station has been assigned: Sta. 15 is the most exposed beach to the wave action (ED=****), while Sta. 13 is sheltered (ED=*).

Triplicate meiofaunal samples were collected manually in July 1994 and February 1995, using Plexiglas cores (3.7 cm Φ) down to a depth of 12 cm; some cores penetrated only down to 8 cm. Below this depth, the presence of large stones hampered the collection of deeper sediment layers. Two additional cores were collected, one for the determination of organic matter (OM) content and the other for sediment texture analysis. The cores were taken randomly from a frame (1 m^2) divided into 16 squares of 625 cm^2 and placed in the middle of the line of tidal excursion between LW and HW. The sediment cores were sliced vertically into 3 sections: 0-4, 4-8 and 8-12 cm and immediately fixed with 4% neutralized formalin in 0.4 µm prefiltered sea water, whereas for OM determination, sediment samples were placed in Petri dishes and stored at -20°C.

Meiofauna was extracted by decantation (Heip *et al.* 1985). Sediments were sieved through a 1000 and a 37 µm mesh. All meiobenthic organisms were counted and identified to higher taxa under a stereomicroscope after staining with Rose Bengal (0.5 g l^{-1}). Some fresh samples were extracted and analyzed immediately after sampling in order to identify soft-body meiofauna. Organic matter analyses were performed on 3 sediment layers (0-4, 4-8 and 8-12 cm) on 3 replicates by ignition loss as reported by Fabiano *et al.* (1995). Sediment chlorophyll-*a* concentrations were below detection limit both with photometric and fluorometric methods. Grain size analysis was carried out using sequential sieving (<0.63 µm - 3.35 mm). Median particle diameter (Md) was calculated according to Buchanan & Kain (1971).

Results

Environmental parameters

Data on sediment texture, organic content and degree of exposure in the five sampling sites are reported in Table 1. Sediments were generally characterized by the dominance of gravel (on average 39 %). Median particle diameter (Md) ranged from ≥3.55 mm (i.e. gravel at Sta. 11 in winter and Sta. 15 in summer) to 0.91 mm (i.e. very coarse sand at Sta. 7 in summer). Temporal differences in sediment texture were observed at Sta. 7, which displayed a large increase in the medium sand fraction in summer (Md = 0.91 and 1.33 in summer and winter, respectively). By contrast at Sta. 15, the very coarse sand fraction increased from summer to winter (Md = ≥3.55 and 1.58 in summer and winter, respectively). The opposite was observed at Sta. 13 where gravel fraction increased from summer to winter with the lowering of the coarse sand fraction (Md = 0.99 and 1.15, respectively). The silt fraction was negligible in both sampling periods (on average <0.03 %). Sediments were poorly sorted and the sorting coefficient decreased from summer to winter, from -1.1 to -0.7 on average (in summer and winter respectively).

Organic matter content ranged from 12.2 (Sta. 11, in summer) to 30.6 mg g^{-1} sed. dry weight (Sta. 7, in winter). On average highest organic matter content was observed in winter (21.9 mg g^{-1}) with a slight decline in summer (18.3 mg g^{-1}).

Table 1

Organic content (expressed as mg/g sed. d. w.), median particle diameter (Md) in mm, gravel and silt fractions (expressed in percentage), sorting coefficient and exposure degree at the five stations investigated in summer (S) and winter (W); n.d=not determined. AVG (average), SE (standard error) and CV (coefficient of variation). Degree of exposure (ED) was assigned as follows: ED=** for the most exposed beach to the wave action and ED=* for the most sheltered one.**

Contenido de materia orgánica (en mg/g sed d.w.), mediana del diámetro de las partículas de sedimento (Md) en mm, fracciones de arcilla y limo (en porcentaje), coeficiente de selección del sedimento y grado de exposición de las cinco estaciones estudiadas en verano (S) e invierno (W); n.d=no determinado. AVG (promedio), SE (error estándar) y CV (coeficiente de variación). El grado de exposición (ED) se asignó de la siguiente manera: ED=**** a la playa más expuesta a la acción de las olas y ED=* a la menos expuesta.

		Sta. 4		Sta. 7		Sta. 11		Sta. 13		Sta. 15	
		S	W	S	W	S	W	S	W	S	W
Organic content	0-4 cm	12.4	22.5	29.9	30.6	12.2	17.8	25.7	16.7	23.6	24.9
	4-8 cm	n.d.	17.2	19.1	n.d	n.d	16.7	16.9	n.d	18.1	n.d
	8-12 cm	n.d	n.d	22.3	n.d	n.d	n.d	18.6	n.d	26.6	n.d
	AVG	12.4	19.9	23.8	30.6	12.2	17.3	20.4	16.7	22.8	24.9
	SE	n.d	1.9	2.6	n.d	n.d	0.4	2.2	n.d	2.0	n.d
	CV	n.d	13.4	19.1	n.d	n.d	3.2	18.7	n.d	15.5	n.d
Md		1.88	1.65	0.91	1.33	1.25	≥3.35	0.99	1.15	≥3.35	1.58
Gravel		46.37	35.76	32.61	33.25	29.49	12.25	26.06	82.53	72.57	16.79
Silt		0	0.018	0	0.086	0	0.004	0	0.017	0	0.017
Sorting Coefficient		-1.3	-0.9	-1.4	-1.4	-1.0	-0.5	-0.8	-0.5	-1.1	-0.3
Exposure Degree		***		***		**		*		****	

Meiofaunal abundance and composition

Meiofaunal abundance and composition in the five stations and in the two sampling periods are reported in Table 2. The highest meiofaunal abundance was observed at Sta. 15 in summer (899.5 ± 110 ind/10cm^2) whereas the lowest was reported at Sta. 11 in winter (4.7 ± 1.2 ind/10cm^2). Large temporal changes in meiofaunal density were reported at Sta. 13 where meiofaunal abundance in winter was 13.5 times higher than in summer. However, generally higher densities were reported in summer: at Sta. 11 and 15 meiofaunal abundance was, respectively, 29.5 and 24.1 times higher in summer than in winter.

In summer, copepods were generally dominant (62.5% of the total meiofaunal density, ranging from 12.4 at Sta. 4 to 79.4% at Sta. 11), followed by turbellarians (22.1%) and nematodes (10.4%). Sta. 4 was characterized, in summer, by the presence of juveniles of the polychaete *Protodrilus* sp. Accounted for 100% of the polychaetes. By contrast, nematodes were generally the dominant taxon in winter (77.3% of the total meiofaunal density, ranging from 24.7 at Sta. 4 to 95.7% at Sta.15) followed by harpacticoid copepods (16.2%) and turbellarians (4.8%). Temporal changes were also observed in terms of number of taxa: 9 taxa were observed in summer whereas only 6 were encountered in winter. Bivalves, oligochaetes, gastrotrichs and amphipods were observed only in summer (accounting together for less than 3% of the total meiofaunal density). By contrast kinorhynchs (0.1% of the total meiofaunal density) were found only in winter.

Meiofaunal vertical distribution displayed clear temporal changes: in summer 58.3% of the total meiofaunal density was concentrated in the top 4 cm, whereas in winter 94.6% of the total meiofaunal density was observed in the top 4 cm. Such pattern was observed at most stations (Figure 2).

Discussion

As expected, meiofaunal densities reported in this study are comparable to those reported in other beach studies (Table 3) but significantly lower than those reported in subtidal sediments. In fact, meiofaunal densities from beaches of the Marconi Gulf were 15 to 10 times lower (in summer and winter, respectively) than densities reported at 10 m depth (Danovaro *et al.* 1994).

Table 2

Meiofaunal abundance (ind/10 cm^2 ± standard deviation) and composition in the stations sampled during summer and winter.

Densidad (ind/10 cm^2 ± desviación estándar) y composición de la meiofauna en las estaciones de muestreo en verano e invierno.

Groups	St 4 Summer	St 4 Winter	St 7 Summer	St 7 Winter	St 11 Summer	St 11 Winter	St 13 Summer	St 13 Winter	St 15 Summer	St 15 Winter
Nematodes	0 ± 0	6.0 ± 1.4	8.0 ± 1.0	10.0 ± 7.1	15.5 ± 3.5	3.7 ± 1.7	17.5 ± 3.5	449.7 ± 57.5	79.5 ± 10.5	35.7 ± 9.5
Copepods	2.0 ± 1.0	6.0 ± 4.9	25.5 ± 4.5	0.3 ± 0.5	108.0 ± 69	0 ± 0	9.5 ± 3.5	91.7 ± 66.8	561.5 ± 153.0	0.3 ± 0.5
Nauplia	2.0 ± 0	1.0 ± 0.8	2.5 ± 1.5	0 ± 0	2.0 ± 0	0.7 ± 0.5	4.5 ± 3.5	5.7 ± 4.9	4.0 ± 1.0	0 ± 0
Polychaetes	10.2 ± 7.4	0.7 ± 0.5	0 ± 0	0.3 ± 0.5	12.0 ± 11	0 ± 0	0 ± 0	2.3 ± 1.2	1.0 ± 0	0 ± 0
Bivalves	1.0 ± 0	0 ± 0	2.0 ± 1	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	1.0 ± 0	0 ± 0
Ostracods	4.5 ± 1.5	5.3 ± 5.0	0 ± 0	0.7 ± 0.9	0 ± 0	0.3 ± 0.5	0 ± 0	1.0 ± 0.8	0 ± 0	0 ± 0
Kinorynchs	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0.7 ± 0.5	0 ± 0	0 ± 0
Turbellarians	1.5 ± 0.5	5.3 ± 6.1	3.0 ± 0	20.7 ± 9.0	1.0 ± 0	0 ± 0	6.5 ± 2.5	4.0 ± 2.2	243.5 ± 25.5	1.3 ± 1.2
Oligochaetes	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	7.0 ± 6	0 ± 0
Gastrotrichs	0 ± 0	0 ± 0	1.5 ± 0.5	0 ± 0	0 ± 0	0 ± 0	2.0 ± 0	0 ± 0	2.0 ± 0	0 ± 0
Amphipods	11.0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	1.0 ± 0	0 ± 0	0 ± 0	0 ± 0
Others	0.3 ± 0.1	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Total	25.5 ± 10.5	24.3 ± 12.7	42.5 ± 1.0	32.0 ± 15.9	138.5 ± 53.0	4.7 ± 1.2	41.0 ± 2.5	555.1 ± 22.9	899.5 ± 110.0	37.3 ± 11.1

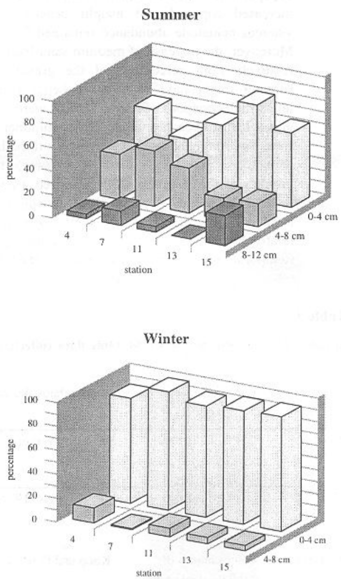

Figure 2

Summer and winter meiofaunal vertical distribution (expressed as percentage).

Distribución vertical de la meiofauna (en porcentaje) en verano e invierno.

Two explanations may be proposed for such low-density values: the oligotrophy of the system, stressed by the absence of primary organic matter (as chloropigments), and the hydrodynamic stress of the surf zone. As far as food availability to consumers is concerned, organic matter content in sandy beach sediments, utilized as a gross measure of the potential available food in the study area, was similar to other beach sites but lower than those reported for subtidal sediments (Fabiano *et al.* 1995). The main exception is represented by Sta. 15, close to the Entella estuary, that received relatively high inputs of organic matter (as allochthonous detritus brought by the river) and displayed the highest meiofaunal densities. However, in all other stations the lack of significant temporal changes in OM content suggests that the large temporal changes in meiofaunal densities and community structure were not dependent upon food availability. Other studies in the same area failed to identify relationships between meiofaunal densities and total organic matter content (Danovaro *et al.* 1994). To this regard, total organic matter concentrations determined by ignition loss do not measure the fraction actually bioavailable to consumers (Fabiano *et al.* 1995), and it is possible that temporal changes in meiofaunal density are more dependent upon changes in the concentration of phytodetritus and other labile organic compounds (Danovaro 1996). The coarse sediment texture did not allow to quantify the labile OM content. However, the undetectable levels of chlorophyll-*a* suggest that the amount of actually available food did not change between sampling periods, and it is likely that this factor did not play a significant role in controlling meiofaunal dynamics in the studied beach environments.

Hydrodynamic stress appeared to play an important role in controlling spatial patterns of meiofaunal density and community structure. In the Mediterranean, the mesolittoral zone is considered a stable environment when compared to other areas characterized by wider tidal excursions. In this study, Stas 4 and 7 were characterized by high values of exposure degree (as a measure of the hydrodynamic stress) and displayed the lowest meiofaunal densities. This result is in agreement with McLachlan & Turner (1994) that in sheltered microtidal beach systems reported wave action playing a major role on sediments texture, interstitial circulation and sediment oxygenation. These physically controlled systems also support an interstitial fauna adapted to a strong hydrodynamic stress.

In this study, at all stations except at Sta. 13, highest densities were reported in summer. This seasonal pattern is in accordance with those found in most of the beach studies in Mediterranean (see Soyer 1985), although Villora-Moreno *et al.* (1991), in the sandy beaches of the Gulf of Valencia (Spain), reported higher densities in winter. Similar seasonal patterns were also reported in the subtidal sites of the Gulf of Marconi (Danovaro 1993) facing the beaches investigated in the present study, with meiofaunal summer densities, on average, about twice those in winter. Higher summer densities are generally expected, as higher temperatures determine an increase in meiofaunal metabolism and reproduction.

The overall meiofaunal community structure reported for the Marconi Gulf beaches showed the typical composition described for other sandy beaches (Giere 1993, Orth *et al.* 1991, Szymelfenig *et al.* 1995), with nematodes accounting, on annual average, for 43.9% of the total density followed by copepods (39.4%) and turbellarians (13.5%). Temporal changes in meiofaunal community structure were characterized by the shift in dominance from nematodes in winter to copepods in summer. Such changes are due to the increased copepod and nauplii density in summer, whereas nematode abundance remained fairly constant. Moreover, the increase of medium sand fraction and the relatively high percentage of the gravel fraction in summer might have provided a better condition for interstitial copepods. Similar results were reported in gravel Iceland beaches where, during summer, copepods were the dominant taxon followed by turbellarians and nematodes ('Olafsson 1991). However, the sandy beaches of the Valencia Gulf displayed a considerably different community composition during summer, as nematodes were the most represented taxon followed by relatively high densities of juvenile polychaetes (temporary meiofauna, Villora-Moreno *et al.* 1991).

Table 3

Comparison between meiofaunal abundances from different sandy beaches around the world. Only data collected from mid tide levels are considered.

Datos comparativos de densidad meiofaunal en diferentes playas arenosas. Fueron considerados solamente datos del nivel mareal medio.

Location	Sampling depth (cm)	Sediment texture	Abundance ind/10 cm^2	Sampling method	Authors
Whitsand Bay East Cornwall	50	Medium sand	220-1890	Hand coring	Harris (1972)
Cape Peninsula (South Africa)	30	Fine sand	5.4-1140.6*	Subsamples of stainless steel corer (200 ml sand)	Koop and Griffiths (1982)
North-eastern coast of Australia	5	Sand	66-1672	Hand coring	Alongi (1987)
Gulf of Valencia		Sand	14.4-1076.4*	Hand coring (30 ml of sed)	Villora-Moreno *et al.* (1991)
Iceland	100	Gravel	91-869	Hand coring	'Olafsson (1991)
Svalbard (Norway)	5	Gravel	4-905 (on average)	Hand coring	Szymelfenig *et al.* (1995)
Gulf of Marconi	12	Gravel	5-900	Hand coring	Present study

* Values transformed from ind./volume to ind/10 cm^2

* Valores transformados de ind./volumen a ind/10 cm^2

As an additional point we noted high densities of *Protodrilus* sp. at Sta. 4. Jouin (1970) suggested that the small size allows this genus to inhabit the interstices present in sediments with a significant fraction of medium sand, but our results suggest that it is adapted to live also in coarser, well sorted sediments.

According to the general patterns of meiofaunal spatial distribution (Gray 1971, Gray and Rieger 1971, Giere 1993), the sandy beach meiofauna of the Ligurian Sea generally showed a slightly aggregated distribution and was mostly concentrated in the top cm of sediments. Meiofaunal concentration in surface sediments was higher in winter than in summer. Similar vertical patterns were reported by Gray and Rieger (1971), who found most of the meiofauna (84%) concentrated in the top 5 cm of the sediments. By contrast, in the beaches of the Cornwall Bay (Harris 1972) in winter and in the Iceland beaches in summer ('Olaffson 1991) highest meiofaunal densities were reported in the 5-10-cm sediment layer.

The results of this study point out that in unsheltered and/or river impacted beaches the structure of the meiofaunal community may be strongly affected by hydrodynamic stress. In agreement with Villora-Moreno *et al.* (1991) the sheltered beaches, characterized by less wave energy and a small grain size favor the dominance of nematodes and turbellarians (such as at Sta. 13). By contrast, according to Brown & McLachlan (1990) beaches characterized by much higher wave energy and/or a large grain size (e.g. Stas. 7 and 11) or close to the river outflow (Sta. 15) showed the dominance of harpacticoid copepods.

Despite the large geographical, environmental and sediment characteristics, the beach meiofaunal densities of the Ligurian Sea were very similar to those reported for the other beaches at high latitudes such as in Iceland and in the Svalbard islands (Table 4) which displayed very similar grain-size and sediment characteristics. The results of this study suggest that different parameters might have different roles in meiofaunal characteristics: 1) the very low absolute meiofaunal densities are consistent with the low sedimentary OM content; 2) changes in meiofaunal densities appear characterized by a clear seasonality (related to temperature) and 3) grain size and/or exposure degree might have a preeminent role in affecting community composition and aggregation.

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