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MEIO EXTREME

Meiofaunal assemblages of the bay of Nisida and the environmental status of the Phlegraean area (Naples, Southern Italy)

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Abstract Nisida is an islet of volcanic origin of the Phlegraean archipelago (Southern Italy) that has been included in the General Reserve of the Regional Park of Phlegraean Islands. The islet has been inaccessible both by land and by sea for a long time and, thus, has maintained its naturalistic value almost unchanged, in contrast with the close Bagnoli area, in which a steel industry has been active for several decades. An investigation was carried out in 2014–2015 at the bay of Nisida (Porto Paone). The main aims of our study were to document the structure of the meiofaunal assemblage, to identify the environmental factors that lead to its spatial and temporal variations, and to evaluate the ecological quality of this area, so bridging a gap in the scientific knowledge of Porto Paone. According to the diverse substrate typology and hydrodynamic regime, four stations were established to evaluate the meiofaunal assemblage over a period of one year. A high number of meiofaunal taxa (21) and a high biodiversity of meiofauna were recorded: the total meiofaunal density was higher in the eastern sector of the bay, where the effects of currents increase the abundance of temporary meiofauna in the sediment by increasing the supply of planktonic larvae of macrofauna (i.e., annelids, molluscs). PERMANOVA revealed significant differences of the assemblage structures at both the temporal and spatial scales. Summer conditions appeared to favor an increase of several taxa, which may be related to both an enhancement of the trophic sources, in turn promoting more trophic lifestyles, and to the biological cycles of individual taxa. Among the environmental variables, sediment variations, temperature, and chlorophyll-a (Chl-a) concentration appeared to be important in influencing the meiofaunal distribution. The results suggest that Porto Paone is characterized by a great richness (21 vs. 8 total taxa), especially if compared with the close, highly impacted area of Bagnoli. According to the current classification of environmental quality based on the meiofaunal richness, Porto Paone may be classified with a high ecological quality.

Keywords Meiofaunal biodiversity · Seasonality · Ecological status · Bay of Nisida · Phlaegraean area

Introduction

Marine ecosystems provide great benefits to society, especially in the coastal areas, but are affected by multiple stressors, ranging from direct impact of human activities to climate changes (Gollner et al. 2010; Zeppilli et al. 2015). Semi-closed coastal systems, such as lagoons, estuaries, and bays, are more vulnerable to the stress impacts. Within benthic assemblages, meiofauna represent a link between the primary production of microalgae and higher trophic levels, serving as a food source for macrofauna and juveniles of fish species (Cibic et al. 2009; Schratzberger and Ingels 2017). This benthic group is one of the most abundant in marine sediments, contributing significantly to marine biodiversity and ecosystem functioning (e.g., Leduc et al. 2013; Baldrighi et al. 2013, 2017; Moens et al. 2013; Pusceddu et al. 2014; Zeppilli et al. 2015). Meiofauna have been increasingly used as a

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bioindicator of environmental quality and represent a promising alternative to other commonly used indicators (Vanaverbeke et al. 2011; Semprucci et al. 2015a), although they are not commonly considered by policy makers and stakeholders (Balsamo et al. 2010; Semprucci et al. 2015b), presumably due to their small size.

Nisida is an islet of volcanic origin in the archipelago of the Phlegraean Islands (Southern Italy) and was inaccessible for a long time. Historically, in the 1800s, Nisida was the site of a Bourbon prison, then of an Italian state penitentiary, and, now, of a reformatory. Since then, access to the island has been restricted and the area is well preserved. For these reasons, and for the need to preserve as best as possible the integrity of Nisida island, its bay, Porto Paone, was included in the Zone B (General Reserve) of the Regional Park of Phlegraean Islands. To date, no faunistic studies on the bay are available; thus, particular attention needs to be paid to the study of its fauna. Thus, a preliminary qualitative survey of the macrobenthic assemblages of the seabed of the bay was carried out in 2012 (Campoli 2016). This survey revealed a well conserved biota with the presence of *Posidonia oceanica* patches alternate to rocky and gravel bottom (Fig. 1). Among the macrofaunal species, *Pinna nobilis* was found, a species listed in Annex II of the Directive of the Council of the European Communities 92/43/EEC. Despite the proximity of this area to the Bagnoli steel industry, the presence of species of community interest revealed by the preliminary survey and the exceptional opportunity to have authorized access to the bay led us to focus on the meiofaunal assemblage, due to its important role in environmental biomonitoring. Accordingly, an investigation was carried out on the meiofaunal composition and biodiversity from 2014 to 2015 covering the whole bay of Nisida, Porto Paone, for the first time. The aims of this survey were to describe the possible spatial variations and temporal fluctuations on meiofauna in an area that has been completely unexplored. To do this, sediment samples were taken at four stations during three different periods in order to (1) describe spatial and temporal variation in meiofaunal communities in relation to the different typologies of habitats selected and temporal fluctuations and (2) evaluate the ecological quality of this area by means of the meiofaunal assemblage.

Materials and methods

Study area

The study area was Porto Paone (40°47′40.30″N; 14° 9′40.22″ E), a flooded crater forming the bay of Nisida, a volcanic islet of the archipelago of Phlegraean Islands connected to the mainland by a stone bridge. It lies very close to Cape Posillipo, just north of Naples, and it is the southern side of Pozzuoli Bay. Volcanic eruptions created this islet around 8000–10,000 years ago (Lirer 1965; Colantoni et al. 1972), resulting in a structure with a circular shape and the flooded crater of Porto Paone. The sea cliffs show the internal structure of the cone to be a pumice tuff indurated by violent mixture with seawater at the time of its eruption and covered with loose arenaceous bed of the same fragmentary matter (Scrope 1872). The whole islet area is about 30 ha wide within a circumference of 2 km, with the highest point at 109 m above sea level. The base of the volcano, at the maximum depth of 17 m, has a diameter of about 1500 m and does not include the nearby islet of Lazzaretto, which is now an integral part of the bridge connecting Nisida to the mainland (Fig. 2).

Historically, Nisida was the site of a Bourbon prison and a reformatory. Since then, access to the island has been

Fig. 1 Typologies of habitats found in the Nisida bay (Porto Paone, Naples): **a** *Posidonia oceanica* meadows; **b**, **c** hard and soft bottoms; **d** *Posidonia oceanica* meadows and *Pinna nobilis*
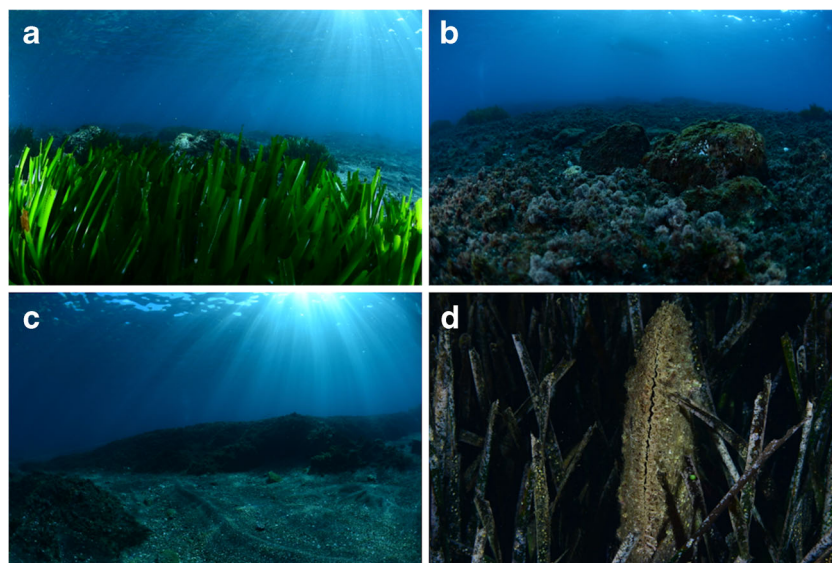
Fig. 2 **a** Study area, bay of Nisida (Porto Paone, Naples); **b** location of the four stations
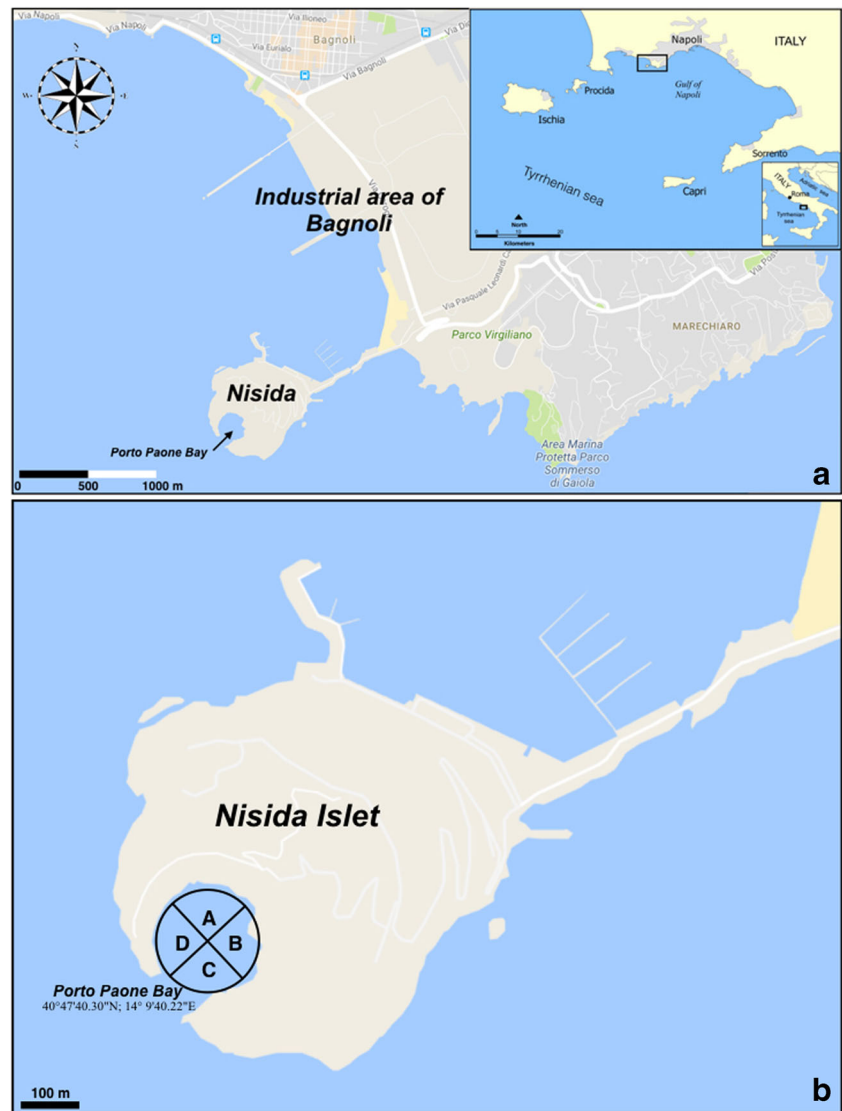
restricted and the area is well preserved. The only source of disturbance for Nisida was the steel industry of Bagnoli (40°48′16.86″N; 14°10′21.69″E) that was active from 1900 to 1992, and released industrial pollutants have yet to be completely removed. However, Nisida islet currently falls in the Zone B of the Regional Park of Phlegraean Fields that was established in 2003 and covers about 2775 ha.

Porto Paone is connected to the Gulf of Naples by a mouth ~70 m wide and ~9 m deep, with its axis directed SW. Inside the bay, the water depth ranges from 0 to 9 m, while outside, it reaches 17 m at the base of the islet. The data available on the sea currents are reported in Fig. 3. It might be expected that the tides, despite the relatively low excursion tide of the Mediterranean Sea (a few decimeters), plays a role in the periodic flushing of Porto Paone. Considering the orientation of the mouth of Porto Paone, it should experience a larger flushing when the circulation in the NE sector of the gulf is anticyclonic, which generally occurs when NW winds are

blowing (Cianelli et al. 2011, 2015; Uttieri et al. 2011). SW winds force a cyclonic circulation which should preclude a strong flushing. During summer months, when a wind breeze regime dominates, there is an alternation of cyclonic and anticyclonic circulations, which should likely set the optimal conditions for a periodic flushing of Porto Paone.

Sampling strategy and processing

Sampling for the meiofaunal analysis was performed at Porto Paone in three different periods: December 2014 and June and November 2015 that, hereafter, are identified as D14, J14, and N15, respectively. The sampling periods were selected according to Semprucci et al. (2010a) and were the periods that seem to greatly affect the fluctuation of meiofauna assemblage. The study area was divided in four quadrants (NW, NE, SE, SW), in which four sampling stations were set up based on diverse substrate typology, habitat, and current exposition in

Fig. 3 Regime of the main water currents in the bay of Nisida (Porto Paone, Naples)
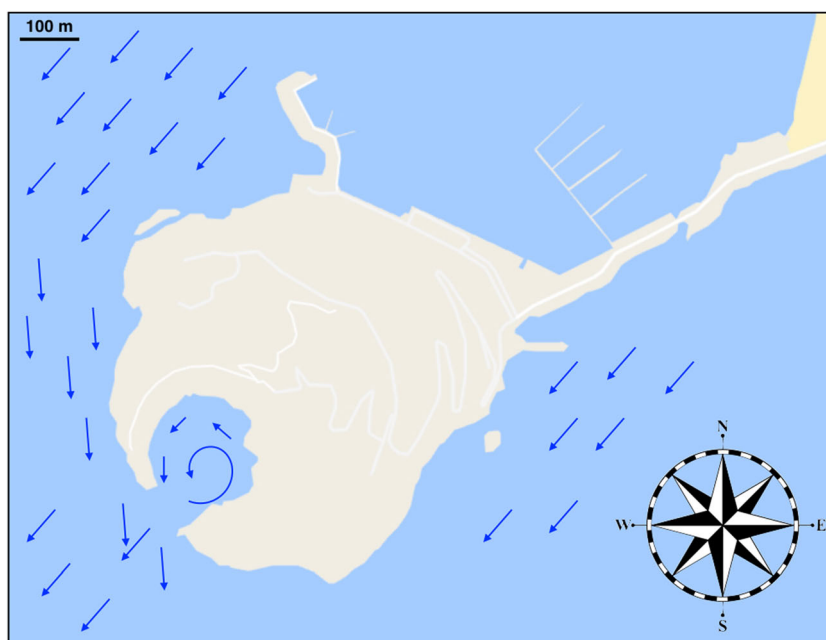
the bay (Figs.1 and 3). St. A was characterized by a seagrass of *Posidonia oceanica*, generally surrounded by coarse sands and sheltered from water currents; St. B was a hard bottom with patches of medium sand and medium level of exposition to currents; St. C was a soft bottom mainly characterized by medium-coarse sands and a high level of hydrodynamism; St. D was a seagrass bed of *Posidonia oceanica*, mainly surrounded by medium-coarse sand, and with a higher level of hydrodynamic conditions. The latter station hosts relevant populations of macrofauna such as *Pinna nobilis* (Fig. 1).

Samples for the quantitative analysis of the meiofauna were collected by a scuba diver using a plexiglass corer tube (diameter 3 cm) driven to a depth of 6 cm and collected randomly in triplicate. A fourth sample was collected at each station for the sedimentological analysis. Samples destined for meiofaunal analysis were treated with a 7% magnesium chloride aqueous solution for narcotizing fauna, then fixed with a 4% formaldehyde solution in buffered seawater, stained with rose bengal, and stored for subsequent processing in the laboratory.

Meiofaunal analysis

Meiofauna were obtained by sieving the samples through 500-42 μm mesh nets and the retained animals were extracted by flotation and multiple decantations, followed by three centrifugations through a silica gel gradient (LUDOX HS-30, density 1.18 g/cm^3) (Heip et al. 1985). Specimens were then sorted by major taxa under a stereomicroscope (Leica MZ6) and counted. When necessary, temporary slides were performed to improve the level of identification of the specimens under a transmitted light optical microscope (Nikon Eclipse E400).

Environmental analyses

At each sampling station, a number of physicochemical parameters of the bottom water [temperature, salinity, pH, and chlorophyll-a (Chl-*a*) content and fluorescence] were measured using a multiparametric probe (Hydrolab DS5). Sediment samples were processed twice, with a hydrogen peroxide solution (30%) and distilled water in the proportion 1:4 for 48 h at room temperature, then washed twice with fresh water in order to remove the salts. After the initial pre-treatment, samples were separated into three size fractions using a decreasing sequence of sieves (mesh of 2 mm and 0.063 mm). Then, the fractions were dried at 60 °C for 6 h and weighed on a Mettler AE50 microbalance (accuracy 0.1 mg) to obtain the dry weight. Grain size analysis was performed according to the Wentworth scale to provide a granulometric characterization of the samples (Krumbein 1934; Folk and Ward 1957; Buchanan 1984).

Statistical analysis

The indices of diversity (H′, Shannon and Weaver 1949) and evenness (J, Pielou 1969) were calculated as $\log_2$ in order to describe the meiofaunal biodiversity of the study area. A data matrix was created from the major faunal groups detected during the present survey. Non-metric multidimensional scaling (nMDS) ordinations derived from Bray–Curtis similarity matrices (fourth-root transformed) were used to view the spatial and temporal variations of the meiofaunal structure (Frontalini et al. 2011). The formal significance of the differences in the meiofaunal taxonomic composition, richness, abundances, and diversity indices (Shannon and Pielou) were

tested using multivariate analysis of variance based on permutations [two-way crossed PERMANOVA, station × period (Anderson 2001)]. A similarity percentage test (SIMPER, cut-off 90%) was performed in order to verify the contribution of each taxon to the dissimilarity (Clarke 1993). All these analyses were performed with the PRIMER v5 software (Clarke and Gorley 2001; Clarke and Warwick 2001) or R statistical software (R Development Core Team 2011).

In order to detect possible relationships between biotic and abiotic variables and the trends of the main abiotic variables, a principal component analysis (PCA) was carried out on the more relevant environmental and faunistic data. Prior to statistical analysis, an additive logarithmic transformation log $(1 + x)$ was performed to remove the effects of difference in magnitude order between variables, to normalize the data, and to increase the importance of smaller values, such as the mid-range species (for a review, see Coccioni et al. 2009). In particular, the relative abundances of the most represented meiofaunal components (Nematoda, adults and juveniles of Copepoda and Polychaeta), the total faunal abundance, richness, equitability (J), and diversity (H′) were projected on the factor-plane as additional variables without contributing to the results of the analysis (Semprucci et al. 2010a). This can provide an insight into the possible influence of the environmental variables (temperature, Chl-a, sand, mud) upon each meiofaunal group (STATISTICA v8 computer program).

Results

Environmental variables

The physico-chemical parameters of the study area are summarized in Table 1. The temperature ranged between 13 °C in D14 and 25 °C in J15, while salinity varied from 37.5 ‰ (J15) to 37.9 ‰ (N15). The pH was alkaline, ranging from 8.13 (J15) to 8.4 (N15). Chl-a ranged from 0.24 µg^{-1} (J15) to 2.97 µg^{-1} (N15). Sediments showed a general prevalence of the sand fraction, followed by gravel and mud. The highest value of gravel was found at the St. A in N15 (81%), the lowest at St. B in D14 (7%). Sand revealed the highest percentages at St. B in D14 (92%) and the lowest at St. A in N15 (19%). Mud fraction was absent in several stations, especially in D14 (St. A, St. C, St. D in D14 and St. A in J15), while the highest values were found at St. B in N15 (8%).

Faunal variables

Most of the studied samples contained a high number of meiofaunal taxa, with a total of 21 faunal groups identified (Table 2). The meiofauna assemblage was largely dominated by infaunal taxa, such as Nematoda and Polychaeta, which, overall, represented 54% of the total assemblage, followed by Copepoda (23%) (Fig. 4).

The structure of the meiofaunal assemblages showed a significant and major dissimilarity in the comparison of periods, while a lower spatial variation was found. However, significant differences were revealed also in the period × station interaction (PERMANOVA results, Table 3). The taxa that mainly contributed to distinguishing the summer period were representatives of both temporary and permanent meiofauna (Gnathostomulida, Nematoda, Gastropoda, Copepoda, Gastrotricha, Polychaeta, Ostracoda, Platyhelminthes, SIMPER, cut-off 90%). Significant differences were detected between the stations specified in Table 3. In particular, the discrimination of St. D was mainly due to the higher abundance of Gastropoda and Polychaeta (SIMPER, 90%).

Among the univariate faunal parameters (namely, richness, density, and Pielou's evenness and Shannon indices) (Fig. 5), PERMANOVA detected significant differences only in the total meiofaunal abundance in all the factors analyzed, but not in their interaction (Table 3). The higher abundances were found

Table 1 Environmental variables collected in the study area (D14 = December 2014, J14 = July 2014, N15 = November 2015)

Samples	Depth	Temperature	Salinity	Ph	Chl-a	Gravel	Sand	Mud
St. A D14	3.50	13.00	38.00	8.20	0.74	32.83	67.17	0.00
St. B D14	6.00	13.00	38.00	8.20	0.74	6.71	92.06	1.23
St. C D14	8.00	13.00	38.00	8.20	0.74	39.16	60.84	0.00
St. D D14	3.25	13.00	38.00	8.20	0.74	49.53	50.47	0.00
St. A J15	3.50	25.00	37.50	8.13	0.24	51.80	48.20	0.00
St. B J15	6.00	25.00	37.50	8.13	0.24	13.77	81.75	4.48
St. C J15	8.00	25.00	37.50	8.13	0.24	11.14	84.22	4.64
St. D J15	3.25	25.00	37.50	8.13	0.24	20.53	78.75	0.72
St. A N15	3.50	19.00	37.90	8.40	2.97	80.50	19.03	0.48
St. B N15	6.00	19.00	37.90	8.40	2.97	28.72	63.00	8.29
St. C N15	8.00	19.00	37.90	8.40	2.97	37.87	62.01	0.13
St. D N15	3.25	19.00	37.90	8.40	2.97	20.08	72.87	7.04

Table 2 Faunal variables collected in the study area (D14 = December 2014, J14 = July 2014, N15 = November 2015)

Taxa	D14 St. A	D14 St. B	D14 St. C	D14 St. D	J15 St. A	J15 St. B	J15 St. C	J15 St. D	N15 St. A	N15 St. B	N15 St. C	N15 St. D
Cnidaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	1.3	1.3
Platyhelminthes	1.7	18.7	5.3	18.0	4.3	22.7	30.3	4.3	20.3	19.3	5.0	13.0
Gnathostomulida	0.0	1.7	0.0	0.0	8.3	16.7	29.3	4.7	3.7	4.0	4.3	13.7
Nematoda	47.0	82.7	127.3	48.0	153.0	164.0	328.3	29.7	13.3	23.0	74.7	79.7
Gastrotricha	1.7	1.0	16.3	0.7	4.0	14.0	19.7	4.7	31.0	1.0	2.7	2.0
Kinorhyncha	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Loricifera	0.0	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Priapulida	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polychaeta	4.7	12.7	13.7	12.0	45.7	41.7	106.0	15.3	29.7	19.7	27.7	94.0
Archianellida	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
Oligochaeta	2.0	0.7	1.0	2.7	1.7	0.0	2.3	0.7	2.3	11.3	3.0	4.3
Brachiopoda	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Gasteropoda	2.3	5.0	11.0	4.0	2.0	2.7	4.3	82.3	4.7	2.3	0.0	1.3
Pycnogonida	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Halacaroidea	0.0	0.0	2.3	0.0	0.3	0.7	1.0	1.0	1.0	0.0	0.3	0.0
Ostracoda	6.3	3.7	14.0	3.7	6.3	11.7	10.0	3.0	0.0	3.7	1.7	3.3
Copepoda	5.0	20.0	41.3	15.0	73.0	109.7	162.7	13.0	7.3	7.0	26.7	39.3
Nauplii	1.0	26.0	35.7	11.0	10.0	30.7	28.0	2.3	2.7	1.3	9.7	9.3
Isopoda	2.3	0.7	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.7	2.3
Amphipoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	1.0	0.7
Chaetognatha	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

in J15 especially if compared with N15 and D14, while St. A and St. D showed lower values than St. C. The other faunal parameters considered did not show significant differences (PERMANOVA, $p > 0.05$). However, richness (number of meiofaunal taxa) generally showed comparable values between the various stations and periods sampled, revealing higher values at St. C (Fig. 5). The Pielou evenness index documented an overall good repartition of the faunal groups, with a higher dominance in J15 and a good evenness especially at St. B and St. D. The comparatively lower biodiversity in J15

was also revealed by Shannon's index, which showed the lowest values at St. A, followed by St. D, St. C, and St. B (Fig. 5).

PCA was used to evaluate possible variations of the meiofauna in relation to the environmental parameters collected from Porto Paone (Fig. 5). The first two components (PC1 and PC2) of the factor plane accounted for a total of 73% of the variance. PC1 explained 41% of the variance and was primarily affected by sediment variables, such as sand ($- 0.75$), mud ($- 0.69$), and temperature ($- 0.63$), while PC2 explained 32% of the variance and was mainly affected by

Fig. 4 Composition of the most abundant meiofaunal taxa (i.e., Nematoda, Polychaeta, Copepoda, and the collective category Others) recorded during the present study
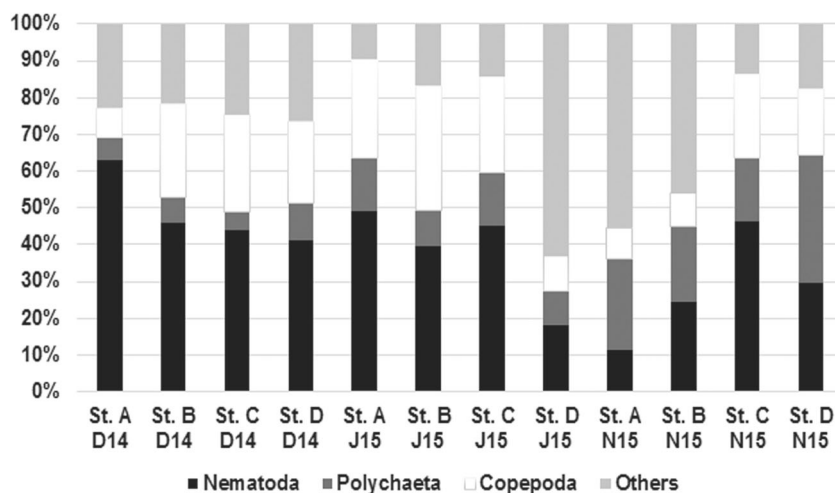
Table 3 PERMANOVA for meiofaunal descriptors (dF = degrees of freedom, MS = mean square

	Factors	dF	MS	Pseudo-F	*p*-Value
Meiofaunal structure of community	Period	2	1.1473	5.3370	***
	Station	3	1.0359	3.2128	***
	Period × station	6	1.8145	2.8137	***
	Residual	24	2.5796		
Richness	Period	2	0.00527	0.1546	n.s.
	Station	3	0.13017	2.5452	n.s.
	Period × station	6	0.07126	0.6967	n.s.
	Residual	24	0.40914		
Abundance	Period	2	0.67437	4.2868	**
	Station	3	0.71574	3.0332	*
	Period × station	6	0.88195	1.8688	n.s.
	Residual	24	1.88776		
Pielou	Period	2	0.014250	1.5496	n.s.
	Station	3	0.018851	1.3666	n.s.
	Period × station	6	0.041796	1.5150	n.s.
	Residual	24	0.110351		
Shannon	Period	2	0.013612	0.8014	n.s.
	Station	3	0.046428	1.8224	n.s.
	Period × station	6	0.066627	1.3076	n.s.
	Residual	24	0.203811		

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; n.s. = not significant
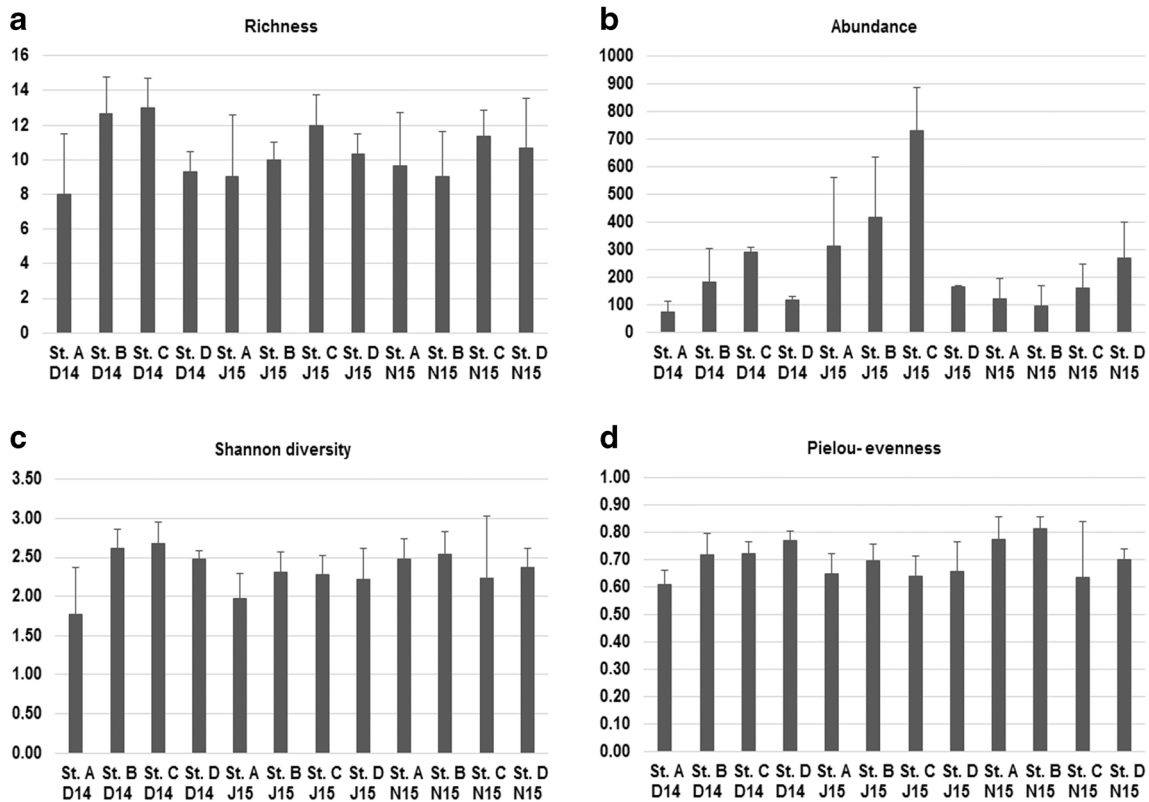
Fig. 5 Trends of richness, total abundance, Shannon diversity, and Pielou evenness of meiofauna recorded during the present study

Chl-a (− 0.81) (Fig. 6a). As for the contribution to the PCA, total meiofauna (− 0.64), Nematoda (− 0.56), and Copepoda (− 0.54) were the main benthic variables along the PC1 axis, while Polychaeta (− 0.50) and J index (− 0.46) were the most relevant factors in PC2. Figure 6b shows that especially St. B and St. D and even the other stations in J15 were in association with PC1 and, thus, with the highest deposition of sand. Instead, the PC2 axis shows that all the stations sampled during N15 were characterized by a peak of Chl-a.

Discussion

As expected, the meiofaunal assemblage revealed by this study was very rich, with a total of 21 identified taxa that included both permanent and temporary meiofauna. The richness was high especially if compared to Tyrrhenian coasts or even to some habitats with a semi-closed nature and Italian Marine Protected Areas (e.g., 8 taxa in Colangelo et al. 2001; 14 and 15 in Sandulli et al. 2004, 2010; max. 8 in Pusceddu et al. 2007; 18 in Cibic et al. 2009; 18 in Frontalini et al. 2014; 12 in Semprucci et al. 2016).

Meiofauna resulted in being mainly dominated by infaunal taxa such as Nematoda and Polychaeta, as reported in other studies (e.g., Cibic et al. 2009; Frontalini et al. 2011; Semprucci et al. 2013, 2015c). Among them, Nematoda are typically permanent fauna, while many Polychaeta pass only a juvenile phase in the meiobenthic compartment (i.e., Hesionidae, Syllidae, and Capitellidae) (Giere 2009).

When the structure of the entire meiofaunal assemblage is considered, a higher dissimilarity can be found in temporal than in spatial comparison (PERMANOVA results). In particular, summer was the period that distinguished the structure of the meiofaunal assemblage in the temporal scale due to an enhancement of the total density of meiofauna and, in particular, of the following taxa: Gnathostomulida, Nematoda, Gastropoda, Copepoda, Gastrotricha, Polychaeta, Ostracoda, and Platyhelminthes (SIMPER results). Also, the total meiofaunal abundance increase was documented by PERMANOVA and may be related to a greater bacterial growth in the summer period that, along with the microphytobenthos, could provide a rich nutritive source for all the meiofaunal grazers and deposit feeders in this period (e.g., Nematoda, Polychaeta) (Giere 2009). On the other hand, the enhancement of these meiofaunal trophic groups may favor the presence of predators (e.g., Gnathostomulida, Platyhelminthes, some Polychaeta and Crustacea species) that, at the same time, increased their abundance in this period.

An additional explanation of the significant increase of the meiofaunal abundance may be related to their biological cycles that have a peak with the higher temperatures of the summer. In this respect, the recruitment of the macrofauna may also have a relevance leading to a temporary change also of the assemblage structure until the end of the juvenile stage (Semprucci et al. 2013).

When the spatial comparison is considered, St. D was the most dissimilar area, mainly due to the presence of two typical taxa of the temporary meiofauna, Gastropoda and Polychaeta (SIMPER results). This station was, in fact, located in the seagrass of *Posidonia oceanica*, the richest area in macrofauna (Campoli 2016). An interesting point highlighted by the PERMANOVA results was the significantly lower abundance of meiofauna in the stations with *Posidonia oceanica* (St. A and St. D), which could suggest a competitive pressure
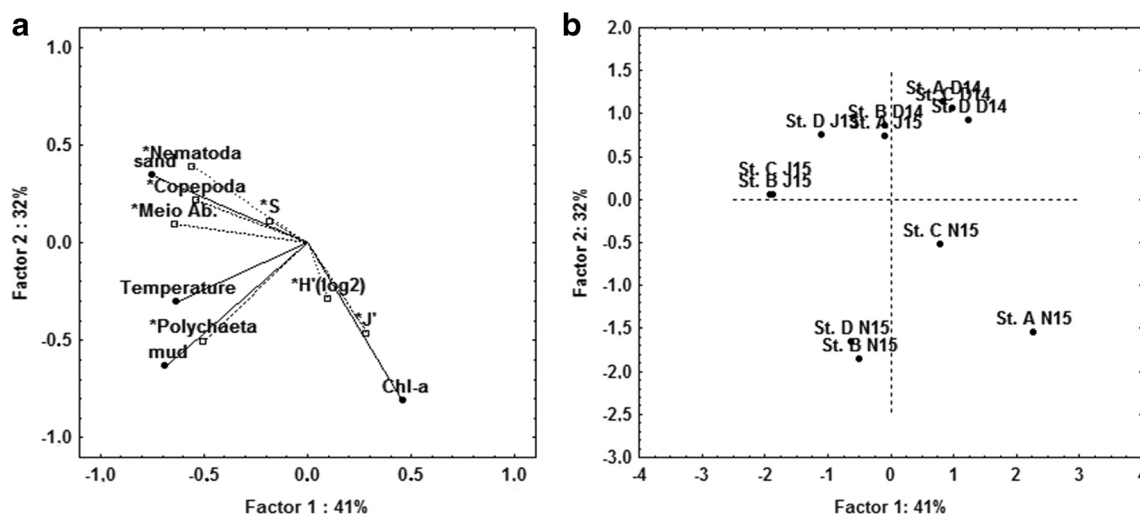
Fig. 6 Principal component analysis (PCA) carried out on the main environmental variables of the bay of Nisida. The relative abundances of the main meiofaunal taxa and their descriptors (richness, abundance, and Shannon and Pielou indices) were projected on the factor plane as supplementary variables without contributing to the results of the analysis. **a** PCA ordination diagram of sampling based on the selected variables; **b** scatter diagram plotting factor 1 and factor 2 of sampling stations

between macrofauna and meiofauna (Semprucci et al. 2010a). Meiofaunal richness as well as biodiversity (namely, H′ and J indices) did not appear significantly different between periods and stations, and only partially matched in trends between the different stations. This is not surprising because these indices consider both the presence and relative abundance of the various taxa, and not only their presence/absence. Despite the fact that H′ and J indices would be more correctly calculated at the species level, their use at higher taxonomic levels is common in meiobenthic ecological studies (Warwick 1993; De Troch et al. 2001; Raes and Vanreusel 2005; Armynot du Chatelet et al. 2016) and probably should be considered more informative than the use of only the number of taxa.

PCA highlighted that PC1 was mainly influenced by the grain size and secondly by temperature. In particular, St. B and St. D and all the other stations sampled during J15 appeared to be associated to the higher values of sand, mud, and secondly to the temperature that appeared to positively affect total meiofauna, Nematoda and Copepoda. Contrary to the known marked relation of the abundance of the phylum Nematoda with the mud fraction (Steyaert et al. 1999; Semprucci et al. 2010a; Frontalini et al. 2014), nematodes here resulted in being more correlated to the sediment sand percentage increase and only secondly to the mud fraction, while Copepoda confirmed their close relation with the sand fraction (Semprucci et al. 2010b; Martinec et al. 2014; El-Serehy et al. 2016). Instead, PC2 is mainly characterized by the peaks of Chl-*a* detected in autumn. Phytoplankton blooms as well as the derived Chl-*a* concentrations are often associated to this season (Vrišer and Vukovič 1999; Hennemann and Petrucio 2010). Among the faunal groups, Polychaeta appeared highly and positively correlated with Chl-*a* and secondly to the mud fraction, probably because the species found were prevalently characterized by a burrowing lifestyle. As for the indices analyzed, only J′ resulted in being significantly correlated to the Chl-*a* increase that can be an indicator of a trophic resource of high quality for benthic assemblages (Boon and Duineveld 1998). In coastal systems strongly influenced by riverine discharges, peaks of Chl-*a* generally affect negatively the meiofaunal assemblage because they are associated to relevant eutrophication phenomena (Semprucci et al. 2010a, 2015c). However, the good equitability found in this study in relation to the Chl-*a* peak seems to suggest that the meiofauna of Porto Paone uses it as a trophic source.

All these observations indicate that Porto Paone is characterized by a high biodiversity of the meiofaunal assemblages and is worthwhile of further investigations. The high biodiversity of Nisida was also confirmed by a comparison with the close, highly stressed area of Bagnoli that showed an overall number of eight taxa versus 21 found at Nisida (Campoli 2016). According to the classification of environmental quality of sediments based on the richness proposed by Danovaro et al. (2004) and modified according to the Water Framework Directive (WFD; Semprucci et al. 2015b), the bay of Porto Paone in Nisida appears to have a high ecological quality.

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