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Benthic foraminifera and heavy metals distribution: A case study from the Naples Harbour (Tyrrhenian Sea, Southern Italy)

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Benthic foraminiferal density and species distribution may be used as pollution indicators.

Abstract

The analysis of 90 surficial sediments from three docks of the Naples Harbour (*Levante*, *Granili*, and *Diaz*) permits to compare the distribution modes of heavy metals with grain sizes, total organic carbon content (TOC) and distribution patterns of benthic foraminifera. Foraminiferal density and species richness decrease with the increasing toxic elements concentrations from the *Levante* to the *Diaz* dock. Median concentrations of Ni, Pb, Zn, and Hg (medians of 21.43 mg/kg, 270.24 mg/kg, 489.65 mg/kg, and 1.18 mg/kg, respectively) were reported for the *Diaz* dock where foraminifera are absent, thus suggesting a possible impact of toxic elements on the benthic ecosystem balance. Compared to the unpolluted marine sediments of the *Granili* dock, the *Levante* area shows higher heavy metals levels and a quasi-oligotypic benthic assemblage. This is dominated by the tolerant species *Ammonia tepida* that may be used as bio-indicator of pollution of anthropised marine sediments.

Keywords: Benthic foraminifera; Heavy metals; Geostatistics; Naples Harbour; Bio-indicators

1. Introduction

Benthic foraminifera are among the more abundant and most conspicuous protozoa in the costal environment and, because they have a short life cycle and specific habitats, they tend to respond quickly to changes in their environments and can be used as an early warning indicator (Kramer and Botterweg, 1991) of possible anthropic contamination. Studies of pollution effects on benthic foraminifera and the possible use of these biota as proxies were first proposed by Resing (1960) and Watkins (1961). In the last years, several papers have been devoted to the possibility to correlate distribution, diversity, and population density of benthic foraminifera assemblage with toxic organic and inorganic compounds distribution (Boltovskoy et al., 1991; Alve, 1995; Yanko et al., 1999; Coccioni, 2000; Scott et al., 2001; Debenay et al., 2001; Bergamin et al., 2003; du Châtelet et al., 2004, and reference therein). Recent studies (Samir and El-Din, 2001; du Châtelet et al., 2004) demonstrated that some benthic species seem extremely sensible to heavy metals and/or organic compounds concentration levels. In particular, some authors (Seiglie, 1975; Setty, 1976; Setty and Nigam, 1984; Yanko and Flexer, 1991; Samir and El-Din, 2001; du Châtelet et al., 2004) suggested that selected benthic foraminifera species (in particular *Ammonia tepida* and some miliolids as *Quinqueloculina seminulum*) seem to better monitor high concentrations of selected toxic elements and/or organic compounds. The main objectives of this work are (i) identification of the distribution modes of the analysed toxic metals relatively to grain size distribution patterns and total organic carbon contents in the studied sediments; (ii) comparison among the

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distribution patterns of the studied heavy metals and the benthic fauna.

2. Material and methods

The harbour of Naples, is located in the eastern Tyrrhenian Sea margin (Gulf of Naples) and is constituted of 11 docks and 30 wharfs that range from 110 to 440 m in length (Fig. 1a). The bottom topography is rather complex and shows a progressive deepening towards the outer part of the harbour (see Fig. 1b). In this study we investigated a total of 90 surface samples from three docks of the Naples Harbour: the *Levante*, *Granili*, and *Diaz* (Fig. 1a). Sediments were collected using a hydraulic vibro-corer with an inner diameter of 10 cm and 6 m long. Three sub-samples were selected from the surficial 20 cm of sediments, homogenized with a plastic scoop, placed into pre-cleaned Ziploc plastic bags for chemical and paleontological analyses and stored at −18 °C on board within an hour of collection.

2.1. Foraminiferal analysis

Each analysed sample was sieved at the 125 μm mesh size. The entire dried residue was microscopically analysed and all the specimens were counted. The foraminifera were hand picked and separated from the sediment. Non-living foraminifera were counted and percentages utilized for statistic analysis. The Loebelich and Tappan classification (1988) was used.

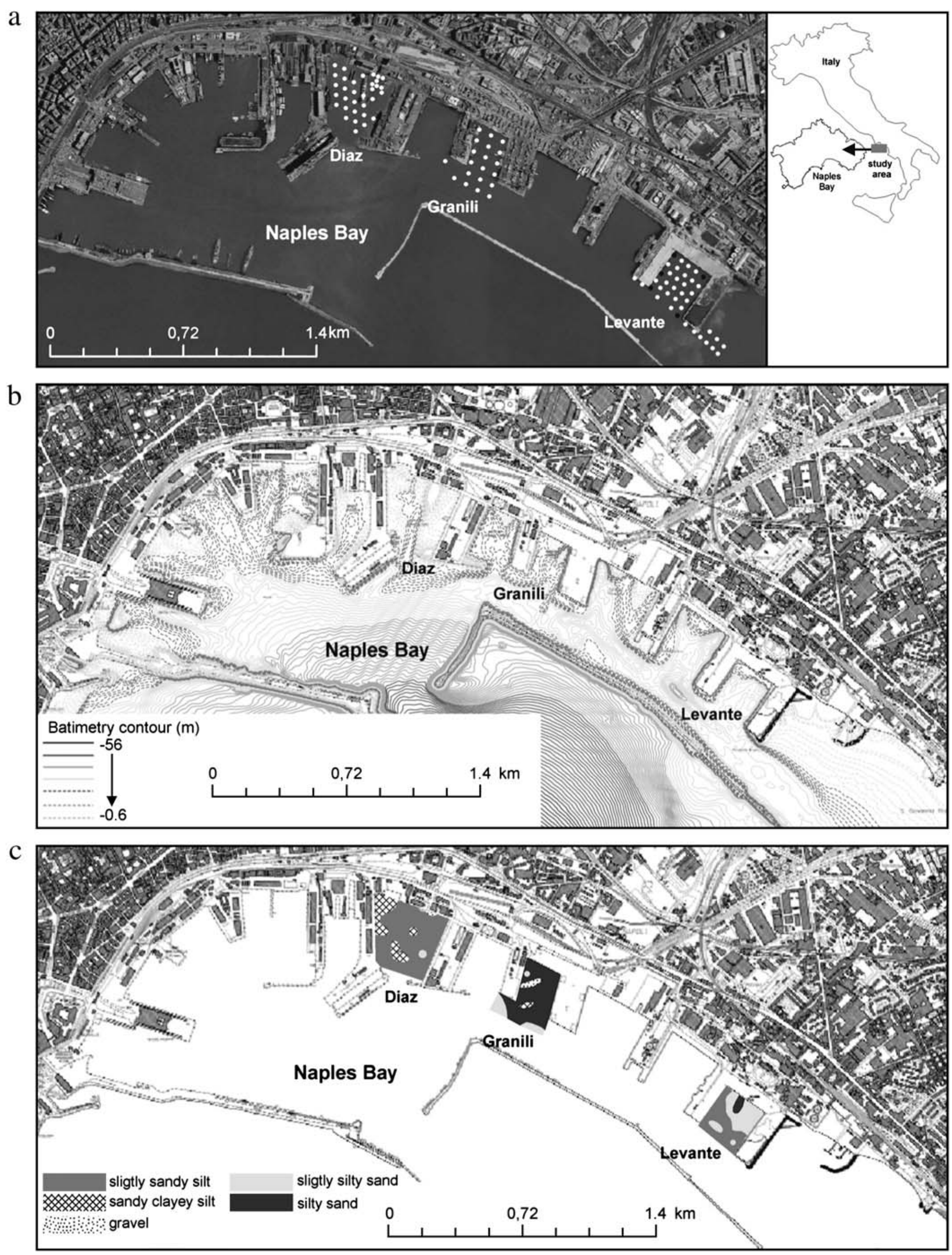

Fig. 1. (a) Location map of the studied docks (*Levante*, *Granili* and *Diaz*) in the harbour of Naples and position of the studied samples (white circle). Black circles in the *Levante* dock show samples where CTD measurements were carried out; (b) topography of the sea floor and (c) grain size of the studied samples.

Table 1
Skewness, kurtosis and significance level of Kolmogorov–Smirnov test for normality (K–S *p*) of the raw and Box–Cox transformed data sets

Data set	*Ammonia tepida*	*Ammonia beccarii*	*Quinqueloculina* spp. deformed	*Planorbulina mediterranensis*	*Quinqueloculina* spp.	*Elphidium* spp.	*Ammonia* spp.	*Rosalina bradyi*	*Cibicides lobatulus*	*Bulimina* spp.
Raw data										
Skewness	0.33	3.48	3.31	2.51	1.42	1.86	0.14	2.88	1.52	4.24
Kurtosis	−1.50	14.83	10.94	6.52	3.69	6.23	−1.37	11.42	1.79	22.39
K–S *p*	0.04	0.00	0.00	0.00	0.39	0.03	0.20	0.00	0.00	0.00
Box–Cox (power transformation) transformed										
Skewness	0.41	2.90	0.94	1.34	3.12	3.89	0.48	2.56	1.05	2.78
Kurtosis	−1.03	9.86	−0.30	1.20	13.10	21.63	−0.86	8.65	0.61	8.89
K–S *p*	0.16	0.03	0.70	0.16	0.05	0.08	0.11	0.45	0.55	0.18

2.2. Q-mode cluster analysis

The original faunal data set contains 34 benthic species. Q-mode hierarchical cluster analysis was only performed on a group of eight benthic species and/or genera due to the exclusion of species or categories occurring with frequencies below 3%. The selected eight categories are *A. tepida*, *Ammonia beccarii*, *Quinqueloculina* spp., *Elphidium* spp., *Cibicides lobatulus*, *Rosalina bradyi*, *Planorbulina mediterranensis*, and *Bulimina* spp.

2.3. Grain size analysis

Samples for grain size analysis were treated with H_2O_2 solution, then washed and dried at 40 °C. Grain size analyses were carried out to establish the percentage of silt and clay (<63 μm) by a Laser Particle-Size Analyzer, and sand fraction (2 mm to 63 μm) by means of a microsieve. The coarser fraction (>2 mm), when present, was made up of gravels. The Shepard (1954) grain size classification was used.

2.4. Heavy metals analysis

'Pseudo-total metal contents' were obtained by digesting samples previously air-dried and sieved through a 2 mm sieve, with aqua regia in Teflon bombs using a microwave oven (CEM Mars X equipment) at a controlled pressure and temperature (step 1: 300 psi, 165 °C, 900 W power for 10 min; step 2: 300 psi, 175 °C, 900 W power for 5 min). The suspension was filtered through 0.45 mm GF/F glass microfibre filters (Whatman). The term 'pseudo-total' is accounted for by the aqua regia digestion which does not completely destroy silicates. Arsenic, Cr, Cu, Ni, Cd, Pb, V, Zn, and Hg concentrations were measured by inductively coupled plasma atomic absorption (ICP-AES) using a Varian Vista MPX. All calibration standards were prepared in the same acid matrix used for the sediment samples. Replicated measures of international reference materials (PACS2), reagent blanks, and duplicated soil samples (about 20% of the total number of samples randomly selected from the set) were used to assess contamination and precision. The analytical precision, measured as relative standard deviation, was routinely between 5 and 6%, and never higher than 10%. All results were calculated with respect to dry weight.

Table 2
Samples number where the different benthic species are present

	Levante dock	*Granili* dock
Ammonia tepida	35	13
Ammonia beccarii	11	14
Quinqueloculina spp. deformed	14	0
Planorbulina mediterranensis	6	12
Quinqueloculina spp.	35	20
Elphidium spp.	21	20
Ammonia spp.	36	16
Rosalina bradyi	9	12
Cibicides lobatulus	17	18
Bulimina spp.	20	2

2.5. Total Organic Carbon (TOC)

Total organic carbon was determined by a ThermoElectron Flash EA 1112 elemental analyzer on freeze-dried powdered samples. The carbonate fraction was eliminated through an HCl treatment in silver capsules.

2.6. Geostatistical methods for generation of spatial distribution maps

The geostatistical analysis was fundamental in defining the best spatial interpolator method and in generating distribution maps (Carlon et al., 2001; McGrath et al., 2004) while GIS algorithms were used to collect, store, analyse the data recorded in the table of ArcGis® software. Since the probability distribution of the raw data sets fails the Kolmogorov–Smirnov test for normality the Box–Cox (power = 0.5) transformation was used to normalize the data (Table 1). The kurtosis values of transformed data, suggest the presence of samples with a particular abundance or lack of benthic species, that represented the main reason to use the Radial Basis Functions (RBF) interpolation technique (Regularized Spline) to produce the grid maps. This method does not assume stationarity (Mitasova and Mitas, 1993). It takes into account the global trend in the data and reproduces possible local variations. On the basis of RBF extrapolated values, contour plots of the benthic distribution in the studied area were produced only for the species recorded in a number of samples higher than 10 according to Cressie (1993) (Table 2).

2.7. Bottom topography

Multibeam data were acquired with a Reason SeaBat 8101 echosounder 210° option with a frequency of 240 kHz and operative in the 0.5/500 m range depth. Water column sound velocities were determined every 8 h by CTD casts.

3. Results

3.1. Grain size distribution patterns

Grain sizes estimated for the three studied areas are presented in Appendix A. The particle size at the sea bottom of the *Levante* dock is characterised by slightly silty sands (subordinate silty sands) and slightly sandy silt in the inner part and in the external ones, respectively (Fig. 1c). The *Granili* dock is mainly dominated by silty sand and subordinately by gravel and sandy clayey silt (Fig. 1c), while the *Diaz* dock is characterised by slightly sandy silt and subordinate sandy clayey silt (Fig. 1c).

Table 3
Basic statistics of the different heavy metals recorded in the three docks along with ER-L (Effects Range – Low) and ER-M (Effects Range – Median) values reported for the sediment guidelines of USEPA by Long et al. (1995) and Ligero et al. (2002)

	Cd (mg kg^{-1})	As (mg kg^{-1})	Cr (mg kg^{-1})	Cu (mg kg^{-1})	Ni (mg kg^{-1})	Pb (mg kg^{-1})	V (mg kg^{-1})	Zn (mg kg^{-1})	Hg (mg kg^{-1})
Levante dock									
Min.	0.08	11.15	68.73	15.38	8.20	34.40	20.08	0.00	0.00
Max.	3.07	165.69	838.50	467.33	154.31	322.38	815.10	1573.00	1.27
Median	0.57	23.20	208.81	94.49	19.01	133.35	142.22	226.99	0.47
MAD	0.42	22.13	116.37	70.97	11.75	61.80	70.96	161.13	0.28
Granili dock									
Min.	0.06	9.19	5.99	19.79	9.12	22.91	50.35	32.51	0.00
Max.	1.92	45.03	388.59	150.19	30.37	225.34	242.69	578.57	1.13
Median	0.64	20.80	21.24	35.21	13.34	36.63	102.65	111.66	0.20
MAD	0.36	4.36	64.89	24.16	2.15	37.63	18.08	130.11	0.20
Diaz dock									
Min.	0.49	10.07	6.89	31.24	10.69	34.60	55.96	45.72	0.02
Max.	2.00	33.03	165.15	626.05	34.89	739.22	115.40	1994.30	7.23
Median	1.02	14.85	44.71	220.04	21.43	270.24	70.80	489.65	1.18
MAD	0.34	2.95	25.07	98.24	6.19	120.20	8.47	274.22	0.64
ER-L	1.20	8.20	81.00	34.00	20.90	46.70	nd	150.00	0.15
ER-M	9.60	70.00	370.00	270.00	51.60	218.00	nd	410.00	0.71

3.2. Heavy metal contents

Concentrations of heavy metals and total organic carbon (TOC) are presented in the Appendix A.

Basic statistics of the different heavy metals recorded in the three docks are summarised in Table 3 and shown in Fig. 2 as Box–Wiskers plots. Generally, the heavy metals show increasing concentrations from the *Granili* dock to the *Diaz* dock with intermediate ones recorded in the *Levante* dock.

Total organic carbon (TOC) contents increase following the order *Levante*–*Granili*–*Diaz* docks (median of 0.41, 1.87, and 4.22%, respectively).

Compared to the ER-L (Effects Range – Low) and ER-M (Effects Range – Median) values reported for the sediment guidelines of USEPA, (Long et al., 1995; Ligero et al., 2002) *Granili* dock generally shows lower concentration values for most heavy metals. Only Cu and Hg show median concentration values close to the ER-L. Conversely, *Diaz* dock shows higher Pb, Zn, and Hg concentration levels than the ER-M levels and higher As and Cu concentration values than the ER-L values (Table 3). The *Levante* dock shows an intermediate situation with As, Cr, Cu, Pb, and Zn characterised by higher concentrations than the ER-L levels, but no heavy metals concentration value higher than ER-M indices.

Concentration levels of As are similar for all the three docks (median values of ~15–20 mg/kg). In the area of the Campania (southern Italy) this element is generally present with moderate to high concentrations in the marine sediments due to the influence of active hydrothermal circulation and related dissolution of As-bearing sulphides as already described by De Vivo et al. (1989), De Vivo and Rolandi (2001) and Federico et al. (2002).

Correlation matrix (Pearson method) calculated for the untransformed heavy metals, TOC and grain size parameters in the three docks (Table 4) shows high correlation coefficients (>0.7) for Cd, Cr, Cu, Pb, Zn, TOC, and silt/clay contents measured in the *Granili* dock. This suggests an important control of grain size and organic matter on the distribution modes of most of the analysed heavy metals in this area. The *Diaz* dock shows a very different behaviour with generally high correlation values estimated among the same trace elements but no correlation with grain size distribution and organic carbon content, thus suggesting a reduced control of fine sediments and/or TOC on the distribution patterns of the toxic elements, whose dispersion is probably driven by important anthropic inputs. The *Levante* dock again shows an intermediate behaviour with high correlation values among most of the heavy metals and correlation values of about 0.5 among heavy metals and grain size.

3.3. The benthic foraminiferal assemblage and distribution

The benthic foraminiferal assemblages are composed almost entirely of small species (ranging from 125 μm to 150 μm; Appendix B), that are present only in sediments of the *Levante* and *Granili* docks, while the *Diaz* dock appears completely barren. Only a restricted number of samples in the *Levante* dock shows morphological deformities (see Appendix B).

A rich population of *A. tepida* was found in all the samples of *Levante* dock with a maximum concentration in the central and outer parts of the area (Fig. 3a). *A. tepida* has a discontinuous distribution in the *Granili* dock with percentages of 19–32% in the innermost part and a progressive decrease in the outer part of the dock (Fig. 3b). A gradual transition between *A. tepida* and *A. beccarii* can be observed moving from the *Levante* to *Granili* dock (Fig. 3c and d). *A. beccarii* is discontinuously present in the *Levante* dock (Fig. 3c), while it is represented in almost all the samples of the *Granili* dock with

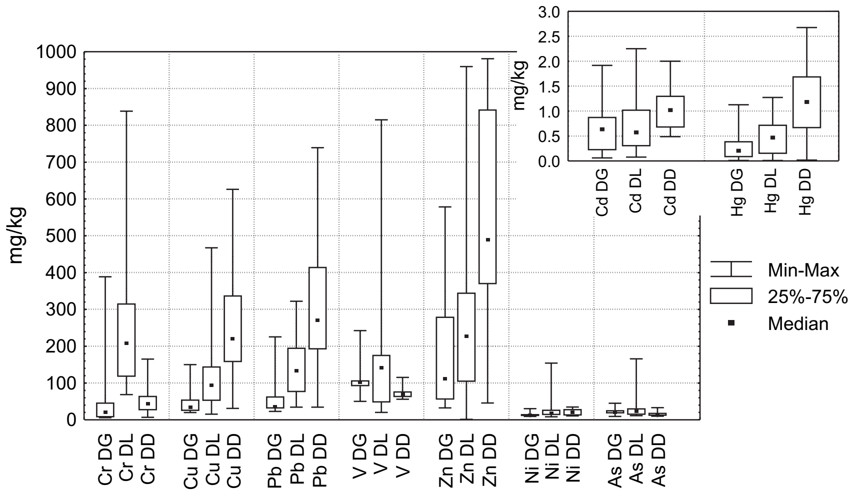

Fig. 2. Box–Wiskers plots of the studied heavy metals in the three docks. DL, DG and DD codes were used to identify samples from the *Levante*, *Granili* and *Diaz* docks, respectively.

Table 4
Correlation matrix (Pearson method) calculated for the untransformed heavy metals, total organic carbon (TOC) and grain size parameters in the three studied docks

	Cd	As	Cr	Cu	Ni	Pb	V	Zn	Hg	TOC	Silt	Clay	Docks
Cd	1.00	0.23	0.67	0.41	0.50	0.60	0.39	0.56	0.58	0.25	0.40	0.09	*Levante*
	1.00	0.38	0.51	0.70	0.57	0.54	0.46	0.81	−0.03	0.58	0.34	0.54	*Granili*
	1.00	0.64	0.90	0.85	0.87	0.87	0.08	0.76	0.68	0.76	0.51	0.46	*Diaz*
As		1.00	0.03	−0.13	−0.08	0.04	−0.16	−0.08	−0.04	0.09	0.01	0.13	*Levante*
		1.00	0.60	0.61	0.91	0.53	0.85	0.41	0.21	0.36	0.09	0.22	*Granili*
		1.00	0.81	0.56	0.59	0.70	0.46	0.53	0.79	0.28	0.33	0.35	*Diaz*
Cr			1.00	0.74	0.79	0.60	0.78	0.90	0.63	0.21	0.34	0.17	*Levante*
			1.00	0.87	0.67	0.97	0.55	0.84	−0.11	0.65	0.54	0.71	*Granili*
			1.00	0.84	0.80	0.90	0.07	0.77	0.78	0.62	0.40	0.43	*Diaz*
Cu				1.00	0.63	0.28	0.64	0.71	0.33	0.02	0.25	−0.02	*Levante*
				1.00	0.76	0.91	0.63	0.87	−0.18	0.75	0.56	0.74	*Granili*
				1.00	0.89	0.85	−0.01	0.96	0.44	0.79	0.58	0.54	*Diaz*
Ni					1.00	0.35	0.96	0.90	0.49	−0.02	0.22	0.01	*Levante*
					1.00	0.61	0.88	0.61	−0.01	0.47	0.20	0.35	*Granili*
					1.00	0.88	0.13	0.87	0.49	0.73	0.54	0.51	*Diaz*
Pb						1.00	0.34	0.54	0.86	0.41	0.47	0.13	*Levante*
						1.00	0.49	0.87	−0.15	0.75	0.61	0.79	*Granili*
						1.00	−0.02	0.85	0.75	0.62	0.44	0.47	*Diaz*
V							1.00	0.91	0.50	−0.07	0.19	−0.01	*Levante*
							1.00	0.43	0.15	0.31	0.29	0.35	*Granili*
							1.00	−0.04	0.08	−0.14	0.07	0.00	*Diaz*
Zn								1.00	0.69	0.09	0.31	0.03	*Levante*
								1.00	−0.17	0.72	0.57	0.77	*Granili*
								1.00	0.41	0.73	0.53	0.51	*Diaz*
Hg									1.00	0.25	0.51	0.11	*Levante*
									1.00	−0.19	−0.13	−0.16	*Granili*
									1.00	0.32	0.18	0.21	*Diaz*
TOC										1.00	0.30	−0.02	*Levante*
										1.00	0.49	0.66	*Granili*
										1.00	0.55	0.51	*Diaz*
Silt											1.00	0.30	*Levante*
											1.00	0.94	*Granili*
											1.00	0.93	*Diaz*

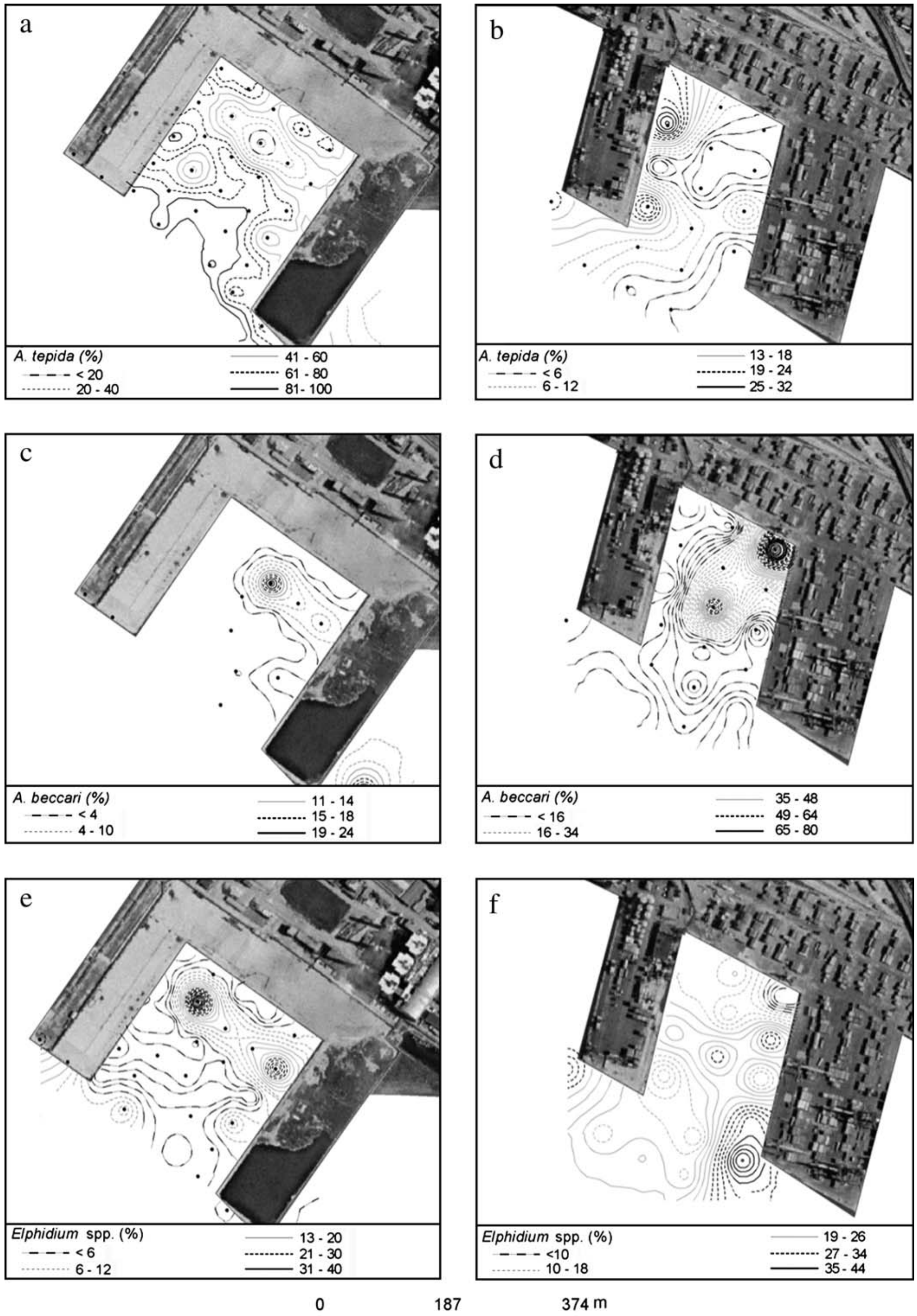

Fig. 3. Distribution of *A. tepida*, *A. beccarii* and *Elphidium* spp. benthic species in the *Levante* (a, c and e) and *Granili* (b, d and f) docks.

abundances up to 82% of the total assemblage (Fig. 3d). *Elphidium* spp. has a somewhat irregular distribution in the two docks (Fig. 3e and f). *Quinqueloculina* spp. occurs in the two docks, except for a few number of samples (Appendix B), with a regular distribution (Fig. 4a and b). *R. bradyi* is not continuously present in the samples of the *Granili* dock (Fig. 4d). In the *Levante* dock *R. bradyi* is exclusively present in the inner part (Fig. 4c). *C. lobatulus* shows a discontinuous distribution reaching the highest percentages (Fig. 4e) in the inner part of the *Levante* dock, while in the *Granili* area *C. lobatulus* is present in all the samples with a discontinuous distribution (Fig. 4f). *Bulimina* spp. is present only in the *Levante* dock (Fig. 5a) while *P. mediterranensis* is almost continuously present in the *Granili* dock (Fig. 5b).

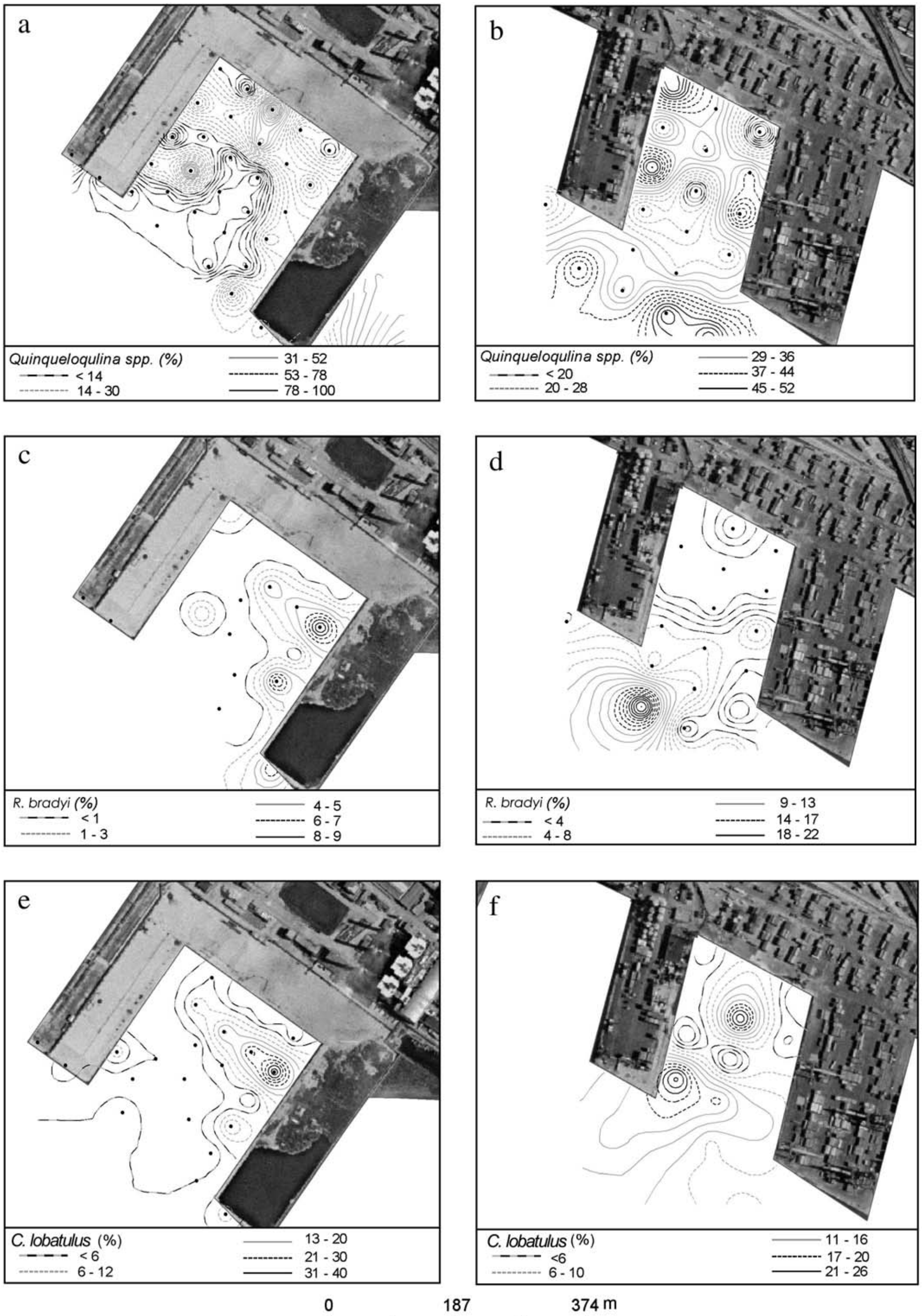

Fig. 4. Distribution of *Quinqueloculina* spp., *R. bradyi* and *C. lobatulus* benthic species in the *Levante* (a, c and e) and *Granili* (b, d and f) docks.

3.4. Q-mode hierarchical cluster analysis

The Q-mode cluster analysis, results in the grouping of samples into three main clusters (I, II and III) (Fig. 6) clearly related to their distribution in the two studied docks. The first cluster contains most samples located in the *Levante* dock with a benthic foraminiferal assemblage dominated by *A. tepida*, and subordinate *Quinqueloculina* spp. and *Elphidium* spp. (Fig. 6, Appendix B). The second cluster is represented by samples of the *Levante* dock and subordinately by samples of the *Granili* dock and is characterised by dominant *Quinqueloculina* spp. and *A. tepida*. Within this cluster two sub-clusters IIa and IIb can be recognised (Fig. 6). Cluster IIa (where samples from *Levante* and *Granili* dock are present) is dominated by

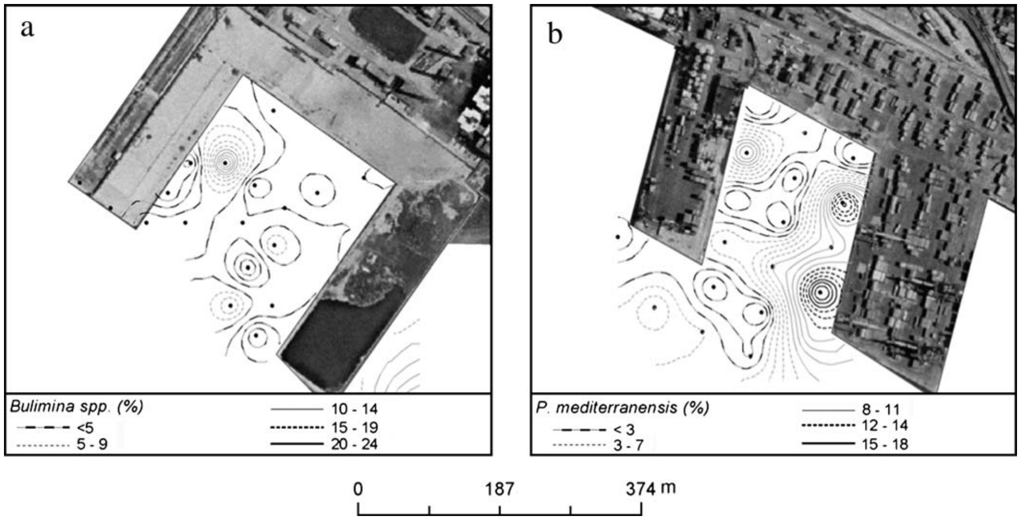

Fig. 5. Distribution of *Bulinima* spp. and *P. mediterranensis* benthic species in the *Levante* (a) and *Granili* (b) docks.

Quinqueloculina spp., *A. tepida*, *Elphidium* spp. and subordinate *C. lobatulus* (Fig. 6, Appendix B) and cluster IIb (which includes only samples from the *Levante* dock) is characterised by abundant *Quinqueloculina* spp. and *A. tepida*. Finally, the third cluster (Fig. 6) characterised by samples located in the *Granili* dock consists of well diversified benthic fauna dominated by *Quinqueloculina* spp. and *Elphidium* spp., with common specimens of *C. lobatulus* and subordinate *R. bradyi*, *A. tepida*, *A. beccarii* and *P. mediterranensis* species (Fig. 6).

4. Discussion

Comparison of basic statistical parameters calculated for the heavy metals and benthic foraminiferal data sets allows a preliminary analysis of hypothetical relationships between the distribution patterns of toxic elements and foraminiferal ecosystem balance.

Firstly, the most polluted *Diaz* dock is barren of benthic foraminifera and constitutes the end member between the three docks. In particular the high concentration of Pb, Hg, Ni and Zn, two to nine times higher than in the other two docks' seems to suggest that these elements alone could strongly influence the mortality of the studied ecosystem. Furthermore, for these four elements, the *Diaz* dock sediments show concentration values that exceed the USEPA ER-M indices suggesting an important toxic effect on the benthic microorganisms. To explore a possible relationship among toxic elements and benthic foraminifera distribution patterns in the

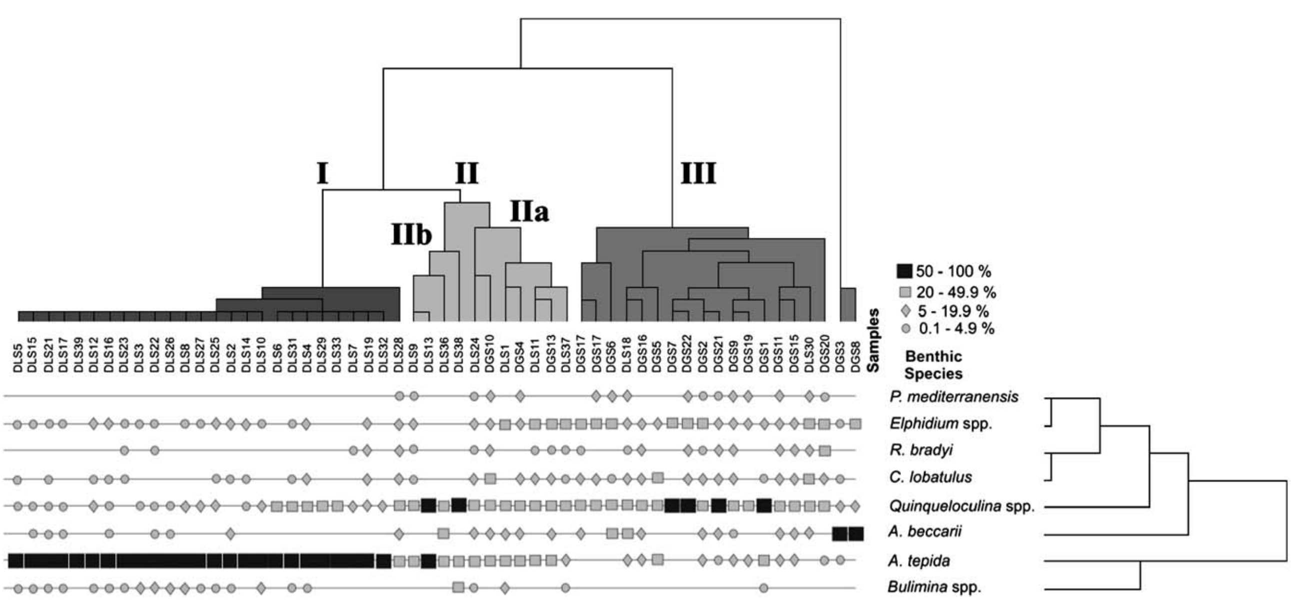

Fig. 6. Dendogram estimated for the harbour samples (top) and calculated by Q-mode hierarchical cluster analysis using the Pearson correlation index. Samples labeled with DL, and DG are from the *Levante* and *Granili* docks, respectively. The relative abundance of each species (right) and each sample is expressed using the chart: 0.1%; 5%; 20%; 50%.

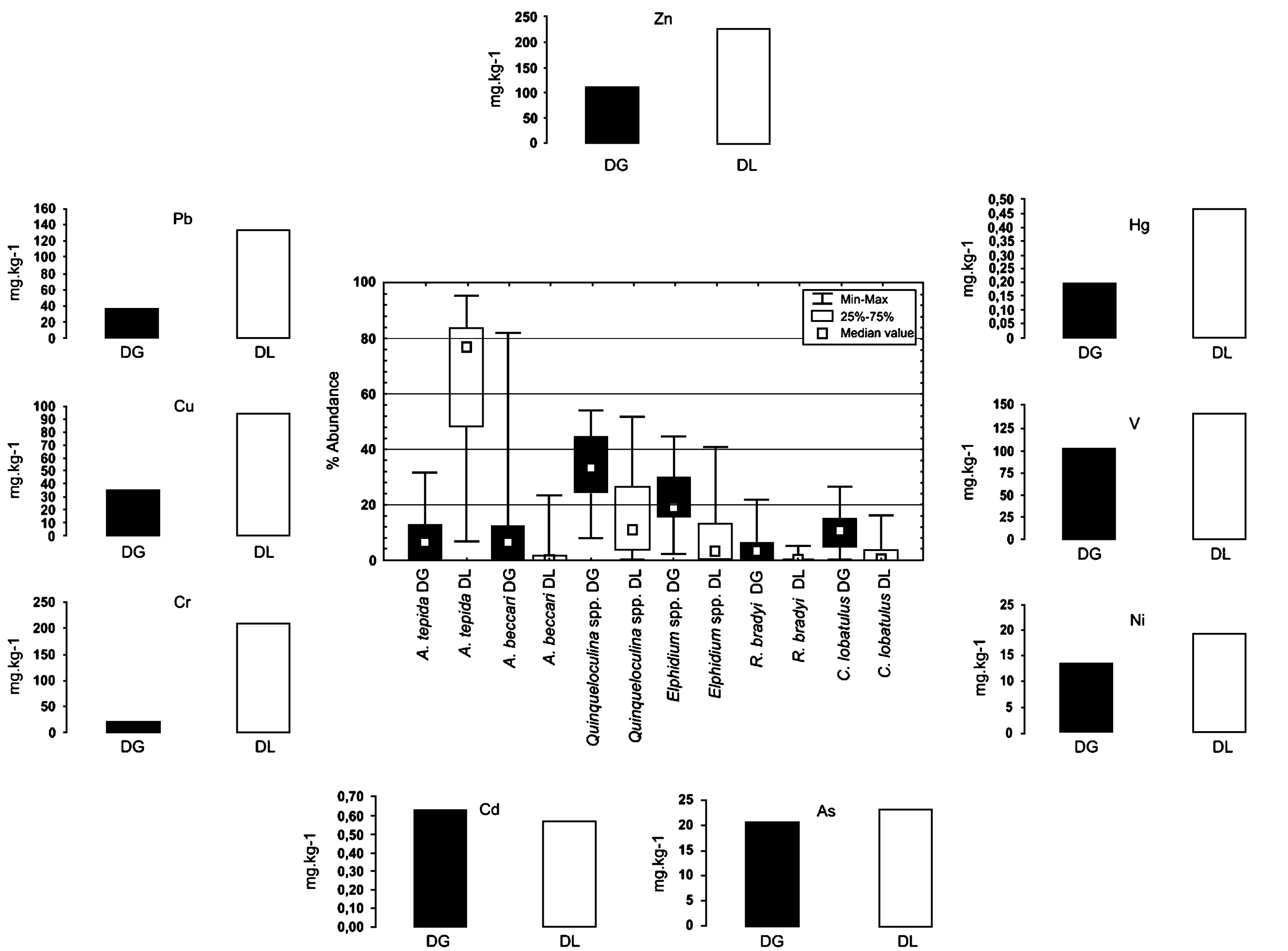

Fig. 7. Box–Wiskers plot (central diagram) calculated for the most significant benthic species found in the *Granili* (black filling) and *Levante* (white filling) docks (DG-*Granili* dock and DL-*Levante* dock), encircled by the median values calculated for the different heavy metals in the two areas.

other two studied docks, we reported in Fig. 7 a synthetic view of median values of the trace metals in the two areas and the basic statistical parameters of the six most abundant benthic species counted in the sediments. The central part of the diagram shows the Box–Wiskers plots for the most significant benthic species found in the *Granili* (black filling) and *Levante* (white filling) docks encircled by the median values calculated for the different heavy metals concentration values measured in the two areas. As earlier documented, the *Levante* dock is characterised by higher concentration (generally 150, 200% more) values for several toxic elements (Pb, Cu, Zn, Cr, Hg, and Ni) than those measured in the *Granili* area. At the same time, differences were identified in the benthic assemblages distribution. In detail, based on the cluster analysis, the *Levante* dock is dominated by *A. tepida* species and subordinated *Quinqueloculina* spp. and *Elphidium* spp., whereas, in the *Granili* dock, the microfauna is characterised by a well diversified assemblage with dominance of *Quinqueloculina* spp. and *Elphidium* spp. *A. tepida* is commonly encountered in restricted environments under pollution stress (Yanko et al., 1994, 1999; Alve, 1995; Debenay et al., 2000, 2001; du Châtelet et al., 2004) and generally described in the literature as a species tolerant to chemical and thermal pollution, fertilizing products, heavy metals, and hydrocarbons (Seiglie, 1975; Setty, 1976; Setty and Nigam, 1984; Yanko and Flexer, 1991).

Measurements of CTD performed in different sites of the area (shown in Fig. 1a) documented a very stable salinity content with values ranging between 37.1 and 37.3‰. For this we exclude the effect of salinity on the benthic assemblage distribution patterns and convey attention towards a possible control of toxic elements distribution as primary controllers of the quasi-oligotypic *A. tepida* assemblage are found in the *Levante* area. Our results confirm the capacity of the *A. tepida* to support very polluted environments and high concentrations of heavy metals, while *Elphidium* spp. and *Quinqueloculina* spp. species seem to badly tolerate high levels of toxic trace metals proliferating in *cleaner* environments, representative of the *Granili* area. However, on the basis of our results it is not possible to identify the master trace elements driving the distribution of benthic foraminifera, since Pb, Hg, Zn, Cu, Ni, and Cd generally covariate in terms of distribution patterns in the studied marine sediments.

5. Conclusions

(1) The heavy metals concentration values in three docks of the harbour of Naples showed different levels of contamination. The *Granili* dock shows concentration values, for all the trace elements, close to the background levels measured by Feo et al. (2005) in marine sediments collected on the continental shelf of the southern Tyrrhenian Sea. Conversely, the *Diaz* dock shows heavy metals concentration values generally higher than the USEPA ER-M levels indicating an important influence of toxic elements on the balance of the benthic ecosystem.

(2) The toxic elements concentration patterns compared with benthic foraminiferal distribution suggested a possible control of the chemical system on benthic foraminifera. The high concentration values recorded in the *Diaz* dock are reflected in a totally barren benthic assemblage. *A. tepida*, dominant in the *Levante* dock, testifies an important chemical stress on this area responding with a quasi-oligothropic assemblage also characterised by 10% of deformed specimens. Conversely, *Quinqueloculina* spp., sporadically present in the *Levante* dock, results as a benthic species very sensitive to pollution. Finally, the *Granili* dock is characterised by a natural benthic assemblage that reflects the limited influence of heavy metals concentration levels present in the sediments.

(3) Our results suggest that quantitative analysis performed on the benthic foraminiferal assemblage represents a suitable tool for monitoring the heavy metals pollution status of marine sediments, although toxic elements concentration levels higher than the USEPA ER-M indices bleach the benthic fauna creating a sill and non-linear effect on the response of the assemblage to chemical contamination.

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Appendix A. Kilometric coordinates, water depths, heavy metals concentration values, total organic carbon (TOC) content and grain size values measured for all the studied samples

	East	North	Depth (m)	Cd (mg kg^{-1})	As (mg kg^{-2})	Cr (mg kg^{-3})	Cu (mg kg^{-4})	Ni (mg kg^{-5})	Pb (mg kg^{-6})	V (mg kg^{-7})	Zn (mg kg^{-8})	Hg (mg kg^{-9})	TOC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
Levante dock																	
DL 1	440423	4520543	6.4	0.41	24.01	173.80	53.18	18.15	152.44	147.43	258.07	0.75	1.30	2.00	50.00	44.00	1.00
DL 2	440464	4520509	9.06	0.38	18.63	151.22	52.60	17.04	56.24	86.83	68.20	0.05	1.12	0.00	69.00	30.00	1.00
DL 3	440511	4520489	12.7	0.16	23.45	114.01	30.51	14.54	54.00	107.99	28.57	0.09	1.39	0.00	47.00	49.00	4.00
DL 4	440540	4520529	11.7	1.26	20.72	410.89	173.00	26.08	236.20	168.66	449.28	0.91	11.11	3.00	41.00	54.00	2.00
DL 5	440570	4520569	12.18	1.48	22.50	467.85	200.96	26.11	244.94	175.09	514.46	0.99	2.98	2.00	32.00	65.00	1.00
DL 6	440607	4520619	12.8	0.97	14.26	449.78	467.33	26.04	118.78	165.92	523.46	0.47	0.17	8.00	38.00	51.00	3.00
DL 7	440640	4520669	9.66	3.07	23.50	360.72	143.90	63.57	190.61	247.28	464.88	0.73	1.75	2.00	43.00	53.00	2.00
DL 8	440563	4520489	13.6	0.83	81.80	313.32	62.01	20.75	76.34	142.84	224.66	0.19	2.58	2.00	85.00	13.00	0.00
DL 9	440597	4520519	13.76	0.08	15.73	68.73	23.18	8.22	46.89	49.52	17.24	0.07	1.20	0.00	43.00	52.00	5.00
DL 10	440616	4520569	14.88	0.20	18.60	111.14	36.48	8.23	64.88	33.85	31.55	0.06	1.57	0.00	88.00	12.00	0.00
DL 11	440656	4520599	12.93	0.47	29.54	220.57	94.07	23.66	133.35	206.94	254.98	0.35	1.48	0.00	51.00	47.00	2.00
DL 12	440680	4520639	11.1	0.29	23.20	114.67	51.80	8.57	123.84	47.34	81.50	0.72	1.82	7.00	47.00	43.00	3.00
DL 13	440717	4520609	11.55	0.24	14.07	292.36	94.49	33.19	128.00	203.78	194.53	0.36	1.36	10.00	61.00	24.00	5.00
DL 14	440548	4520439	14.15	0.76	15.99	291.92	101.04	27.77	116.49	183.17	296.62	0.32	3.09	2.00	40.00	52.00	6.00
DL 15	440603	4520459	14.67	0.72	24.50	275.60	118.41	21.63	223.79	142.22	307.33	0.82	2.70	4.00	47.00	46.00	3.00
DL 18	440698	4520559	14.09	0.15	38.38	118.59	17.27	16.10	80.91	146.67	109.81	0.36	0.43	1.00	75.00	23.00	1.00
DL 19	440758	4520579	10.34	0.37	25.36	177.42	96.95	24.56	143.10	149.45	230.11	0.62	1.43	5.00	54.00	35.00	6.00
DL 21	440646	4520429	15.16	0.99	13.62	315.00	110.06	15.51	151.89	109.23	238.60	0.61	2.78	2.00	45.00	47.00	6.00
DL 24	440738	4520529	14.79	0.29	15.45	154.93	192.64	19.32	36.13	191.75	153.62	0.00	0.34	0.00	72.00	27.00	1.00
DL 25	440800	4520549	10.38	0.10	18.48	81.24	15.38	8.43	34.40	48.80	0.00	0.08	0.33	0.00	57.00	40.00	3.00
DL 26	440623	4520379	14.23	1.04	14.99	400.60	186.97	23.92	276.70	151.95	387.58	0.71	3.47	0.00	38.00	56.00	6.00
DL 27	440678	4520379	14.89	1.19	19.80	464.60	179.61	33.49	194.38	220.21	494.31	0.59	1.18	2.00	49.00	44.00	5.00
DL 29	440736	4520459	15.11	0.70	15.05	295.68	127.35	19.01	185.96	125.91	514.55	0.59	2.74	15.00	56.00	28.00	1.00
DL 30	440772	4520499	14.18	0.36	11.15	210.39	384.45	34.36	43.81	189.35	213.37	0.00	1.89	0.00	70.00	30.00	0.00
DL 31	440657	4520339	14.62	1.02	26.25	235.14	111.04	16.17	322.38	104.31	280.95	1.16	3.27	0.00	28.00	69.00	3.00
DL 33	440749	4520249	5.28	0.64	32.20	170.17	68.81	15.53	149.84	44.70	124.13	0.33	2.78	3.00	59.00	36.00	2.00
DL 36	440834	4520249	7.74	0.57	23.57	166.44	81.63	25.33	263.30	165.44	280.59	0.67	1.40	6.00	72.00	22.00	0.00
DL 39	440849	4520159	12.2	0.42	15.46	147.06	72.82	10.86	112.61	42.35	105.15	0.27		2.00	28.00	69.00	1.00
DL 40	440910	4520169	8.9	0.33	69.21	111.81	57.99	8.45	87.43	28.51	75.84	0.15	4.63	6.00	45.00	48.00	1.00
DL 41	440878	4520129	12.94	1.03	82.09	208.81	101.20	14.78	190.47	32.67	157.75	0.59	4.10	2.00	37.00	58.00	3.00
DL 16	440639	4520489	14.63	1.45	26.78	838.50	429.00	154.31	235.30	815.10	1573.00	1.27	1.75	0.00	40.00	57.00	3.00

(*Appendix continued on next page*)

Appendix A (*continued*)

	East	North	Depth (m)	Cd (mg kg^{-1})	As (mg kg^{-2})	Cr (mg kg^{-3})	Cu (mg kg^{-4})	Ni (mg kg^{-5})	Pb (mg kg^{-6})	V (mg kg^{-7})	Zn (mg kg^{-8})	Hg (mg kg^{-9})	TOC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
DL 17	440655	4520539	14.7	0.48	26.62	165.93	58.88	16.24	154.02	134.82	226.99	0.72	0.43	1.00	51.00	45.00	3.00
DL 22	440681	4520459	14.98	1.69	124.98	471.71	189.63	28.06	244.37	111.57	344.02	0.59	3.46	0.00	60.00	33.00	7.00
DL 23	440695	4520509	14.8	0.24	61.26	114.06	35.75	10.10	63.88	35.38	70.37	0.15	1.92	2.00	56.00	34.00	8.00
DL 28	440708	4520419	15.3	1.30	79.26	198.99	94.49	23.58	152.25	156.10	379.28	0.76	1.84	22.00	37.00	38.00	3.00
DL 32	440700	4520289	14.8	1.00	165.69	232.44	83.44	16.56	130.38	74.44	138.69	0.26	2.37	0.00	42.00	55.00	3.00
DL 35	440782	4520219	9.46	0.41	17.16	104.73	52.15	8.20	77.59	20.08	109.26	0.15	3.56	5.50	72.50	21.00	1.00
DL 37	440816	4520189	10.93	0.69	13.72	331.57	141.04	37.53	235.87	215.07	303.20	0.48	5.73	3.00	47.00	48.00	2.00
DL 38	440874	4520209	8.3	0.31	15.21	116.02	62.48	10.07	98.52	38.62	99.18	0.23	3.63	4.00	39.00	54.00	3.00
Granili dock																	
DG 1	439572	4521357	9.84	0.86	19.42	42.55	79.19	13.50	62.38	92.47	188.56	0.26	0.79	9.56	63.56	24.49	2.40
DG 2	439635	4521324	8.79	0.68	20.56	25.88	39.29	13.74	40.50	104.76	92.89	0.08	0.88	1.30	89.06	8.85	0.79
DG 3	439699	4521290	11.68	0.13	18.62	10.12	26.79	11.77	30.72	87.60	110.54	0.00	0.12	10.99	67.42	20.35	1.23
DG 4	439557	4521297	9.22	1.27	20.10	49.03	54.79	14.55	62.37	105.43	369.25	0.40	0.98	0.00	64.25	32.23	3.53
DG 5	439621	4521263	9.99	0.88	23.59	89.23	53.03	15.15	78.25	106.18	252.06	0.43	1.45	30.77	52.45	15.00	1.79
DG 6	439685	4521230	14.21	0.63	21.04	20.23	32.67	13.20	35.10	116.50	112.78	0.09	0.27	0.51	92.04	7.02	0.42
DG 7	439542	4521237	10.32	1.52	9.19	14.57	37.31	9.12	38.16	50.35	345.02	0.20	0.27	42.26	46.34	10.05	1.35
DG 8	439606	4521204	12.47	0.07	15.38	5.99	22.91	9.91	22.91	101.93	32.51	0.04	0.17	0.31	78.55	19.70	1.44
DG 9	439670	4521170	11.40	0.12	20.25	22.25	33.10	11.47	34.93	93.12	68.80	0.20	0.33	0.83	91.48	7.21	0.48
DG 10	439528	4521177	10.34	0.32	20.28	36.84	48.07	13.64	52.40	93.52	163.11	0.25	0.69	10.87	77.27	11.06	0.80
DG 11	439592	4521144	11.33	0.09	26.87	9.53	19.79	15.14	23.19	77.29	42.57	0.14	0.17	1.69	95.16	3.15	0.00
DG 12	439655	4521110	13.12	0.68	25.02	9.46	22.01	12.75	25.51	100.51	96.55	0.03	0.25	2.98	88.17	8.34	0.51
DG 13	439385	4521184	10.90	0.77	25.38	388.59	106.21	15.04	225.34	103.72	520.30	1.13	1.22	0.00	59.71	35.77	4.52
DG 15	439513	4521117	9.92	0.64	24.53	36.15	48.55	13.70	47.99	97.68	114.96	0.19	0.49	0.00	97.42	2.25	0.33
DG 16	439577	4521083	13.43	0.59	28.31	8.30	21.29	13.47	22.95	128.91	54.77	<0.10	0.21	0.28	88.41	10.64	0.67
DG 17	439641	4521050	11.04	0.06	17.13	6.59	25.01	12.07	35.06	103.37	37.91	0.18	0.13	0.24	85.59	13.33	0.84
DG 19	439434	4521090	12.67	0.98	22.41	91.45	89.47	12.51	131.02	100.88	304.71	0.77	1.28	0.53	68.29	27.86	3.32
DG 20	439498	4521057	14.96	0.56	21.93	8.65	32.61	12.43	34.24	105.56	47.97	0.19	0.49	0.00	81.10	17.89	1.01
DG 21	439562	4521024	13.73	0.45	18.88	6.66	28.66	11.45	34.25	119.01	58.78	0.36	0.25	0.00	66.02	31.03	2.94
DG 22	439626	4520990	13.50	1.92	45.03	320.02	150.19	30.37	183.04	242.69	578.57	0.59	1.11	0.00	71.32	25.30	3.38
Diaz dock																	
DD 1	438778	4521697	4.81	1.56	17.89	96.88	626.05	34.89	658.59	61.42	1994.30	1.77	9.21	0.18	22.01	68.86	8.95
DD 2	438829	4521678	5.03	2.00	22.89	150.94	620.72	32.96	483.60	72.00	1289.13	1.72	10.76	0.77	19.07	70.00	10.16
DD 3	439040	4521627	4.97	1.01	15.96	51.42	251.39	22.34	293.51	69.02	663.33	1.24	5.29	0.00	27.71	63.24	9.06
DD 4	438931	4521639	7.53	1.19	16.83	47.73	247.62	24.10	288.43	83.41	575.80	1.18	4.22	0.00	34.58	57.74	7.68
DD 6	439007	4521611	2.11	1.02	18.94	56.31	336.81	30.85	459.93	78.28	841.71	1.20	2.70	0.00	31.50	59.81	8.69
DD 8	438982	4521593	3.03	1.19	13.18	45.11	224.78	21.48	270.24	63.91	458.74	1.09	9.27	0.33	26.11	64.80	8.77
DD 9	439008	4521584	2.13	1.30	13.73	44.71	245.23	21.80	278.38	69.23	489.65	1.35	4.44	0.00	43.52	50.68	5.81
DD 10	439033	4521574	3.40	1.09	12.35	40.34	215.95	19.39	254.42	64.12	451.19	1.31	6.30	0.00	32.76	59.42	7.82
DD 11	438780	4521643	7.53	1.63	16.79	78.38	371.58	33.38	434.64	67.13	1070.17	1.68	9.93	0.11	20.12	69.44	10.33
DD 12	438831	4521624	7.64	0.96	13.50	50.21	199.03	12.41	258.46	63.54	442.23	1.74	2.91	0.35	31.51	60.39	7.74
DD 13	438882	4521604	8.39	0.68	11.06	22.79	127.47	11.50	163.42	55.96	315.14	0.74	5.12	0.41	32.99	57.03	9.57
DD 15	438983	4521566	2.41	1.27	14.30	43.20	238.61	22.11	287.61	72.39	483.20	1.86	6.69	0.10	32.10	61.38	6.42
DD 16	439034	4521547	3.81	1.23	12.75	40.88	224.77	21.43	272.97	65.19	471.17	1.30	5.25	11.16	29.85	52.65	6.34
DD 17	438782	4521588	9.33	1.98	33.03	165.15	343.95	29.06	739.22	79.47	870.20	7.23	4.75	2.33	37.37	52.18	8.13
DD 18	438833	4521569	10.15	0.49	17.70	6.89	31.24	13.26	34.60	115.40	45.72	0.02	0.29	0.00	43.52	50.68	5.81
DD 19	438884	4521550	9.09	0.91	14.97	31.31	159.49	15.26	221.19	72.31	365.46	0.85	1.59	0.00	26.62	63.01	10.37
DD 20	438934	4521531	7.34	0.66	16.23	31.51	158.90	17.08	218.73	83.61	391.90	0.54	3.51	1.35	44.53	47.88	6.23
DD 21	438985	4521512	1.30	0.56	11.48	19.72	49.06	10.69	99.83	75.99	176.44	0.35	1.43	43.14	55.39	1.46	0.00
DD 22	438784	4521534	8.91	1.75	18.39	80.16	434.97	29.13	429.10	92.70	1028.37	1.90	8.63	0.00	14.53	74.85	10.63
DD 23	438835	4521515	9.91	0.89	16.23	48.03	220.04	19.39	237.95	75.96	577.19	1.10	3.57	0.08	15.06	74.27	10.59
DD 24	438886	4521496	9.96	0.61	13.69	27.90	153.28	15.03	162.63	74.34	370.19	0.67	3.32	0.16	41.69	50.80	7.35
DD 25	438936	4521477	6.17	0.49	10.77	18.39	95.43	11.32	112.89	58.24	233.08	0.41	1.81	27.31	42.22	26.74	3.72
DD 27	438786	4521480	7.66	1.38	17.71	81.89	352.21	27.79	399.36	75.86	940.11	1.45	6.68	1.21	24.98	64.09	9.71
DD 28	438837	4521461	9.20	1.61	17.90	84.88	369.64	30.51	465.16	83.05	908.48	1.77	6.50	0.00	19.88	69.32	10.80
DD 29	438887	4521442	10.94	1.18	12.66	63.89	248.89	24.23	346.28	60.02	590.96	0.40	2.46	0.18	31.04	60.63	8.14
DD 30	438938	4521423	6.94	1.11	11.48	50.70	216.54	23.05	413.73	63.66	507.35	1.42	6.07	1.71	35.05	54.17	9.07
DD 31	438989	4521404	5.79	0.84	10.07	26.84	126.95	15.25	204.84	58.56	270.48	0.77	2.48	0.57	52.05	41.78	5.61
DD 32	438839	4521407	9.49	0.97	14.85	32.11	185.43	13.16	188.00	71.27	384.68	0.51	3.35	2.50	20.83	67.83	8.84
DD 33	438889	4521388	10.14	0.69	16.22	35.29	169.33	17.80	193.13	70.80	496.71	0.76	3.92	0.00	20.91	68.96	10.13
DD 34	438940	4521369	6.74	0.58	12.84	18.91	135.63	12.08	131.16	64.42	247.35	0.72	2.15	0.00	45.50	47.41	7.08
DD 35	438892	4521333	9.46	0.50	14.25	26.22	178.89	12.74	194.17	60.64	495.83	0.57	3.43	0.05	34.95	56.45	8.56

Appendix B. Percentages of the benthic species recorded in the studied samples

Core	*Ammodiscus planorbis*	*Ammodiscus sp.*	*Ammonia beccarii*	*Ammonia tepida*	*Asterigerinata mamilla*	*Bolivina pseudoplicata*	*Buccella frigida*	*Bulimina elongata*	*Bulimina gibba*	*Bulimina marginata*	*Cibicidella variabilis*	*Cibicidella variabilis deformed*	*Cibicides lobatulus*	*Cibicides lobatulus deformed*	*Cribrostomoides jeffresy*	*Eggerella scabra*	*Elphidium aculeatum*	*Elphidium complanatum*	*Elphidium crispum*
DLS1			5,3	31,6			5,3	5,3									5,3	5,3	5,3
DLS2			5,1	76,9				2,6					2,6				2,6	7,7	
DLS3				91,2				6,0											
DLS4				60,7				1,6					6,6					1,6	
DLS5				94,3				1,6					0,1				0,1		
DLS6				68,2															
DLS7				83,8															
DLS8		1,4		80,1				6,1	0,4						0,7				0,4
DLS9	8,2			34,7									2,0						
DLS10				72,1			0,9	14,2											
DLS11				25,9			3,7						7,4						
DLS12	1,8			83,3				2,6					3,5					0,9	
DLS13				48,3															
DLS14				82,6									4,3						
DLS15			0,2	95,4				0,4						0,2		0,2			
DLS16	1,1		0,6	72,8	0,6		1,1		3,9				0,6						
DLS17	0,8		2,3	86,5					1,5					0,8					0,8
DLS18			23,3	6,7									11,7	1,7					
DLS19				76,9															
DLS20																			
DLS21			2,2	89,0			0,9	1,3					1,3						
DLS22			0,5	88,8				6,9											
DLS23				85,7			2,0	4,1					4,1						
DLS24			9,1	25,0				2,3				2,3	15,9						
DLS25				72,1			4,4	4,4					1,5					1,5	
DLS26			1,6	87,0				8,3						2,1					
DLS27				85,7				4,8											
DLS28	1,9		5,8	40,4			1,9						9,6						
DLS29				77,8															
DLS30			10,0										22,5						
DLS31	2,2			62,6				1,1					2,2						
DLS32				64,3									7,1						
DLS33				75,0															
DLS35							100,0												
DLS36			25,0	37,5															
DLS37				16,0		4,0	8,0			4,0			4,0				4,0		
DLS38				25,0				25,0											
DLS39				100,0															
DLS40																			
DLS41																			

Core	*Elphidium cuvilleri*	*Elphidium granosum*	*Elphidium punctatum*	*Elphidium sp.*	*Heterolepa pseudoungeriana*	*Miliolidae*	*Planorbulina mediterranensis*	*Quinqueloculina padana*	*Quinqueloculina contorta*	*Quinqueloculina milletti*	*Quinqueloculina oblonga*	*Quinqueloculina seminulum*	*Quinqueloculina sp.*	*Quinqueloculina spp. deformed*	*Rosalina bradyi*	*Textularia calva*	*Textularia pseudorugosa*	*Triloculina austriaca*	*Triloculina plicata*
DLS1				10,5					5,3			15,8	5,3						
DLS2				2,6															
DLS3				0,4					0,4				2,0						
DLS4									1,6			3,3	18,0						
DLS5				0,1					0,3				2,2	0,7					0,6
DLS6													18,2	13,6					
DLS7													5,4	8,1	2,7				
DLS8			0,4	0,7					1,8	1,1	0,4		4,7	1,4					0,4
DLS9			2,0	2,0			2,0		2,0			2,0	32,7	6,1	4,1				2,0
DLS10				0,5									6,4	4,6				0,9	
DLS11				33,3			3,7						22,2	3,7					
DLS12				1,8								0,9	1,8	2,6					0,9
DLS13									10,3			3,4	37,9						
DLS14				8,7									4,3						
DLS15				0,2					0,2			0,2	1,2	1,8			0,2		
DLS16	0,6	0,6	1,1	3,3		6,7			2,8				0,6	1,1		0,6			
DLS17			0,8			0,8			0,8			3,0							1,5
DLS18				3,3			5,0		16,7			3,3	18,3		5,0				5,0
DLS19													15,4						7,7
DLS20																			
DLS21			0,4	1,3					0,9			0,9	1,8						
DLS22				0,2	0,2							0,5	0,5	1,2	0,5			0,2	
DLS23															2,0				2,0
DLS24							2,3		11,4			9,1	6,8		4,5			6,8	
DLS25				4,4									10,3						1,5
DLS26									0,5			0,5							
DLS27				3,2									6,3						
DLS28				3,8			1,9		1,9	5,8			5,8	9,6	7,7			1,9	1,9
DLS29									11,1			11,1							
DLS30				7,5			5,0		7,5	17,5		5,0	2,5		10,0			10,0	
DLS31				1,1					1,1				17,6	12,1					
DLS32					7,1								14,3		7,1				
DLS33													25,0						
DLS35																			
DLS36													37,5						
DLS37			12,0	8,0	4,0				12,0				16,0	4,0	4,0				
DLS38												25,0	25,0						
DLS39																			
DLS40													100,0						
DLS41													100,0						

(Appendix B continued on next page)

Core	DGS1	DGS2	DGS3	DGS4	DGS5	DGS6	DGS7	DGS8	DGS9	DGS10	DGS11	DGS12	DGS13	DGS15	DGS16	DGS17	DGS19	DGS20	DGS21	DGS22
Triloculina plicata		3,6		10,5					1,8		3,9	7,5			6,3	5,6	0,0	4,3	9,1	
Triloculina austriaca																				
Textularia pseudorugosa																				
Textularia calva																				
Rosalina bradyi		3,6							7,1	5,3	5,9	2,5	4,2	5,1	8,3		11,1	21,7	1,8	6,7
Quinqueloculina spp. deformed																				
Quinqueloculina sp.	37,8	3,6		21,1	25,0	26,9						5,0	8,3	5,1		5,6	27,8		7,3	13,3
Quinqueloculina seminulum	2,7		2,0						3,6		2,0	2,5	4,2		6,3	22,2		8,7	12,7	6,7
Quinqueloculina oblonga									1,8											
Quinqueloculina milletti	5,4	3,6										2,5								
Quinqueloculina contorta	8,1	28,6	6,0	5,3	12,5	11,5	50,0	14,3	37,5	21,1	21,6	15,0	8,3	28,2	22,9	5,6	16,7	21,7	30,9	33,3
Quinqueloculina padana									1,8											
Planorbulina mediterranensis		3,6		10,5		15,4			8,9	5,3	7,8	17,5				11,1	5,6	4,3	1,8	6,7
Miliolidae																				
Heterolepa pseudoungeriana	2,7	3,6												2,6	2,1					
Elphidium sp.	5,4	12,5	2,0	10,5	12,5	11,5		14,3	1,8			5,0	4,2	2,6	8,3		5,6	8,7	9,1	
Elphidium punctatum	2,7					3,8														
Elphidium granosum				2,6																
Elphidium cuvilleri																				
Elphidium crispum							25,0	14,3	1,8		3,9	15,0	8,3	5,1	2,1	11,1	5,6	4,3	1,8	13,3
Elphidium complanatum	8,1	7,1		5,3		15,4			10,7	10,5	11,8	15,0	20,8	10,3	4,2	16,7	5,6	8,7	5,5	20,0
Elphidium aculeatum																				
Eggerella scabra																				
Cribrostomoides jeffreysi																				
Cibicides lobatulus deformed																				
Cibicides lobatulus	2,7	10,7	2,0	5,3	25,0	3,8			8,9	26,3	17,6	12,5	12,5	17,9	10,4	11,1	16,7	13,0	9,1	6,7
Cibicidella variabilis deformed																				
Cibicidella variabilis											2,0							4,3		
Bulimina marginata																				
Bulimina gibba																				
Bulimina elongata	2,7																			
Buccella frigida		5,4					25,0		1,8		3,9	5,0			6,3					
Bolivina pseudoplicata																				
Asterigerinata mamilla																				
Ammonia tepida	21,6	8,9	4,0	31,6					14,3	26,3	9,8		20,8	10,3	8,3		11,1	4,3	1,8	
Ammonia beccarii		5,4	82,0	5,3	25,0	23,1		57,1	3,6	5,3	9,8	10,0	8,3	7,7	14,6				7,3	
Ammodiscus sp.																				
Ammodiscus planorbis																				

References

Alve, E., 1995. Benthic foraminiferal response to estuarine pollution: a review. Journal of Foraminiferal Research 25, 190–203.

Bergamin, L., Romano, E., Gabellini, M., Ausili, A., Carboni, M.G., 2003. Chemical–physical and ecological characteristics in the environmental project of a polluted coastal area: Bagnoli case study. Mediterranean Marine Science 4/2, 5–20.

Boltovskoy, E., Scott, D.B., Medioli, F.S., 1991. Morphological variations of benthic foraminiferal tests in response to changes in ecological parameters: a review. Journal of Paleontology 65 (2), 175–185.

Carlon, C., Critto, A., Marcomini, A., Nathanail, P., 2001. Risk based characterisation of contaminated industrial site using multivariate and geostatistical tools. Environmental Pollution 111, 417–427.

du Châtelet, E.A., Debenay, J.-P., Soulard, R., 2004. Foraminiferal proxies for pollution monitoring in moderately polluted harbors. Environmental Pollution 127, 27–40.

Coccioni, R., 2000. Benthic foraminifera as bioindicators of heavy metal pollution. A case study from the Goro Lagoon (Italy). Environmental Micropaleontology 15, 71–103.

Cressie, N., 1993. Statistics for Spatial Data, Revised ed. John Wiley and Sons, New York, 900 pp.

Debenay, J.-P., Guillou, J.J., Redois, F., Gelsin, E., 2000. Distribution trends of foraminiferal assemblages in paralic environments: a base for using foraminifera as early warning indicators of anthropic stress. In: Martin, R. (Ed.), Environmental Micropaleontology. Plenum Publishing Corporation, New York, pp. 39–67.

Debenay, J.-P., Tsakiridis, E., Soulard, R., Grossel, H., 2001. Factors determining the distribution of foraminiferal assemblages in Port Joinville Harbor (Ile d'Yeu, France): the influence of pollution. Marine Micropaleontology 43, 75–118.

De Vivo, B., Belkin, H.E., Barbieri, M., Chelini, W., Lattanzi, P., Lima, A., Tolomeo, L., 1989. The Campi Flegrei (Italy) geothermal system: a fluid inclusion study of Mofete and San Vito fields. Journal of Volcanology and Geothermal Research 36, 303–326.

De Vivo, B., Rolandi, G., 2001. Mount Vesuvius and volcanism of the Campanian plain. Mineralogy and Petrology 73, 233.

Federico, C., Aiuppa, A., Allard, P., Bellomo, S., Michel, A., Parello, F., Valenza, M., 2002. Magmatic gas–water interactions at Vesuvius volcano: major, minor and trace element composition of the volcanic aquifer. Geochimica et Cosmochimica Acta 66, 963–981.

Feo, M.L., Salvagio Manta, D., Marsella, E., Sprovieri, M., Sammartino, S., Ferraro, L., Saggiomo, V., 2005. Mapping of organic compounds and heavy metals in the marine sediments of the Campania coastal environment (central Italy). In: The 32nd International Geological Congress (32IGC) will be held from August 20 to 28, 2004 in Florence, Italy, 629 pp.

Kramer, K.J.M., Botterweg, J., 1991. Aquatic biological early warning systems: an overview. In: Jeffrey, D.W., Mudden, B. (Eds.), Bioindicators and Environmental Management. Academic Press, London, pp. 95–126.

Loebelich, A.R., Tappan, H., 1988. In: Foraminiferal Genera and their Classification, vol. 2. Van Nostrad Reinhold, New York, 970 pp.

Ligero, R.A., Barbera, M., Casas-Ruiz, M., Sales, D., Lopez-Aguayo, F., 2002. Dating of marine sediments and time evolution of heavy metal concentration in the Bay of Cadiz, Spain. Environmental Pollution 118, 97–108.

Long, E.R., MacDonald, D.D., Smith, S.L., Calder, F.D., 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental Management 19, 81–97.

McGrath, D., Zhang, C., Carton, O.T., 2004. Geostatistical analysis and hazard assessment on soil lead in Silvermines area, Ireland. Environmental Pollution 127, 239–248.

Mitasova, H., Mitas, L., 1993. Interpolation by regularized spline tension: I. Theory and implementation. Mathematical Geology 25, 641–655.

Resing, J.M., 1960. Foraminiferal ecology around ocean outfalls off southern California. In: Person, E. (Ed.), Disposal in the Marine Environment. Pergamon Press, London, pp. 104–121.

Scott, D.B., Medioli, F.S., Schafer, C.T., 2001. Monitoring of Coastal Environments Using Foraminifera and Thecamoebian Indicators. Cambridge University Press, 176 pp.

Samir, A.M., El-Din, A.B., 2001. Benthic foraminiferal assemblages and morphological abnormalities as pollution proxies in two Egyptian bays. Marine Micropaleontology 41, 193–227.

Seiglie, G.A., 1975. Foraminifers of Guayanilla bay and their use as environmental indicators. Revista Espanola de Micropaleontologia 7 (3), 453–487.

Setty, M.G.A.P., 1976. The sensitivity of benthonic foraminifera in polluted marine environment of Cola Bay, Goa. Indian Colloque of Micropaleontological Stratigraphy, Proceeding 6, 225–234.

Setty, M.G.A.P., Nigam, R., 1984. Benthic foraminifera as pollution indices in the marine environments of West coast of India. Rivista Italiana di Paleontologia e Stratigrafia 89 (3), 421–436.

Shepard, F.P., 1954. Nomenclature based on sand, silt, clay ratios. Journal of Sedimentary Petrology 24, 151–158.

Watkins, J.G., 1961. Foraminiferal ecology around the Orange County, California, ocean sewe outfall. Micropaleontology 7 (2), 199–206.

Yanko, V., Flexer, A., 1991. Foraminiferal benthonic assemblages as indicators of pollution (an example of Northwestern shelf of the Black Sea). In: Proceedings of Third Annual Symposium on the Mediterranean Margin of Israel, Haifa, Israel, 5 pp.

Yanko, V., Kronfeld, J., Flexer, A., 1994. Response of benthic foraminifera to various pollution sources implications for pollution monitoring. Journal of Foraminiferal Research 24 (1), 1–17.

Yanko, V., Arnold, A., Parker, W., 1999. Effect of marine pollution on benthic foraminifera. In: Sen Gupta, B.K. (Ed.), Modern Foraminifera. Kluwer Academic, Dordecht, pp. 217–235.