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FORAMINIFERAL PROXIES FOR ENVIRONMENTAL MONITORING IN THE POLLUTED LAGOON OF SANTA GILLA (CAGLIARI, ITALY)

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Key words: Benthic foraminifera, morphological abnormalities, trace elements pollution, Bio-indicator.

Abstract. The results from scientific literature evidence that the benthic foraminifera are excellent indicators to monitoring the marine-coastal environments (Armynot du Châtelet et al., 2004; Coccioni, 2000; Debenay et al., 2000; Kravchuk, 2006; Murray, 2006; Samir & El-Din, 2001; Scott et al., 2005). This study is based on an analysis of eighteen samples of surface sediment collected in the lagoon of Santa Gilla in October 2006. The physical-chemical characterization of waters, geochemical and sedimentological analysis have integrated the analysis of benthic foraminifera. Statistical analysis revealed a possible control of trace element on the benthic foraminiferal assemblage, faunal density, species diversity and the development of specific morphological abnormalities.

Introduction

Foraminifera are marine protoctists with mineralized test, very widely widespread in sediments all over the world with more than 40,000 cited species (Loeblich and Tappan, 1987).

They are commonly used by the geologists due to their abundance in the geological records from the Cambrian (>500 million of years) to the present times.

Benthic foraminifera are increasingly used as environmental bio-indicators of pollution in coastal and marginal marine settings. Because of their high sensitivity to environmental conditions, they are increasingly used for ecological and paleoecological studies all over the world (p.e. Samir et al., 2003; Scott et al., 2005).

Numerous studies have shown that the distribution of benthic foraminiferal assemblages can be related to several environmental and sedimentological conditions. The response of foraminifera to the changed environmental conditions is reflected in the variation in abundance and morphology of the test. The foraminiferal test has high preservation potential thus making these

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microorganisms one of the most useful proxy for the long as well as short-term temporal variation in the amount and type of toxins in all kinds of marine environments, especially the near-shore coastal areas.

Their community structure provides useful information on the general characteristics of the environment quality and more species are sensitive to specific environmental parameters (e.g., Alve, 1991, 1995; Yanko et al., 1994, 1999; Coccioni, 2000; Samir, 2000; Debenay et al., 2001, 2005; Geslin et al., 2002; Coccioni et al., 2003, 2005; Armynot du Châtelet et al., 2004; Coccioni & Marsili, 2005; Frontalini & Coccioni, 2008; Cherchi et al., 2009; Frontalini et al., 2009). Using an interdisciplinary approach (micropaleontological, mineralogical, geochemical and statistical), the goal of this preliminary study is to produce environmental patterns from an impacted coastal area in the lagoon of Santa Gilla. This research provides basic data for the monitoring of coastal environmental conditions, an approach that has never before been applied in Sardinia.

1. Study area

The lagoon of Santa Gilla, on an area of about 13 km2, is located on the southern coast of Sardinia (Italy) and communicates with the Mediterranean through a narrow channel (Fig. 1). On the northern shore, the lagoon has two major freshwater inflows from the Rii Flumini Mannu and Cixerri rivers. On the west, the on-shore industrial area and the urban area of Cagliari discharged untreated wastewater from the mid-1960s to mid-1980s (Degetto et al., 1997).

Fig. 1 - Satellite image of the lagoon of Santa Gilla with sampling stations

The average depth of 1m, with a maximum of about 2m in the artificial channel that connects the lagoon to the sea (Porcu, 1976). The exchange of water with the sea is faster in the southern basin (2-3 days) while in the innermost part is about 8-12 (Degetto et al., 1997). The two main tributaries have a flow of 12 m3s-1, with peak 30 m3s-1 in winter. The lagoon is filled by sediments represented predominantly silt-sand to a depth of about 50m from the Upper Pleistocene to the present (Orrù et al., 2004). Over the last century the area has been undergoing great environmental changes, in particular a) reclamation works of Rii Cixerri and Flumini Mannu (1904); b) implementation of saltworks by Contivecchi (20s); c) the installation of the industrial complex of Macchiareddu (60s) e d) the construction of the Port Channel (70s).

Physicochemical geochemical, sedimentological and benthic foraminiferal data (biocenosis) have been analyzed to investigate the relationship between these sensitive microrganisms and trace elements pollution.

2. Materials and methods

Sediment samples were collected from 18 stations during October 2006 in the lagoon of Santa Gilla (fig. 1, tab. 1). Samples were preserved in ethanol and Rose of Bengal for biocenotic recognition (Walton, 1952). After this method, living specimens are stained in bright rose colour and can be easily differentiated from dead specimens. Live assemblages are representative of the environmental conditions. All the 18 samples were dried in over at 50°C. Subsequently, the samples were wet-sieved over 63 µm. The sediment retained in each sieve was dried at 50°C and weighed.

In this study we employ data from >63 µm size fraction and at least 300 benthic foraminifera from each sample were separated and counted using a binocular microscope.

The living assemblages (Rose Bengal stained) was utilized for statistical data processing. Benthic foraminifera were identified according to Loeblich & Tappan (1987).

The species diversity was quantified by Species Richness (S), Faunal Density (FD), Dominance (D), Shannon-Weaver (H), Evenness (J), Simpson (1-D), Equitability (E), Fisher-α.

In addition, the FAI corresponding to the total percentage of abnormal foraminiferal specimens in each sample and the Foraminiferal Monitoring Index (FMI, defined as the percentage of abnormal species within the assemblage) (Coccioni et al., 2005) were calculated for each sample.

The result of quantitative analysis were processed with statistical software (SPSS 13.0 and Statistica 6.0) in order to carry out hierarchical clustering (Q-mode Cluster Analysis) and Principal Component Analysis. Only species more abundant than 2% in at least one sample were considered to create a matrix data for the statistical analysis.

Tab. 1 **-** Geographic coordinate of sampling stations, water depth, and physicochemical characteristics of the bottom water

Stazione	Lat (N)	Long (E)	Depth (m)	T (°C)	pH	Salinity	Eh	DO (mg/l)
SG1	39° 13,249'	009° 05,202'	1,6	22,19	7,8	35,01	17	7,96
SG2	39° 13,119'	009° 05,658'	1,9	22,14	7,71	36,74	158	6,68
SG3	39° 13,695'	009° 05,347'	1,6	22,26	7,63	35,86	150	6,96
SG4	39° 14,267'	009° 05,037'	1,8	22,62	7,73	34,55	-108	6
SG5	39° 14,566'	009° 04,806'	1	23,01	8,24	32,65	2	12,92
SG6	39° 14,162'	009° 04,335'	1,4	22,51	8	32	31	9,71
SG7	39° 14,389'	009° 04,197'	1,5	22,55	7,7	33,45	60	8,33
SG8	39° 15,320'	009° 02,873'	1,8	22,92	7,8	31,98	64	7,9
SG9	39° 15,548'	009° 02,368'	1,8	23,06	8,15	30,51	62	14,94
SG10	39° 15,981'	009° 02,090'	0,9	23,77	8,19	28,56	10	1,86
SG11	39° 15,895'	009° 01,285'	0,4	24,18	8,33	22,4	-173	13,81
SG12	39° 15,024'	009° 01,684'	1,4	22,84	8,14	31,67	18	10,83
SG13	39° 14,829'	009° 01,711'	0,8	21,03	7,96	21,71	104	7,23
SG14	39° 14,506'	009° 01,850'	1,6	22,96	7,97	32,06	42	8,78
SG15	39° 14,324'	009° 02,169'	1,6	22,68	7,76	31,94	52	5,53
SG16	39° 13,841'	009° 03,809'	1,5	22,01	8,06	31,82	102	9,12
SG17	39° 13,943'	009° 04,197'	1,9	22,37	7,76	34,73	49	7,4
SG19	39° 14,102'	009° 01,289'	0,4	23,68	7,48	24,58	137	10,88

For the grain size analysis, the samples were treated with an H2O2 solution to reduce the organic matter, and were then sieved and dried at 40 °C. Grain size analysis was conducted by Sedigraph (Micrometrics 5100) to determine the percentage of silt and clay (<63 µm), whereas the >63 µm fraction was dried and fractionated by ASTM micro-sieve. Shepard (1954) grain size classification was used.

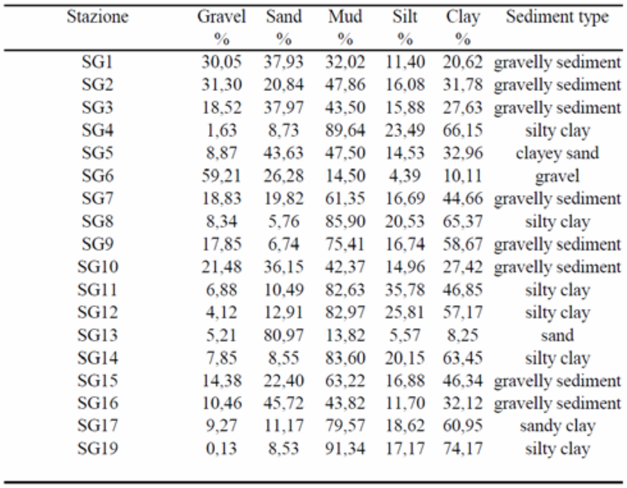
The trace element content was investigated in the superficial sediments. Activation Laboratories Ltd. (Ontario, Canada, http://www.actlabs.com) analyzed a fraction of 0.5 g of a sample for 32 elements using inductively coupled plasma optical emission spectrometry (ICP-OES), which is a multi-element technique capable of measuring concentrations at very low detection limits (mg kg^{-1} to ▯g k^{1}).

Geochemical analysis of sediments and grain-size parameter, correlated to biotic indexes provide data on the environmental stress.

3. Results

The bottom of the Santa Gilla lagoon is mostly covered by mud (60%, with an average of about 17:02% 43.04% silt and clay), except some patches in particular samples SG6, SG13, SG16 showing a tendency to coarser grain size, respectively sand, gravely and gravely sediment (tab. 2).

Tab. 2 - Grain size values and classification (Shepard, 1954)



Stazione	Gravel %	Sand %	Mud %	Silt %	Clay %	Sediment type
SG1	30,05	37,93	32,02	11,40	20,62	gravelly sediment
SG2	31,30	20,84	47,86	16,08	31,78	gravelly sediment
SG3	18,52	37,97	43,50	15,88	27,63	gravelly sediment
SG4	1,63	8,73	89,64	23,49	66,15	silty clay
SG5	8,87	43,63	47,50	14,53	32,96	clayey sand
SG6	59,21	26,28	14,50	4,39	10,11	gravel
SG7	18,83	19,82	61,35	16,69	44,66	gravelly sediment
SG8	8,34	5,76	85,90	20,53	65,37	silty clay
SG9	17,85	6,74	75,41	16,74	58,67	gravelly sediment
SG10	21,48	36,15	42,37	14,96	27,42	gravelly sediment
SG11	6,88	10,49	82,63	35,78	46,85	silty clay
SG12	4,12	12,91	82,97	25,81	57,17	silty clay
SG13	5,21	80,97	13,82	5,57	8,25	sand
SG14	7,85	8,55	83,60	20,15	63,45	silty clay
SG15	14,38	22,40	63,22	16,88	46,34	gravelly sediment
SG16	10,46	45,72	43,82	11,70	32,12	gravelly sediment
SG17	9,27	11,17	79,57	18,62	60,95	sandy clay
SG19	0,13	8,53	91,34	17,17	74,17	silty clay

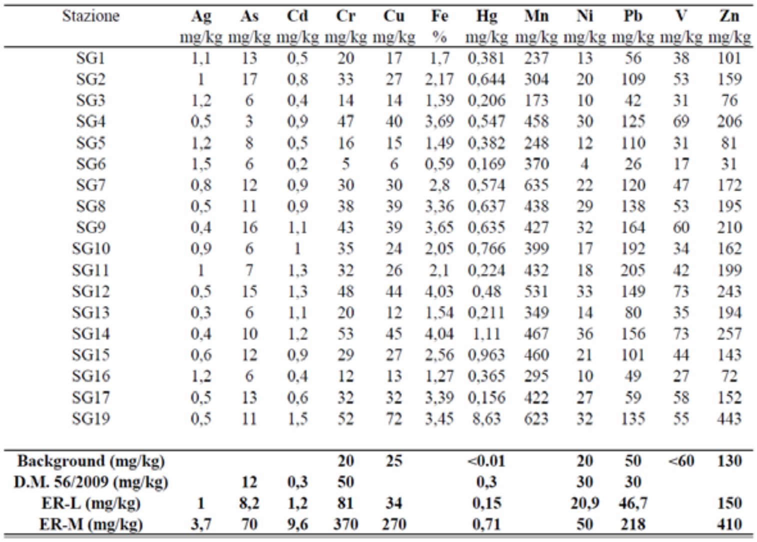
The concentration of trace elements varies greatly from the least polluted to the most polluted samples with, for example, Hg up to 8.63 mg/kg (SG19), Cd up to 1.5 mg/kg (SG19), Ni up to 36 mg/kg (SG14), and Pb up to 205 mg/kg (SG11). Some stations show occasionally enriched in As (up to 17 mg/kg, SG2) and Cr (up to 53 mg/kg, SG14) (tab. 3).

The highest concentrations of trace elements are found in the innermost part of the lagoon, in those stations located in front of the industrial complex which results more industrialized compared to the outer area.

A total of 37 benthic foraminiferal species were identified. The biocenosis of the lagoon are largely dominated by *Ammonia tepida*, *Haynesina germanica* and *Elphidium oceanensis* and, subordinately, by bolivinids (fig. 2).

During the sampling, S varies from 3 (SG12 and SG14) to 26 (SG2). The highest FD is found in station SG19 (180), with a mean of 46.9. The Shannon–Weaver index varies from 0.54 (SG17) to 2.27 (SG2), J from 0.25 (SG17) to 0.81 (SG12), D from 0.15 (SG2) to 0.74 (SG11), E from 0.19 (SG5) to 0.81 (SG12), and 1-D from 0.26 (SG17) to 0.85 (SG2). The Fisher a index ranges from 0.44 (SG14) to 5.18 (SG2), with mean values of 1. The FAI varies from station to station, ranging from 4.5 (SG3) to 10.34 (SG4) with an average value of 6.67. The FMI is between 30 (SG6) and 100 (SG12 and SG14) (tab. 4).

Tab. 3 - Trace element contents compared to background concentrations (per-industrial age) reported by Degetto et al. (1997), quality standard in sediments from coastal marine, lagoon and coastal lake waters, as established by D.M. 367/2003 and ER–L (effect range low) and ER–M (effect range median) values reported for the sediment guidelines of USEPA by Long et al. (1995) and Ligero et al. (2002)



Stazione	Ag mg/kg	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Fe %	Hg mg/kg	Mn mg/kg	Ni mg/kg	Pb mg/kg	V mg/kg	Zn mg/kg
SG1	1,1	13	0,5	20	17	1,7	0,381	237	13	56	38	101
SG2	1	17	0,8	33	27	2,17	0,644	304	20	109	53	159
SG3	1,2	6	0,4	14	14	1,39	0,206	173	10	42	31	76
SG4	0,5	3	0,9	47	40	3,69	0,547	458	30	125	69	206
SG5	1,2	8	0,5	16	15	1,49	0,382	248	12	110	31	81
SG6	1,5	6	0,2	5	6	0,59	0,169	370	4	26	17	31
SG7	0,8	12	0,9	30	30	2,8	0,574	635	22	120	47	172
SG8	0,5	11	0,9	38	39	3,36	0,637	438	29	138	53	195
SG9	0,4	16	1,1	43	39	3,65	0,635	427	32	164	60	210
SG10	0,9	6	1	35	24	2,05	0,766	399	17	192	34	162
SG11	1	7	1,3	32	26	2,1	0,224	432	18	205	42	199
SG12	0,5	15	1,3	48	44	4,03	0,48	531	33	149	73	243
SG13	0,3	6	1,1	20	12	1,54	0,211	349	14	80	35	194
SG14	0,4	10	1,2	53	45	4,04	1,11	467	36	156	73	257
SG15	0,6	12	0,9	29	27	2,56	0,963	460	21	101	44	143
SG16	1,2	6	0,4	12	13	1,27	0,365	295	10	49	27	72
SG17	0,5	13	0,6	32	32	3,39	0,156	422	27	59	58	152
SG19	0,5	11	1,5	52	72	3,45	8,63	623	32	135	55	443
Background (mg/kg)				**20**	**25**		**<0.01**		**20**	**50**	**<60**	**130**
D.M. 56/2009 (mg/kg)		**12**	**0,3**	**50**			**0,3**		**30**	**30**		
ER-L (mg/kg)	**1**	**8,2**	**1,2**	**81**	**34**		**0,15**		**20,9**	**46,7**		**150**
ER-M (mg/kg)	**3,7**	**70**	**9,6**	**370**	**270**		**0,71**		**50**	**218**		**410**

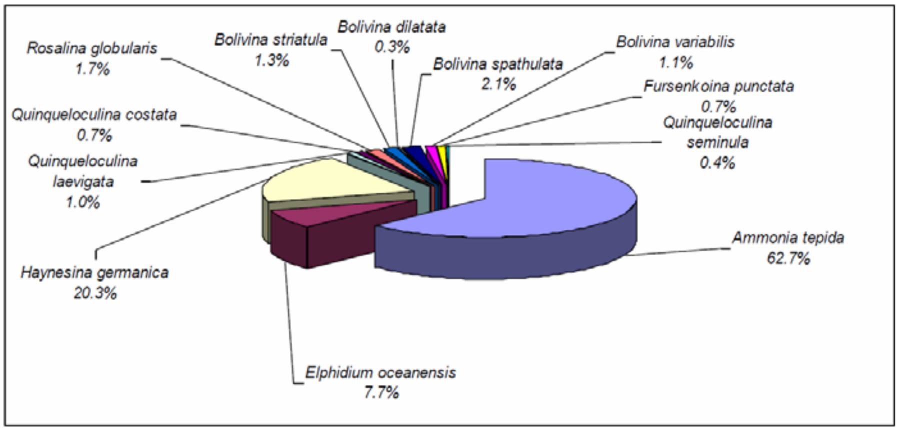


Fig. 2 - Circular diagram of the benthic foraminiferal assemblages

Abnormal specimens were recognized as belonging mainly to *A. tepida*, *E. oceanensis*, *H. germanica* and bolivinids (fig. 3).

Tab. 4 - Faunal parameters and relative abundance of selected species. The asterisk marks indicate that the species affected by morphological abnormalities. FAI = foraminiferal abnormality index and FMI = foraminiferal monitoring index

	SG1	SG2	SG3	SG4	SG5	SG6	SG7	SG8	SG9	SG10	SG11	SG12	SG13	SG14	SG15	SG16	SG17	SG19
*Ammonia tepida**	54,02	26,19	61,80	55,17	68,95	55,01	57,43	74,47	61,81	68,30	84,50	48,08	61,32	56,85	43,19	72,97	85,06	80,38
Bolivina dilatata	2,25	1,54	0,31	0,00	0,34	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,33	0,00	0,28	0,00
*Bolivina spathulata**	4,18	21,05	5,12	0,00	1,89	1,69	0,61	0,94	0,17	0,00	0,00	0,00	0,00	0,00	0,00	0,42	0,41	0,00
*Bolivina striatula**	3,22	13,35	1,71	0,00	0,51	1,95	0,61	0,47	1,22	0,00	0,00	0,00	0,00	0,00	0,00	0,84	0,00	0,00
*Bolivina variabilis**	0,96	8,34	1,55	0,00	0,51	1,17	2,44	0,47	0,35	0,12	0,00	0,00	0,00	0,00	2,33	0,42	0,83	0,00
*Elphidium oceanensis**	12,22	0,77	10,56	15,52	4,63	7,67	0,61	8,90	10,94	1,11	8,47	6,49	16,76	2,03	2,66	10,08	0,83	17,31
Fursenkoina punctata	2,89	2,57	0,93	3,45	0,17	0,91	0,61	0,47	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,14	0,00
*Hayensina germanica**	14,47	3,08	11,65	18,97	19,73	11,05	33,81	12,88	21,88	28,99	6,55	45,43	14,41	41,12	49,17	13,73	12,17	1,92
Quinqueloculina costata	0,00	1,16	0,16	0,00	0,86	2,08	0,61	0,00	1,04	0,00	0,16	0,00	5,44	0,00	0,33	0,00	0,00	0,00
Quinqueloculina laevigata	0,00	8,22	1,09	1,72	0,34	2,60	0,00	0,47	0,87	0,61	0,32	0,00	0,88	0,00	0,33	0,42	0,00	0,00
Quinqueloculina seminula	0,00	2,31	0,31	0,00	0,17	1,82	1,22	0,00	0,00	0,12	0,00	0,00	0,29	0,00	0,00	0,14	0,00	0,00
*Rosalina globularis**	2,89	5,52	3,42	1,72	1,20	10,40	1,43	0,70	1,74	0,00	0,00	0,00	0,00	0,00	1,33	0,14	0,14	0,38
S (Species Richness)	12	26	16	8	15	20	11	10	9	10	5	3	11	3	9	11	9	4
FD (Foraminiferal Density)	14,26	12,73	14,66	3,91	10,59	79,12	26,92	36,03	96,81	54,56	50,94	46,12	10,68	57,86	10,52	72,93	65,14	180,56
Fisher α index	2,48	5,18	2,97	2,52	2,81	3,75	2,00	1,83	1,51	1,61	0,74	0,45	1,86	0,44	1,75	1,85	1,45	0,67
D (Dominance)	0,33	0,15	0,41	0,37	0,52	0,33	0,45	0,58	0,44	0,55	0,73	0,44	0,43	0,49	0,43	0,56	0,74	0,68
H (Shannon-Weaver index)	1,58	2,27	1,40	1,33	1,04	1,68	1,08	0,89	1,12	0,76	0,56	0,89	1,15	0,77	1,03	0,91	0,54	0,58
1-D	0,67	0,85	0,59	0,63	0,48	0,67	0,55	0,42	0,56	0,45	0,27	0,56	0,57	0,51	0,57	0,44	0,26	0,32
J (Evenness)	0,63	0,70	0,51	0,64	0,39	0,56	0,45	0,39	0,51	0,33	0,35	0,81	0,48	0,70	0,47	0,38	0,25	0,42
E (Equitability)	0,40	0,37	0,25	0,47	0,19	0,27	0,27	0,24	0,34	0,21	0,35	0,81	0,29	0,72	0,31	0,23	0,19	0,44
FAI	4,82	5,13	4,50	10,34	7,55	5,59	9,37	6,32	6,25	5,28	6,07	7,37	6,62	7,36	6,31	5,32	5,81	10,00
FMI	50,00	30,77	37,50	37,50	33,33	30,00	45,45	50,00	33,33	40,00	60,00	100,00	36,36	100,00	33,33	36,36	33,33	75,00
no. Specimens	311,00	779,00	644,00	58,00	583,00	769,00	491,00	427,00	576,00	814,00	626,00	339,00	680,00	394,00	301,00	714,00	723,00	260,00

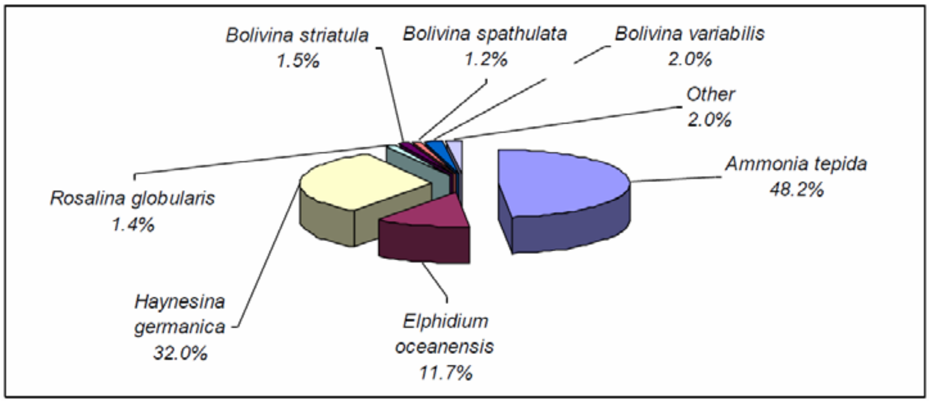


Fig. 3 - Circular diagram of the benthic foraminiferal abnormality assemblages

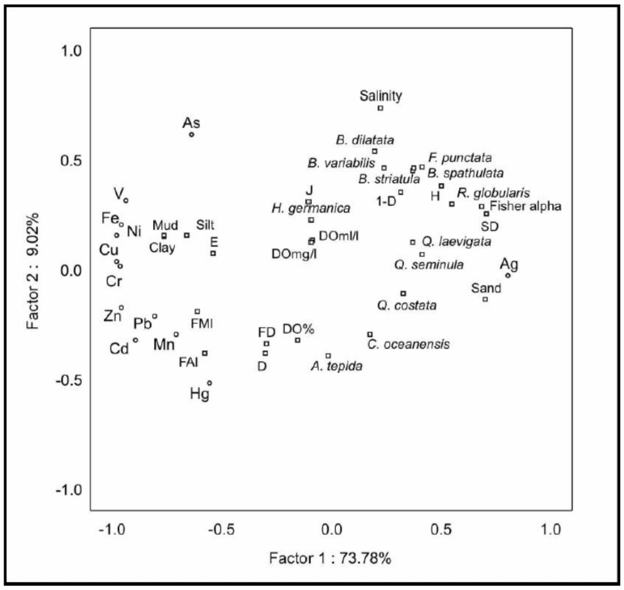


Fig. 4 - PCA ordination diagram of sampling based on the selected trace elements

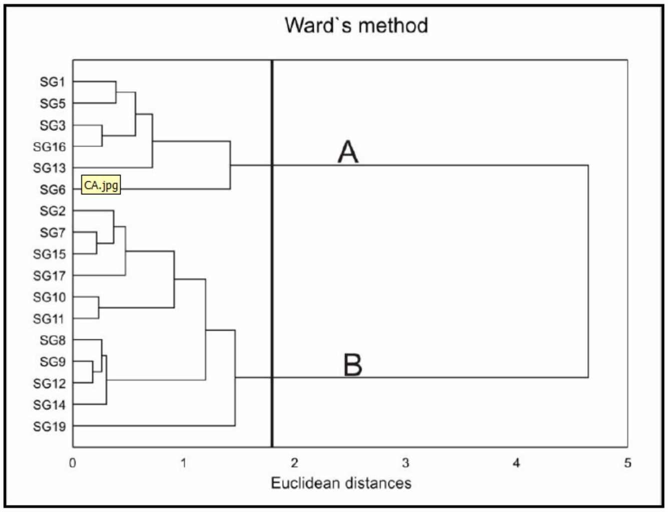


Fig. 5 - Output of Cluster Analysis (CA)

Statistical analysis, in particular PCA, shows a possible control of these pollutants both on the taxonomic composition of the benthic foraminiferal assemblages and the development of test abnormalities which is used as additional tool for the pollution monitoring (fig. 4).

The Q mode cluster analysis results in the grouping of samples into two separate clusters (A and B) according to their degree of pollution (fig. 5). Cluster A (less polluted) includes stations located near the middle-outermost part of the lagoon, whereas Cluster B (most polluted) comprises samples located in the innermost part of the study area.

Discussion and conclusion

In nature, many environmental variables together influence the functioning and composition of an ecosystem or community. In particular, heavy metal pollution in marine ecosystems affects survival, growth and reproduction of organisms in harbors, near heavy industry and mines, and in environments where riverine input is high.

The analysis of sediments and the benthic foraminifera assemblages by statistical analysis, indicated that the lagoon of Santa Gilla is deeply affected by trace element pollution (Cd, Ni, Pb, Zn and Hg).

According to trace element distributions and contents revealed by CA and PCA, the greatest degree of pollution is found in the innermost-middle part of the lagoon, which corresponds to the stations located in front of the industrial complex. Pollution recorded in this area (Cluster B) seems to be associated with the silty-clay fraction. This result is also confirmed by PCA, in which sand has no statistical affinity with any variable such as pollutants or foraminiferal species.

Each species of foraminifera has its own threshold of sensitivity to different environmental parameters and to different types of pollution. Benthic foraminifera respond to elevated concentrations of certain heavy metals by changes in their test morphology, size and structure.

Occurrence of the dominant species *Ammonia tepida*, *Haynesina germanica* and bolivinids in the sediments is commonly encountered in restricted environments under pollution stress (e.g. Setty & Nigam, 1984; Yanko & Flexer, 1991; Stubbles et al. 1993; Yanko et al. 1994, 1999; Coccioni, 2000; Armynot du Chatelet et al. 2004).

Diversity indexes (Hayek & Buzas, 1997; Spellerberg, 2005) can provide some further information on the structure of the studied communities (tab. 4).

The Fisher α index represents the richness of the benthic associations. This index is a relationship between the number of species and number of individuals in a group, in samples taken in the Santa Gilla lagoon has low values (<6) indicating stress conditions. The Shannon-Weaver index represents the number of individuals for taxon and number of taxa present in each sample. Lower values are generally recorded in correspondence of stressful environmental conditions (with opportunistic or pioneer species), with one species this index has value of 0. Usually takes values ranging between 1 and 3.5, rarely exceeding 4.5; values less than 1 indicate environmental stress is particularly high, found in heavily polluted areas. In the samples has a mean value of 1.09 indicating an environment subjected to a strong environmental stress. Both evenness and equitability are measures of the uniformity in the distribution of the different taxa (Hammer & Harper, 2005), their value being higher when all the taxa are equally abundant in the given sample.

The general trend of increasing equitability as species richness and abundances decrease suggests that whatever factor is acting on the community, it achieves two separate effects: it eliminates a number of taxa altogether, while acting on the surviving taxa by leveling out their numbers.

The assemblages of the Santa Gilla lagoon are characterized by a high number of abnormalities, probably in response to the anthropogenic discharge of pollutants. Morphological variations in the benthic foraminifera tests have been related to a mixing of several parameters: temperature, salinity, carbonate solubility, depth, nutrients, bottom type, oxygen dissolution, lighting, pollution, currents, trace elements and rapid changes in the environment (Boltovskoy et al. 1991). *A. tepida* can live in restricted environments under stress, and can acquire deformities due principally the presence of heavy metals (Sharifi et al. 1991; Yanko et al. 1998; Samir 2000). Several authors have concluded that the evaluation of deformities in the foraminifera tests could be used as a bioindicator of heavy metal pollution (Alve 1991; Yanko et al. 1994, 1998; Geslin et al. 1998). The proportions of foraminiferal abnormalities have been recorded in polluted areas by several authors: 10–20% in an estuary in England (Sharifi et al., 1991), 3–5% to 7% in a Norwegian fjord (Alve, 1991), 2–3% at the coast of Israel (Yanko et al., 1998), more than 10% in the Goro Lagoon, Italy (Coccioni, 2000) and up to 11% in the Manzalah Lagoon, Egypt (Samir, 2000).

On the basis of this study, the correlation between biodiversity (several indexes) and pollutants was recognized. A strongly positive correlation with heavy metal concentration is shown by the FAI and FMI. Cluster analysis, based on foraminiferal assemblages and geochemistry, exhibits a definite separation of the highly includes stations located in the innermost part of the study area and less polluted sampling sites near the middle-outermost part of the lagoon.

Concentration of heavy metals, which is measured in the foraminiferal species in the coastal lagoons, may serve as an indicator which helps mangers to identify anthropogenic impacts and assess the need for remediation measures.

The research on the lagoon of S. Gilla confirms and supports the suitability of studying benthic foraminifera as a technique for the *in situ* continuous biomonitoring of trace element pollution in coastal marine sediments. This work aimed at studying the response of benthic foraminifera to contaminants in the marine and transitional environments.

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