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# Benthic foraminifera from the coastal zone of Baia (Naples, Italy): Assemblage distribution and modification as tools for environmental characterisation

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ABSTRACT

The coastal zone of Baia (Naples) is currently included in a protected marine area, but in past it was affected by strong anthropogenic pressure for commercial harbour activity. In order to investigate the impact of past activities, a multidisciplinary characterisation was undertaken to evaluate the environmental quality of marine sediments. Thirty-six grab samples were collected for grain-size, heavy metals, PAHs and PCBs analyses. Rose Bengal stained replicates were taken for the analysis of benthic foraminifera. Chemical analyses highlighted sediment pollution mainly due to Cu, Hg, Pb, Zn, PAHs and PCBs in the northern and southern part of the study area, where some sunken vessels had been present for many decades. Modifications of foraminiferal diversity and density, and increased percentage of abnormal specimens, were considered as indicators of environmental degradation. Correlation between faunal parameters and pollutant concentrations was found by means of statistical analysis. The highest degree of environmental stress shown by foraminifera in the northern sector could be referable to the high concentrations of PCBs (up to 144 ng $g^{-1}$ d.w.).



## 1. Introduction

The use of foraminifera as pollution indicators started at the end of the 1950s (Zalesny, 1959). Since then, the response of foraminifera to an increasing variety of polluted environments have been investigated, demonstrating the utility of these organisms as pollution indicators (see Nigam et al., 2006 for a review).

Particularly, the response of foraminifera in important, heavily polluted harbours, such as Rio de Janeiro, Montevideo and Naples has already been studied (Vilela et al., 2004; Burone et al., 2006; Ferraro et al., 2006). Signals of environmental stress, such as lowered foraminiferal density and diversity, increased percentages of abnormal tests and specimens with reduced size were shown in these cases by the foraminiferal assemblages. More recently, Romano et al. (2009) studied the effect of heavy pollution mainly due to Hg, PAHs and PCBs on the foraminiferal assemblages from the Augusta harbour (Eastern Sicily, Italy). Stunted assemblages and percentages of abnormal specimens exceeding background values highlighted ecological degradation in the most polluted area, while foraminiferal density and diversity did not seem affected by pollution.

Foraminifera were recognised as pollution indicators also in harbours of the Atlantic French coast. Debenay et al. (2001) showed that sediment texture and pollutants influence the distribution of foraminifera in the Port of Joinville, characterised by significant Cu, Pb and Zn pollution. However, they found that the most polluted areas were characterised by an increasing abundance of pollution-tolerant species. Arminot du Châtelet et al. (2004) studied foraminifera and pollutants distribution in four moderately polluted harbours of the French coast. They found that foraminifera diversity and density were negatively correlated with heavy metal and PAHs concentration.

On the whole, from the above cited papers it may be deduced that decreased foraminiferal diversity and density, increased number of pollution-tolerant species, increased number of abnormal specimens and reduced size may be considered to be indicators of environmental degradation. However, regarding the different response of each faunal parameter, it may be concluded that the peculiar environmental setting of different areas determine different response of foraminiferal fauna.

The present study examines the results of the environmental characterisation of the coastal zone of Baia (Naples, Italy) in terms of pollutants and foraminifera distribution, also taking into account sediment features. A particular goal is to highlight, by means of statistical analysis, the correlation between pollutants distribution and faunal parameters indicating environmental stress referable to a deteriorated ecological health status of the benthic environment.

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## 2. Study area

The coastal zone of Baia is located in the Pozzuoli Gulf (Tyrrhenian Sea, Fig. 1), which is included in the Phlegrean Fields, an active volcanic area (Rosi and Sbrana, 1987), currently characterised by earthquakes, gas emissions and bradiseismic phenomena. Particularly, the Pozzuoli Gulf is the marine sector of the Phlegrean caldera which originated about 12 kyr BP from the volcano-tectonic collapse related to the deposition of the Neapolitan Yellow Tuff (Orsi et al., 1995). Successively sedimentation in the Pozzuoli Gulf was conditioned by tectonic subsidence and sea-level rise, with the deposition of volcanic deposits and marine sedimentary sequences (Russo et al., 1998). The study area is a wide bay not affected by significant fresh-water runoff. Preliminary salinity measures were carried out on coast to large transects for the environmental characterisation of the Baia marine area which included the present study. Results highlighted low salinity variability (37.72–38.03) both in space and at a single site, along the water column (unpublished data). The central part of the study area is characterised by the presence of a wide *Caulerpa prolifera* meadow.

The whole Gulf of Pozzuoli is characterised by important Roman ruins including urban sites with residential houses, thermal baths, fisheries and harbour buildings. Presently, many of these archaeological remains are below the sea-level, due to the subsidence related to the volcanic activity. Baia is the most important archaeological site in the Pozzuoli Gulf. It started to expand in the 2nd century B.C. and it reached the maximum development during the imperial age, when the site was frequented by the Roman aristocracy thanks to the presence of thermal sources. The decline started in the 4th century A.D., and gradually Baia was abandoned because of the increasing subsidence (Paoletti et al., 2005).

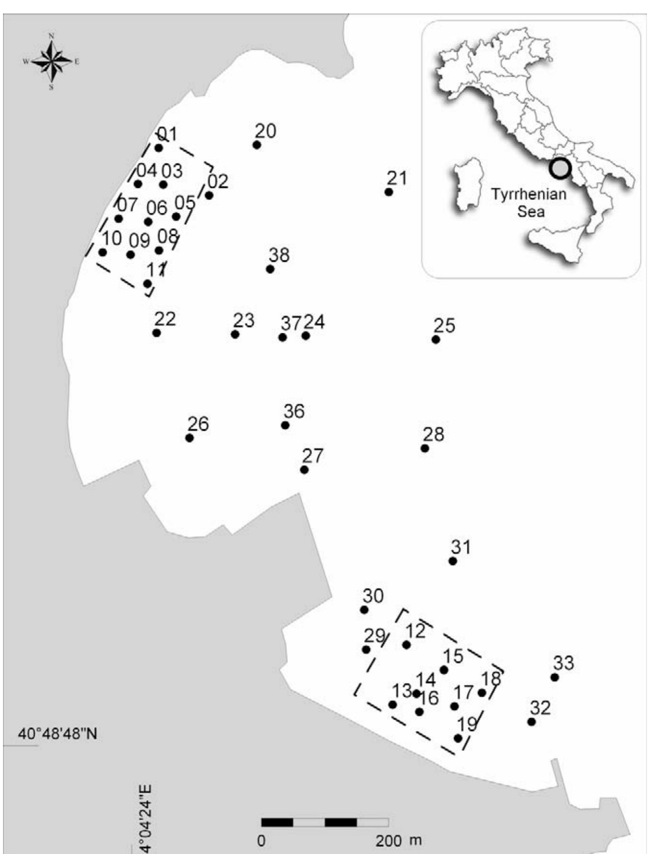


**Fig. 1.** Location of the study area and sampling stations in the Baia coastal zone. The dotted line delimits the northern and southern wreck area.

In the last decades of the 20th century, a commercial harbour was operating on the Baia coastal zone while, more recently, the same area has been used mainly for pleasure boating. The presence for many years of five abandoned sunken vessels on the sea-bottom at two different locations, in the northern and southern part of the study area, both within 5 m water depth, may have been responsible for environmental degradation. At the moment, only one of these vessels is still in place in the southern sector, while the others were removed in 2005.

In 2000 the Italian Ministry of Environment created the "Baia Underwater Park" for the safeguard of the archaeological site. The park is divided into three areas with different degrees of protection and the present study area is included the sector with the lowest degree of protection. In the same year, the coastal zone of Baia was included in the Contaminated Site of National Relevance named "Litorale Domitio Flegreo ed Agro Aversano".

## 3. Materials and methods

Thirty-six superficial sediment samples were collected by van Veen grab in January 2006, after the removal of four of the five sunken vessels, in order to investigate the degree of ecological degradation and the possible need of remediation action. The sediment sampling was organised in transects perpendicular to the coast, with a larger number of stations in two areas, called hereafter "northern wreck area" and "southern wreck area" due to the presence of the sunken vessels (Fig. 1). Three aliquots (about 50 $cm^3$) were collected, from the upper layer (2 cm) of central undisturbed grab sample, for heavy metals, PAHs and PCBs and foraminifera analysis. Sub-samples for foraminiferal analyses were immediately stained by a Rose Bengal – ethyl alcohol solution to assist with the recognition of living specimens, according to Walton (1952). All samples were analysed for grain-size, heavy metals (As, Ba, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Zn), Polycyclic Aromatic Hydrocarbons (PAHs), Polychlorinated Biphenyls (PCBs) and foraminifera (quantitative analysis).

### 3.1. Grain-size

Each sample was treated (24–48 h, room temperature) with a solution of hydrogen peroxide (30%) and distilled water (1:3), and then washed. Successively samples were wet-separated into two fractions using a sieve with a 63 μm mesh. The coarse and fine fractions were oven-dried at 40 °C and finally weighed. The coarse fraction was sieved by mechanical movement on ASTM series sieves with meshes ranging from −1 to +4 ϕ, with intervals of 0.5, and successively the sediment from each sieve was weighted. The fine fraction was split in order to obtain the maximum random distribution of grains, and then put in suspension in a solution of distilled water and sodium hexa-metaphosphate (0.05%), at the rate of 2.5 g of sample per 80 mL of solution, put in an ultrasounds bath for 2 min, and finally analysed by means of a X-ray sedigraph (Micromeritics Sedigraph 5100). Sediment typology was determined using the Shepard classification (Shepard, 1954). In order to highlight the important gravel content in some samples, this classification was modified considering gravel. So, gravel, sand and mud (silt + clay) constitute the vertices of the triangle, instead of sand, silt and clay, like as in the original classification by Shepard.

### 3.2. Heavy metals

Metal dissolution was conducted using microwave-assisted digestion (Milestone MLS Ethos TC high performance microwave digestion unit). About 0.5 g of oven-dried (48 h, 35 °C) sediment