*Bollettino della Società Paleontologica Italiana, 52 (1), 2013, 35-44. Modena*

# Preliminary data on benthic foraminiferal assemblages and sedimentological characterisation from some polluted and unpolluted coastal areas of Sardinia (Italy)

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*KEY WORDS - Living benthic foraminifera, grain-size analysis, shallow waters, Sardinia, western Mediterranean Sea.*

*ABSTRACT - The relationship between living benthic foraminiferal faunas and the grain-size distribution of surface sediments was studied in three Sardinian coastal areas: a) the shallow inner shelf between Portoscuso and S. Pietro and the S. Antioco islands; b) the Porto Torres harbour; and c) the La Maddalena Archipelago. This investigation forms part of the research project "EU MOMAR".*

*Benthic foraminifera were identified in 17 samples collected from the three analysed areas. Biotic parameters (Species' Richness, Foraminiferal Density and the Fisher-α index) were calculated to quantify the foraminiferal assemblages within the context of environmental parameters. Grain-size analyses were performed to verify the granulometric nature of the bottom sediments. On the basis of the data obtained, the spatial distribution of the foraminiferal assemblages has allowed highly to less stressed environments to be distinguished and the ecological quality status to be evaluated.*

*The most abundant taxa are* Quinqueloculina ungeriana *d'Orbigny, 1846,* Peneroplis pertusus *(Forskal, 1775) and* Ammonia tepida *(Cushman, 1926) from the Portoscuso samples,* P. pertusus, Quinqueloculina seminula *(Linnaeus, 1758) and* Q. laevigata *d'Orbigny, 1839 from the Porto Torres samples and* P. pertusus, Bolivina spathulata *(Williamson, 1858) and* Bolivina striatula *Cushman, 1922 from the La Maddalena samples. Among these dominant species,* Ammonia tepida *and bolivinids appear to show tolerance to environmental disturbance and are therefore particularly suitable as bio-indicators in coastal areas. The sampling sites characterised by better environmental conditions present an epiphytic biocoenosis with* Lobatula lobatula *(Walker & Jacob, 1798),* Planorbulina mediterranensis *d'Orbigny, 1826,* Elphidium crispum *(Linnaeus, 1758) and peneroplids.*

*Correlations are still ongoing between sedimentological features, benthic foraminiferal assemblages and chemical data from these sampled areas, with a view to understanding the environmental anthropogenic impact on coastal systems.*

*RIASSUNTO* - [Dati preliminari sulle associazioni a foraminiferi bentonici e caratterizzazione tessiturale dei sedimenti in alcune zone costiere inquinate e non inquinate della Sardegna (Italia)] - *La relazione esistente tra le biocenosi a foraminiferi bentonici e le caratteristiche granulometriche di campioni di sedimento superficiale è stata studiata in tre aree costiere della Sardegna: sud-occidentale (Portoscuso) e settentrionale (Porto Torres e La Maddalena), ed è stata eseguita nell'ambito del Progetto Europeo MOMAR.*

*Le peculiari condizioni geologiche, geomorfologiche e ambientali hanno consentito di riconoscere e quantificare le associazioni a foraminiferi sulla base degli indici biotici (Ricchezza specifica, Densità, Indice di Fisher-α) in ampi areali costieri. Le analisi granulometriche sono state eseguite al fine di documentare la natura granulometrica dei sedimenti di fondo. E' stato possibile distinguere, grazie allo studio dei foraminiferi bentonici viventi, ambienti soggetti a basso ed elevato stress ambientale ed è stato possibile valutare lo stato di qualità ecologica.*

*Le specie dominanti provenienti dai campioni di Portoscuso sono* Quinqueloculina ungeriana *d'Orbigny, 1846,* Peneroplis pertusus *(Forskal, 1775) e* Ammonia tepida *(Cushman, 1926), dai campioni di Porto Torres* P. pertusus, Quinqueloculina seminula *(Linnaeus, 1758) e* Q. laevigata *d'Orbigny, 1839 e dai campioni provenienti da La Maddalena* P. pertusus, Bolivina spathulata *(Williamson, 1858) e* Bolivina striatula *Cushman, 1922. Tra queste specie dominanti,* Ammonia tepida *e le bolivine sembrano essere le specie maggiormente tolleranti ai disturbi ambientali e sono particolarmente adatte come bioindicatori in zone costiere. I siti di campionamento caratterizzati da migliori condizioni ambientali presentano una biocenosi epifita con* Lobatula lobatula *(Walker & Jacob, 1798),* Planorbulina mediterranensis *d'Orbigny, 1826,* Elphidium crispum *(Linnaeus, 1758) e peneroplidi.*

*Correlazioni tra le caratteristiche sedimentologiche, le biocenosi a foraminiferi bentonici e i dati chimici relativi alle concentrazioni degli inquinanti inorganici e organici sono in corso di studio allo scopo di definire con maggiore dettaglio l'impatto antropico nelle aree costiere indagate.*

## INTRODUCTION

A preliminary study of shallow-water living benthic foraminifera from some coastal areas of Sardinia (Cagliari Gulf, Portoscuso, Porto Torres and La Maddalena Archipelago) has been performed as part of the research project "EU MOMAR" in order to obtain information on the environmental quality of these areas. The MOMAR

*ISSN 0375-7633* doi:10.4435/BSPI.2013.08

(Integrated System for Monitoring and Control of the Marine Environment) project aims to develop a common system of marine environmental monitoring in Tuscany, Sardinia and Corsica (VV.AA., 2012). This work improves accessibility and cross-border cooperation for the exploitation of natural resources through an integrated scientific plan, aiming to analyse the coastal marine ecosystem and the pressures upon it in order to recognize and prevent the dynamics of environmental emergencies. This study forms part of this wider project (still in progress), and examines the biodiversity of benthic foraminifera in order to focus on their potential use as biological indicators of pollution in environmentally complex settings. In this paper we have illustrated benthic foraminiferal distribution in three areas of Sardinia (Portoscuso, Porto Torres and La Maddalena) in order to identify the sites more subject to environmental stress. Living benthic foraminiferal assemblages and sedimentological characterisation of the Gulf of Cagliari have been already described in a previous paper (Buosi et al., 2013, this issue).

Benthic foraminiferal assemblages are useful as bioindicator of specific environments in coastal systems. They constitute in fact the most diverse and widespread group of shelled microorganisms in modern oceans, have relatively short life-cycles and many specimens can be retrieved from a relatively small sample (e.g., Boltovskoy & Wright, 1976; Debenay et al., 1996; Murray, 2006). Moreover, environmental parameters, such as substrate nature and texture, bathymetry, temperature, dissolved oxygen, salinity, light, sedimentation rate, organic carbon, anthropogenic pollutants, and toxins, strongly influence the distribution of living benthic foraminifera (e.g., Yanko et al., 1999; Mendes et al., 2004; Pascual et al., 2008; Armynot du Châtelet et al., 2009a, b; Frezza & Carboni, 2009; Mojtahid et al., 2009; Buosi et al., 2012; Celia Magno et al., 2012). Changes in benthic faunal abundance, species composition and variation in test morphology provide evidence of fluctuation in several environmental factors and can therefore be used as efficient tools for determining ecosystem conditions. These bioindicators are considered to be a basic way of monitoring ecological factors and anthropogenic pressure (e.g., Alve, 1991; Yanko et al., 1998; Debenay et al., 2001; Coccioni et al., 2003, 2005; Armynot du Châtelet et al., 2004; Caruso et al., 2011; Frontalini & Coccioni, 2011).

## STUDY AREAS

The sampled sites, which are in the southwest and the northern coastal systems of Sardinia (Fig. 1), are remarkably varied in terms of interrelated ecological factors. Physiographical and geomorphological features, and the variability of the nature of the substrates, grain-size and texture of the bottom sediments, as well as water depth, hydrodynamic energy and temperature, differ between the analysed coastal settings. The anthropogenic activity in these coastal areas also has a major impact in differential ways (e.g., heavy metal contaminations, $CO_2$ discharge, PAHs, etc.) on the bottom environmental conditions.

### *The Portoscuso area*

Physiographically, the coastal area is partially bordered to the south and west by the islands of S. Pietro and S. Antioco, but is connected to the north by the open sea (Fig. 1d). The coastline is dominated by sandy deposits (Pleistocene-Holocene in age), while Oligo-Miocene volcanic rocks crop out northwards of Portoscuso, S. Pietro and S. Antioco islands. In this area, which is limited by volcanic frameworks and fairly sheltered, alluvial plains and coastal lagoons developed from the Pleistocene to the Holocene. Eolianites and silty submarine beaches characterise the bottom sediments between Portoscuso and Calasetta. The volcanic rocky bottom is covered irregularly by gravel and sand, at the northeastern end of the S. Pietro Island (Atzeni & Ginesu, 1993; Di Gregorio et al., 1996). This south-western coast of Sardinia has been under major anthropogenic pressure since the 1960s, when the Portoscuso-Portovesme district began to develop and expand its activities. The Portovesme Harbour, built in 1870 to ship ores (zinc blend, galena and pyrite) from the historical mines of the Sulcis-Iglesiente district, received major inputs from industrial discharge until a few decades ago. Previous environmental studies on heavy metal contaminations were carried out by several authors (Schintu & Degetto, 1999; Bettini & Zannin, 2002; ARPAS, 2007; Cherchi et al., 2009, 2012). The sampling stations have been selected for their different environmental conditions. A major industrial district and a loading port (Portovesme) are located south of Portoscuso (PS7, PS8), ferry traffic is a daily presence at Calasetta (PS13), while in the shelf facing the sandy beach to the west of Calasetta (PS12), and in the northern end of S. Pietro Island (PS16), there is only tourist traffic during summer.

### *The Porto Torres area*

The wide inlet of Porto Torres is situated in the northern part of the Oligo-Miocene basin of Sardinia, which spreads into the Gulf of Asinara (Thomas & Gennesseaux, 1986). Sand and silt bottom sediments cover the Paleozoic substrate at the Stintino peninsula, which belongs to the Hercynian metamorphic complex. Marine Burdigalian deposits crop out along the coastline near Porto Torres, where major industrial and commercial activities are located. Porto Torres is one of the most important harbours in Sardinia both in terms of passengers and goods' traffic (mainly petrochemical products), and is divided into two main sections: the civilian harbour (PT10), which is semi-enclosed and bounded by the western wharf to the west and north-west, and the eastern wharf on the east and north-east, whereas the industrial harbour (PT5 and PT8) is located at west of the civil harbour. The PAHs (Polycyclic aromatic hydrocarbons) concentrations in the Porto Torres' sediments range from relatively low to moderate when compared to other urbanized worldwide coastal area and this is probably due to oil spills from petrochemical plants near the shoreline, and from ships and tankers (De Luca et al., 2004). In the Gulf of Asinara, the sampled stations are located respectively at the northern end of the peninsula of Stintino, facing the Asinara Island (PT1, Fig. 1a), and in the Porto Torres harbour (PT5, PT8, PT10; Fig. 1b).

*La Maddalena Archipelago*

This archipelago, which is located northeastern to Palau (Fig. 1c), represents the final part of the NNE Hercynian plutonic basement, which is comprised prevalently of leucogranites and crossed by the N-S late dykes' system. The islands and the coasts of northeast Sardinia (Gallura) form a complex system of channels, bays and paleo-fluvial valleys (*rias*) (Bartole & De Muro, 2012). Regressive-transgressive eustatic cycles have been responsible for erosional and depositional events, the last of which is Pleistocene-Holocene in age. This area is characterised by numerous small and larger islands in which sand and silt from a granite source comprise the bottom sediments (MA6, MA9, MA22 and MA24). The archipelago belongs to a natural park, which ensures environmental protection. It is only in the La Maddalena harbour (MA27, MA28) and at the S. Stefano stations (MA29, MA30) that anthropogenic pressure is recorded, due to decades of military activities.

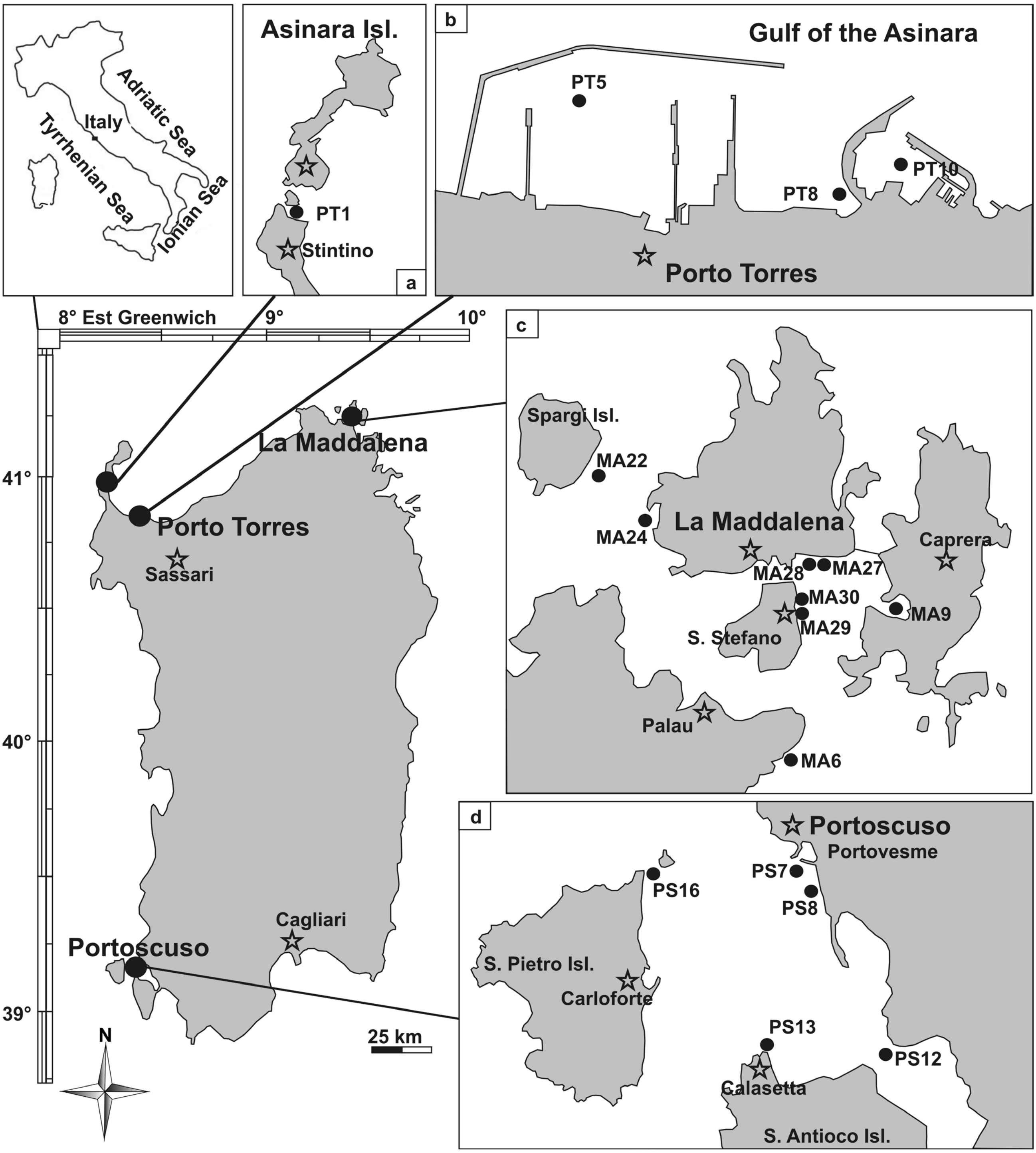


Fig. 1 - Study area and location of sampling stations: a) Asinara Island, b) Porto Torres harbour c) La Maddalena Archipelago and d) Portoscuso area.

## MATERIALS AND METHODS

This study is based on 17 surface sediment samples collected from the three areas described above: Portoscuso, Porto Torres and La Maddalena. The samples were obtained by means of a Van Veen grab sampler (3 l) which collects sediment over a surface area of about 400 $cm^2$ (about 0-2 cm depth). According to Schönfeld et al. (2012) grab samplers create a strong bow wave when they touch the ground. Furthermore, grabs may only scrape the surface, distort the structure of the underlying sediments, and often do not close accurately. A large part of the sample is washed out when the grab is hoisted through the water column, and an intact sediment surface is rarely preserved (Schönfeld, 2012). In our case, the device that we have used was appropriate, the jaws were closed tightly and the sediment surface was at pristine condition.

Two aliquots from each sample were taken at each station and stored in polyethylene jars. The first was used for a thorough study of the benthic foraminiferal assemblages and the second for sedimentological analysis.

Samples for the foraminiferal analysis were preserved in ethanol and Rose Bengal (2 g of Rose Bengal in 1000 ml of ethyl alcohol) for at least two weeks for biocenotic recognition (Walton, 1952; Schönfeld et al., 2012). When using this method, living specimens are stained a bright rose colour and can be easily differentiated from their dead counterparts. All samples, a constant volume of about 50 $cm^3$, were dried at 50 °C and weighed. They were then gently washed with tap water through a 63 µm sieve to remove clay, silt and any excess dye. The residual fraction so obtained was re-dried at 50 °C and weighed again to determine by difference the mud fraction. In this study we employ data from a >63 µm size fraction and, when possible, at least 300 benthic foraminifera from each sample were separated and counted using a binocular microscope. All counted foraminifera have to be picked out and stored in micropalaeontological slides. Benthic foraminifera were identified according to Loeblich & Tappan (1987), Cimerman & Langer (1991), Sgarrella & Moncharmont Zei (1993), Hottinger et al. (1993). Furthermore, other publications about the Mediterranean Sea were studied (e.g., Bizon & Bizon, 1984; Langer, 1993; Mendes et al., 2004; Frezza & Carboni, 2009). Species' diversity was quantified by Species' Richness (S, the number of species in a sample), Foraminiferal Density (FD, the number of specimens per 1 g of dry sediment) and the Fisher-α index, calculated using the PAST statistical software (Hammer et al., 2001).

In order to obtain the particle size distribution of the inorganic components, the sediment samples were pre-dried, weighed and treated with 10% hydrogen peroxide ($H_2O_2$). Thereafter, the sediments were washed using a 63 µm sieve. The <6700 µm and >63 µm fraction was then further dry sieved through a battery of sieves spaced at 1/4 phi (ø) per unit. The <63 µm fractions were, when present, preserved and analysed using the pipette sedimentation method (Folk & Ward, 1957; Folk, 1974).

A 0.5% sodium hexametaphosphate solution was used to analyse the fine fraction by pipette; at this concentration, the sodium hexametaphosphate acts as dispersant.

## RESULTS

Table 1 shows the grain-size characterisation of the bottom sediments from the study areas.

The samples collected at the Portoscuso stations are composed of sand (95.7%-99.8%), with a minimum percentage of gravel (8%). The only sample taken at S. Pietro Isl. (PS16) is constituted of gravelly sand. In northern Sardinia, the samples that were located in the innermost part of the port area of Porto Torres are mainly made of gravelly mud (PT5), sandy mud (PT8) and silty sand (PT10), whereas the sample from Asinara Isl. (PT1) is composed of sandy sediment. The bottom sediments

| Sample | Lat (N) | Long (E) | Depth (m) | % Gravel | % Sand | % Silt | % Clay | Sediment type |
|---|---|---|---|---|---|---|---|---|
| PS7 | 39.18595 | 008.38804 | 9 | 0.6 | 99.4 | 0.0 | 0.0 | Slightly gravelly sand |
| PS8 | 39.17978 | 008.40058 | 3 | 0.1 | 99.8 | 0.1 | 0.0 | Slightly gravelly sand |
| PS12 | 39.11162 | 008.43677 | 1 | 4.3 | 95.7 | 0.0 | 0.0 | Slightly gravelly sand |
| PS13 | 39.11333 | 008.37333 | 4 | | | | | No analysis |
| PS16 | 39.18451 | 008.31029 | 5 | 28.3 | 71.7 | 0.0 | 0.0 | Gravelly sand |
| PT1 | 40.96371 | 008.21453 | 2 | 7.9 | 92.1 | 0.0 | 0.0 | Gravelly sand |
| PT5 | 40.84771 | 008.36146 | 14 | 5.1 | 25.7 | 35.8 | 33.4 | Gravelly mud |
| PT8 | 40.83976 | 008.39161 | 3 | 0.0 | 40.3 | 38.4 | 21.3 | Sandy mud |
| PT10 | 40.84183 | 008.39807 | 4 | 0.0 | 78.2 | 15.7 | 6.1 | Silty sand |
| MA6 | 41.163589 | 009.417765 | 6 | 1.8 | 92.0 | 6.2 | 0.0 | Slightly gravelly sand |
| MA9 | 41.200912 | 009.453142 | 4 | 14.1 | 82.5 | 3.4 | 0.0 | Gravelly sand |
| MA22 | 41.233851 | 009.355595 | 5 | 0.6 | 97.9 | 1.5 | 0.0 | Slightly gravelly sand |
| MA24 | 41.22062 | 009.377201 | 11 | 3.2 | 95.4 | 1.4 | 0.0 | Slightly gravelly sand |
| MA27 | 41.211394 | 009.428949 | 10 | 7.9 | 53.4 | 15.0 | 23.7 | Gravelly muddy sand |
| MA28 | 41.2123 | 009.43127 | 10 | 12.9 | 68.7 | 14.5 | 3.9 | Gravelly muddy sand |
| MA29 | 41.2005 | 009.42138 | 9 | 15.8 | 63.6 | 15.1 | 5.4 | Gravelly muddy sand |
| MA30 | 41.20308 | 009.42073 | 8 | 25.0 | 52.7 | 14.1 | 8.2 | Gravelly muddy sand |

Tab. 1 - Depth and grain size of the examined samples (granulometric data for PS13 were lost). Classification follows Folk and Ward (1957).

of La Maddalena are constituted of sand (76%), with an average percentage of gravel of 10% and mud of 14%. Most of the stations that are located in peripheral sites in the area around La Maddalena (MA6, MA9, MA22 and MA24) belong to the sand group (slightly gravelly sand and gravelly sand). The samples taken from the innermost part of the port area of the La Maddalena and S. Stefano Isl. (MA27, MA28, MA29 and MA30) are comprised of gravelly muddy sand (Tab. 1).

Benthic foraminiferal assemblages are highly different in the study areas, varying between coastal areas characterised by bad, poor, moderate, good and high ecological quality status of environment (Fig. 2).

In the Portoscuso area (Fig. 2a), we recognized a total of 64 species belonging to 35 genera: 18 species have relative abundances greater than 5% in at least one sample (Tab. 2). The living assemblages are largely dominated by *Quinqueloculina ungeriana* d´Orbigny, 1846 (10%) and subordinately by *Peneroplis pertusus* (Forskal, 1775) (7%) and *Ammonia tepida* (Cushman, 1926) (7%) (Fig. 3a). Sample PS8 has the highest biodiversity, with 37 different taxa identified (S), and 4.54 and 10.93 values for FD and Fisher-α, respectively. The most abundant species are: *P. pertusus*, *Peneroplis planatus* (Fichtel & Moll, 1798), *Elphidium crispum* (Linnaeus, 1758) and *Lobatula lobatula* (Walker & Jacob, 1798). Species' Richness and FD significantly decline in samples PS13 (9 and 2.59) and PS16 (4 and 0.06), collected near the Calasetta harbour and S. Pietro Isl., respectively.

The living biocoenosis from the Porto Torres samples consists of 74 species and 40 genera (Fig. 2b), with 12 species having a relative abundance greater than 5% in at least one sample (Tab. 2). The most abundant taxa are *P. pertusus* (18%), *Quinqueloculina seminula* (Linnaeus, 1758) (8%) and *Q. laevigata* d´Orbigny, 1839 (6%) (Fig. 3b). In sample PT5 the biotic indices reveal significant low values in Species' Richness (5), Fisher-α index (0.00) and FD (0.23). The highest values were recovered in sample PT1 for S (33) and FD (16.74) indexes, and in sample PT8 for Fisher-α (13.10) index.

Foraminiferal distribution in the La Maddalena area is highly variable (Fig. 2c). A total of 40 genera and 78 benthic foraminiferal species were identified, with 12 species having a relative abundance greater than 5% in at least one sample (Tab. 2, Fig. 3c). Foraminiferal Density (FD) varies from 0.04 at station MA29 to 7.04 at station MA22. Species' Richness is also variable, ranging from three species at stations MA29 and MA30 to 39 at station MA22 (southeast of Spargi Isl.). The Fisher-α index ranges from 0 in the MA29 and MA30 samples (S. Stefano harbour) to 14.70 in MA22. In the MA27-30 samples, the biocoenosis is almost absent, with very few of the stained individuals belonging to *Bolivina striatula* Cushman, 1922, *B. spathulata* and *Rosalina globularis* d´Orbigny, 1826. In the sampling sites characterised by better environmental conditions and located far away from the port areas (MA6, MA9, MA22 and MA24), the foraminiferal assemblages are dominated by *P. pertusus*, *P. planatus* and *R. globularis*.

This paper is a preliminary status report of a still ongoing project and thus the number of samples and supplementary information on foraminiferal biocoenosis are limited. Correlations will be performed

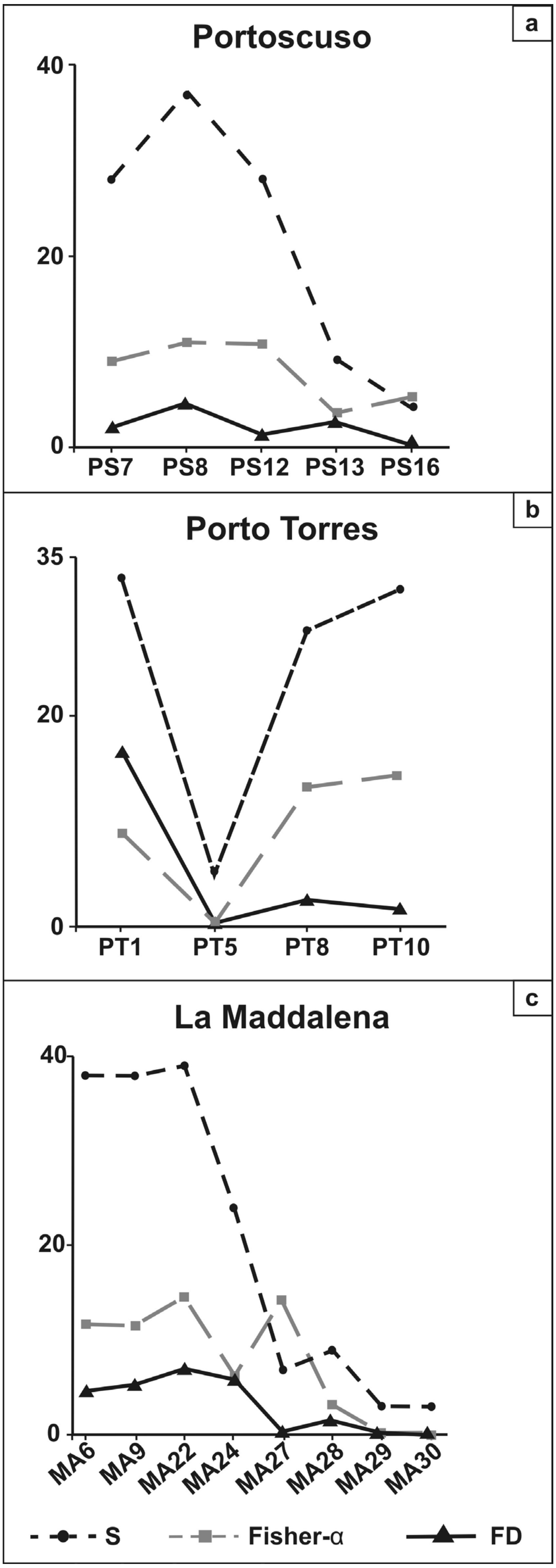


Fig. 2 - Biotic indices from the: a) Portoscuso area, b) Porto Torres area and c) La Maddalena Archipelago.

| Portoscuso | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PS7 | | PS8 | | PS12 | | PS13 | | PS16 | |
| | n. | % | n. | % | n. | % | n. | % | n. | % |
| *Ammonia beccarii* (Linnaeus, 1758) | 31 | 15.65 | 6 | 1.92 | 10 | 7.46 | 0 | 0.00 | 0 | 0.00 |
| *Ammonia tepida* (Cushman, 1926) | 0 | 0.00 | 0 | 0.00 | 5 | 3.73 | 13 | 32.50 | 0 | 0.00 |
| *Asterigerinata mamilla* (Williamson, 1848) | 0 | 0.00 | 23 | 7.37 | 2 | 1.49 | 0 | 0.00 | 0 | 0.00 |
| *Bolivina spathulata* (Williamson, 1858) | 0 | 0.00 | 5 | 1.60 | 3 | 2.23 | 9 | 22.50 | 0 | 0.00 |
| *Bolivina striatula* Cushman, 1922 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 6 | 15.00 | 0 | 0.00 |
| *Elphidium crispum* (Linnaeus, 1758) | 14 | 7.07 | 3 | 0.96 | 13 | 9.70 | 0 | 0.00 | 0 | 0.00 |
| *Elphidium macellum* (Fichtel & Moll, 1798) | 0 | 0.0 | 7 | 2.24 | 13 | 9.70 | 0 | 0.00 | 0 | 0.00 |
| *Lobatula lobatula* (Walker & Jacob, 1798) | 8 | 4.04 | 30 | 9.61 | 14 | 10.44 | 0 | 0.00 | 0 | 0.00 |
| *Peneroplis pertusus* (Forskal, 1775) | 1 | 0.50 | 97 | 31.08 | 3 | 2.23 | 0 | 0.00 | 0 | 0.00 |
| *Peneroplis planatus* (Fichtel & Moll, 1798) | 3 | 1.51 | 18 | 5.76 | 14 | 10.44 | 0 | 0.00 | 0 | 0.00 |
| *Quinqueloculina auberiana* d'Orbigny, 1839 | 20 | 10.10 | 10 | 3.20 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| *Quinqueloculina limbata* d´Orbigny, 1826 | 30 | 15.15 | 1 | 0.32 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| *Quinqueloculina stelligera* Schlumberger, 1893 | 0 | 0.00 | 16 | 5.12 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| *Quinqueloculina ungeriana* d´Orbigny, 1846 | 28 | 14.14 | 7 | 2.24 | 0 | 0.00 | 0 | 0.00 | 2 | 33.33 |
| *Rosalina floridana* (Cushman, 1922) | 0 | 0.00 | 0 | 0.00 | 7 | 5.22 | 0 | 0.00 | 0 | 0.00 |
| *Rosalina globularis* d´Orbigny, 1826 | 0 | 0.00 | 7 | 2.24 | 5 | 3.73 | 2 | 5.00 | 0 | 0.00 |
| *Rosalina macropora* (Hofker, 1951) | 0 | 0.00 | 18 | 5.76 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| *Siphonaperta aspera* (d'Orbigny, 1826) | 0 | 0.00 | 4 | 1.28 | 8 | 5.97 | 0 | 0.00 | 0 | 0.00 |
| No. specimens | 198 | | 312 | | 134 | | 40 | | 6 | |

| Porto Torres | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | PT1 | | PT5 | | PT8 | | PT10 | |
| | n. | % | n. | % | n. | % | n. | % |
| *Ammonia tepida* (Cushman, 1926) | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 11 | 9.24 |
| *Bolivina spathulata* (Williamson, 1858) | 0 | 0.00 | 0 | 0.00 | 5 | 5.10 | 2 | 1.68 |
| *Miliolinella subrotunda* (Montagu, 1803) | 9 | 2.55 | 0 | 0.00 | 3 | 3.06 | 15 | 12.60 |
| *Peneroplis pertusus* (Forskal, 1775) | 167 | 47.44 | 0 | 0.00 | 22 | 22.44 | 3 | 2.52 |
| *Peneroplis planatus* (Fichtel & Moll, 1798) | 30 | 8.52 | 0 | 0.00 | 7 | 7.14 | 4 | 3.36 |
| *Planorbulina mediterranensis* d'Orbigny, 1826 | 9 | 2.55 | 0 | 0.00 | 4 | 4.08 | 10 | 8.40 |
| *Quinqueloculina auberiana* d'Orbigny, 1839 | 23 | 6.53 | 0 | 0.00 | 4 | 4.08 | 0 | 0.00 |
| *Quinqueloculina laevigata* d´Orbigny, 1839 | 7 | 1.98 | 0 | 0.00 | 13 | 13.26 | 12 | 10.08 |
| *Quinqueloculina seminula* (Linnaeus, 1758) | 9 | 2.55 | 1 | 20.00 | 0 | 0.00 | 10 | 8.40 |
| *Quinqueloculina stalkeri* Loeblich & Tappan, 1953 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 7 | 5.88 |
| *Rosalina globularis* d´Orbigny, 1826 | 0 | 0.00 | 0 | 0.00 | 5 | 5.10 | 1 | 0.84 |
| *Spirillina vivipara* Saidova, 1975 | 0 | 0.00 | 0 | 0.00 | 6 | 6.12 | 0 | 0.00 |
| No. specimens | 352 | | 5 | | 98 | | 119 | |

| La Maddalena | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MA6 | | MA9 | | MA22 | | MA24 | | MA27 | | MA28 | | MA29 | | MA30 | |
| | n. | % | n. | % | n. | % | n. | % | n. | % | n. | % | n. | % | n. | % |
| *Ammonia tepida* (Cushman, 1926) | 1 | 0.34 | 0 | 0.00 | 10 | 5.18 | 0 | 0.00 | 0 | 0.00 | 1 | 1.79 | 1 | 33.33 | 0 | 0.00 |
| *Bolivina spathulata* (Williamson, 1858) | 13 | 4.45 | 2 | 0.66 | 6 | 3.10 | 0 | 0.00 | 2 | 22.22 | 15 | 26.78 | 0 | 0.00 | 1 | 33.33 |
| *Bolivina striatula* Cushman, 1922 | 8 | 2.73 | 1 | 0.33 | 10 | 5.18 | 0 | 0.00 | 1 | 11.11 | 16 | 28.57 | 1 | 33.33 | 0 | 0.00 |
| *Elphidium crispum* (Linnaeus, 1758) | 0 | 0.00 | 7 | 2.32 | 1 | 0.51 | 35 | 11.07 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| *Peneroplis pertusus* (Forskal, 1775) | 47 | 16.09 | 117 | 38.87 | 37 | 19.17 | 95 | 30.06 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| *Peneroplis planatus* (Fichtel & Moll, 1798) | 36 | 12.32 | 24 | 7.97 | 3 | 1.55 | 45 | 14.24 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| *Quinqueloculina laevigata* d´Orbigny, 1839 | 7 | 2.39 | 4 | 1.32 | 13 | 6.73 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| *Quinqueloculina stelligera* Schlumberger, 1893 | 4 | 1.36 | 0 | 0.00 | 11 | 5.69 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| *Quinqueloculina ungeriana* d´Orbigny, 1846 | 2 | 0.68 | 0 | 0.00 | 9 | 4.66 | 42 | 13.29 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| *Rosalina globularis* d´Orbigny, 1826 | 60 | 20.54 | 14 | 4.65 | 11 | 5.69 | 2 | 0.63 | 0 | 0.00 | 15 | 26.78 | 0 | 0.00 | 0 | 0.00 |
| *Sorites orbiculus* (Forskal, 1775) | 15 | 5.13 | 7 | 2.32 | 5 | 2.59 | 13 | 4.11 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| *Sorites variabilis* Lacroix, 1941 | 19 | 6.50 | 34 | 11.29 | 1 | 0.51 | 2 | 0.63 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| No. specimens | 292 | | 301 | | 193 | | 316 | | 9 | | 56 | | 3 | | 3 | |

between sedimentological features, benthic foraminiferal assemblages and chemical data from these sampled areas, with a view to understanding the environmental anthropogenic impact on coastal systems.

## DISCUSSION

The worldwide urbanization of coastal systems, lagoons and estuaries, leading to the continuous discharge of human-derived contaminants, has resulted in the widespread contamination of these environments. The contaminants usually sink from the water column into the bottom sediments that act as a natural trap. Because benthic organisms dwell in these sediments, they have been used as a traditional tool for the study of pollution impact on coastal environments (e.g., Dabbous & Scott, 2012).

The sediments from the examined areas are predominantly composed of sand, with varying percentages of gravel and mud. The highest amounts of fine sediment are found in port areas like Porto Torres (PT5 and PT8), La Maddalena (MA27 and MA28) and the S. Stefano (MA29 and MA30) harbours to the north (Fig. 1). With the installation of permanent large scale docks, coastal marine currents were significantly modified and harbour structures act as traps for fine-grained sediments, mainly clay and silt. These types of muddy sediments characterise many industrialized harbour basins worldwide and profoundly influence the composition of foraminiferal assemblages (Armynot du Châtelet et al., 2011). Muddy sediments favour contaminant accumulation, such species are more exposed to polluted habitats and consequently their tolerance to anthropogenically-altered conditions may be considered an adaptive strategy (Celia Magno et al., 2012). Benthic foraminiferal taxa that can tolerate highly stressed environments are among the last organisms that disappear at heavily impacted sites (Scott et al., 2001). In the studied assemblages, we noted a decline in biodiversity under the more stressed ecological conditions, the lowest values in Species' Richness, Foraminiferal Density and the Fisher-α index.

In samples from Portoscuso coastal areas, we found the lowest biodiversity values in the PS13 and PS16 samples, located respectively at the Calasetta port and the northern end of S. Pietro Island. The harbours and dockyards are known as important sites where sediment-associated pollutants can accumulate and where foraminiferal diversity declines, as reported by several authors (e.g., Debenay et al., 2001; Armynot du Châtelet et al., 2004, 2011; Coccioni et al., 2009; Ferraro et al., 2009; Martins et al., 2011). In the samples collected in the port area of Calasetta, the accumulation of high concentrations of contaminants in the sediments may be the cause of the stressed conditions highlighted by our benthic foraminiferal analysis. As for sample PS16, we hypothesize that there is a significant influence on the distribution of the biocenosis due to the bathymetry and granulometric features of the sediment. Its texture, which is predominantly coarse sand, is probably not conducive

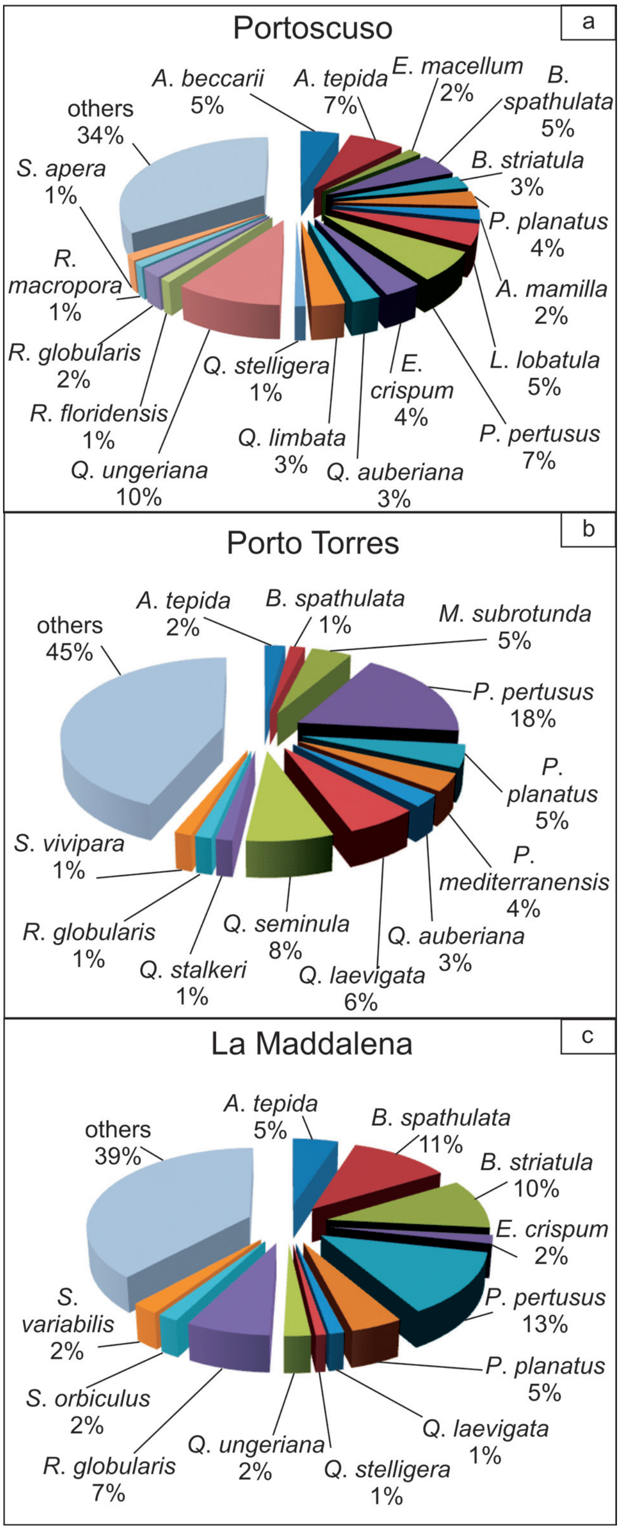

Fig. 3 - Relative abundance of species in the: a) Portoscuso area, b) Porto Torres area and c) La Maddalena Archipelago.

to the accumulation of metals. The dominant biocoenosis comprising epiphytic and epifaunal species, such as *Q. ungeriana*, *P. pertusus, A. tepida*, *E. crispum* and *L. lobatula*, that are widespread, with notable abundance

Tab. 2 - List of species with relative abundance greater than 5% in at least one sample, for each geographic area.

on the bottoms with vegetation cover, particularly on *Posidonia oceanica* (L.) Delile, 1813 leaves and rhizomes (Langer, 1988). The stressed environmental conditions in the Portoscuso area have also been highlighted in a previous study (Cherchi et al., 2009) by way of an analysis of the biotic indices of foraminifera tests. In this polluted area, increasing pollution resulted in low species' diversity, low population density and more frequent abnormal specimens. Studies of marine sediments collected in Portoscuso-Portovesme revealed high concentrations of Hg, Cd, Pb and Zn (Schintu & Degetto, 1999; Cherchi et al., 2009). The metal concentration falls with an increase in distance between the sampling station and the industrial effluent discharge point. The statistical analysis reported by Cherchi et al. (2009) reveals the possible control of the pollutants with respect to both the taxonomic composition of the benthic foraminiferal assemblages and the development of test abnormalities. The discovery of very depauperate foraminiferal assemblages and the occurrence of abnormalities were particularly emphasized in the Portovesme stations near the industrial complex and along the south coast that receives the industrial pollutant flux transferred by the southwards littoral current. The foraminiferal assemblages recognized in our study are very similar to those reported by Cherchi et al. (2009). The differences concern only the greater relative abundance of bolivinids that are known to survive in oxygen-deficit environments (Bernhard, 1986; Murray, 1991; Debenay, 2009). In polluted areas these species are found in high proportions in muddy sediments, where they resist metal increases and other chemical pollution (e.g., Debenay et al., 2001; Frontalini et al., 2009; Armynot du Châtelet et al., 2011).

In our samples from northern Sardinia (Fig. 1), foraminiferal diversity is higher in samples located far away from the port areas, in particular near the Asinara Isl. (northwest Sardinia, PT1) and in the Spargi e Caprera islands (La Maddalena Archipelago, MA9 and MA22) that present better environmental conditions, also highlighted by the highest values of biotic index (16.74 FD and 14.70 Fisher- α index). The biocoenosis at these sites is dominated by epiphytic species like *P. pertusus*, *P. planatus* and *Planorbulina mediterranensis* d'Orbigny, 1826, miliolids, and species of the gen. *Rosalina*. The other analysed sampling sites of north Sardinia (Porto Torres, La Maddalena and S. Stefano harbours) reveal a drastic fall in Species' Richness, the Fisher-α index and Foraminiferal Density, with a greater abundance of opportunistic infaunal species like *A. tepida* and bolivinids. These taxa have been reported by several authors as species tolerant to trace element pollution, and their increasing dominance is an indicator of stressed environmental conditions (e.g., Setty & Nigam, 1984; Murray, 1991; Frontalini & Coccioni, 2008; Frontalini et al., 2009; Armynot du Châtelet et al., 2011). According to De Luca et al. (2004), the PAHs (Polycyclic aromatic hydrocarbons) concentrations in the Porto Torres' sediments range from relatively low to moderate when compared to other urbanized worldwide coastal areas. According to these authors, the general pollution source in Porto Torres harbour is probably due to oil spills from petrochemical plants near the shoreline, and from ships and tankers with respect to the presence of pyrolytic PAHs in more polluted sediments. Meanwhile, this also indicates the negligible contribution of terrigenous flows (e.g. municipal or river waters) to the PAH balance of the harbour. Indeed, Lafabrie et al. (2009) found high Pb concentrations at Porto Torres harbour. The different type of bottom sediment, constituted by silty sand, linked to the low hydrodynamic energy and the high concentrations of nutrients that characterise the harbour environments could explain the higher biodiversity values observed in PT10 sample from the Porto Torres harbour compared with the other samples collected in this area. These environmental conditions can cause the growth of large populations (Armynot du Châtelet et al., 2009a, 2011), even if the input of large amounts of organic material can also obliterate the benthic community.

Foraminiferal studies of northern Sardinia-southern Corsica are still very rare, and mainly focus on the distribution and ecology of assemblages in the Strait of Bonifacio (Buosi et al., 2012), Lavezzi Isl. (southern Corsica; Langer, 1988) and the Corsica shelf (Bizon & Bizon, 1984). Buosi et al. (2012) have shown that the qualitative and quantitative distribution of foraminifera in the Strait of Bonifacio is greatly influenced by strong currents, bathymetry and the sedimentary substrate. In particular, sediment texture, which is heavily influenced by hydrodynamics, is a critical parameter in the distribution of species. Under the highest current velocities, the coarse sands and gravels include a foraminiferal assemblage dominated by *Textularia agglutinans* d'Orbigny, 1839, *E. crispum* and *Eponides concameratus* (Montagu, 1808). Agglutinated shells, particularly textulariids, are very common (15-20%) in the sediments in the Strait of Bonifacio. Epiphytic species, especially *Rosalina vilardeboana* d'Orbigny, 1839, *L. lobatula* and *P. mediterranensis*, are strongly influenced by the distribution of *Posidonia* meadows.

In a recent paper, Bouchet et al. (2012) define criteria for the use of benthic foraminifera as a quick and efficient biomonitoring tool for implementing marine legislation. They also propose an index for the evaluation of ecological quality status (EcoQS) using the effective number of species derived from 0-2 cm of bottom sediments, >63 µm, living wet-picked assemblages. On the basis of the EcoQS, our samples are classified as: 1) high status quality for PT10 (Porto Torres) and MA22 (La Maddalena Archipelago); 2) good for PS7, PS8, PS12 (Portoscuso), PT8 (Porto Torres) and MA6 (La Maddalena Archipelago); 3) moderate for PT1 (near Asinara Isl.), MA9 and MA24 (Maddalena Archipelago); 4) poor for PS13, PT5, MA27 and MA28; and 5) bad for PS16, MA29 and MA30. Accordingly, it can be speculated in the present investigation that the port areas of Porto Torres (PT5), La Maddalena (MA27-30) and Calasetta (PS13) are more sensitive to environmental stress conditions. The observed decline in biodiversity can be correlated to grain-size parameters, in fact these samples are mainly constituted by silty sediments, but in absence of additional environmental data (e.g., organic matter content, dissolved oxygen, salinity, concentrations of anthropogenic pollutants) it is not possible to identify additional factors limiting the distribution of benthic foraminiferal assemblages. As for sample PS16, we hypothesize that the distribution of the biocenosis can be due to high percentage of gravel (30%) in the bottom sediment. Correlations between sedimentological features, benthic foraminiferal assemblages and chemical data (analyses in progress) from these sampled sites will enhance our understanding of the environmental anthropogenic impact on coastal systems. These correlations will also enable the identification of the bioindicator species that can be used to define the health status of this marine coastal environment.

## CONCLUSION

A preliminary study of shallow-water living benthic foraminifera from some coastal areas of Sardinia (Portoscuso, Porto Torres and La Maddalena) has been carried out as part of the MOMAR European research project. On the basis of our data, the spatial distribution of the foraminiferal assemblages allows us to distinguish highly to less stressed environments and evaluate the ecological quality status. The biotic indices (Species' Richness, Foraminiferal Density and the Fisher-α index) fall significantly, mainly in the samples located in the port areas of the coastal systems studied. The foraminiferal associations in these sites are characterized by opportunistic and infaunal species that are tolerant to environmental stress, such as *A. tepida* and bolivinids. Meanwhile, in sampling sites characterized by better environmental conditions, there is an epiphytic biocoenosis with species that generally live in vegetated bottom sediments (especially on the leaves of *P. oceanica*), such as *L. lobatula*, *P. mediterranensis*, *E. crispum* and peneroplids. In almost all examined samples, sediment grain-size seems to influence the distribution of foraminiferal species.

Knowledge of the textural and sedimentological properties of sediments is an important prerequisite for evaluating the response of benthic foraminifera and determining the status of the environmental stress in the examined areas. Future studies from these coastal areas will aim to better understand the anthropogenic changes impact on foraminiferal assemblages as well as identifying additional indicator species that can be used to define the pollution status and vulnerability of the ecosystem.

## ACKNOWLEDGEMENTS

This work was supported by the EU MOMAR Project which provided also the sediments sampling. The authors warmly thank J. Schönfeld and D. Violanti for their useful comments and suggestions. We extend our special gratitude to the editors A. Rosso and R. Sanfilippo.

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Manuscript received 11 September 2012
Revised manuscript accepted 21 June 2013
Published online 28 June 2013