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STUDY OF BENTHIC FORAMINIFERA IN THE SICILIAN CHANNEL AND THEIR APPLICABILITY AS BIO-INDICATORS

SETTORE SCIENTIFICO DISCIPLINARE DI AFFERENZA: BIO/07
TESI DI DOTTORATO DI MARIANNA MUSCO, MATRICOLA 955662

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Sommario

Introduction to the study of benthic foraminifera in the Sicily Channel, and their applicability as bio-indicators

This study focuses on the analyses of morphology, ecology and distribution of benthic foraminifera ("forams"; Lipps *et al.*, 2011), in function of actual and past environmental variables.

Marine microorganisms, especially forams, play a significant role in global biogeochemical cycles of inorganic and organic compounds, making them one of the most important animal groups on the earth (Lee and Anderson, 1991; Degré *et al.*, 2006; Pascal *et al.*, 2009).

Ecological studies posed a great interest on the relationship between foraminiferal communities and the environmental compartments (physical, chemical and biological variables - Murray, 2006): substrate texture, organic carbon, TOC, and hydrographic parameters (e.g. Temperature, Salinity, dissolved Oxygen, etc…) exercise important roles on benthic forams distribution, influencing faunal changes with the increasing depth (Jorissen *et al.*, 1992, 1995, 1998; Annin, 2001; Mendes *et al.*, 2004; Armynot du Châtelet *et al.*, 2009a, 2009b; Mojtahid *et al.*, 2009). Moreover water currents showed to have a crucial role on benthic foraminiferal communities, influencing their microhabitats (Schröder-Adams *et al.*, 2008).

Faunal changes in benthic foraminiferal communities are considered good proxies for environmental altering (Murray, 2000; Annin, 2001), due to their sensitivity to environmental parameters variations (Moore, 1964; Yanko *et al.* 1999), to which forams often show a species-species responses (Fursenko, 1978).

This sensitivity is the results of a combination of factors such as their great geographical distribution, with different species adapted to different living environments, and their rapid growth (Walton, 1964) with short reproductive and life cycles (from six month to one year; Boltovskoy, 1964).

The response of forams to the changed environmental conditions is shown by the abundance and morphology variations of their test, which presents high preservation potential thus making these microorganisms a useful proxy for temporal variations in pollution of marine environments, especially the coastal areas (Nigam *et al.*, 2006).

Objectives of the Thesis

Studies on benthic forams provide numerous information on the environment they live in, although there are differences in the way they're used as bioindicators, which include the analysis of abundance and/or diversity of benthic foraminiferal assemblages (population level), the presence/absence of sensitive or tolerant taxa (species level) and of shell's malformations (specimens level).

This study aims to detect benthic foraminiferal assemblages in the Sicily Channel and to possibly identify them as bio-indicators, able to provide an overview on the conditions of Sicily marine environment.

To achieve this objective, the first Chapter of this work has investigated the taxonomy and distribution of benthic foraminiferal species, through the creation of a preliminary *Atlas of benthic foraminifers of the Sicily Channel*, an important instrument for the use of these communities in the bio-indication field.

This Atlas was accompanied by a taxonomical study based on the application of morphometric variations as classification instrument, among three morphological species of the benthic genus *Bolivina* (d'Orbigny, 1843), which could allow for a more objective identification of forams species (Appendix I); the choice of the genus *Bolivina* was based on its abundance in the samples and on its morphology (test biserial, elongate, ovoid to triangular in outline, somewhat compressed - Loeblich and Tappan, 1988) thus making it a simple model for morphometric investigations (Parker *et al.*, 1999; Hayward *et al.*, 2004).

Chapter 2 has addressed the central study of the applicability of benthic forams as bioindicators of environmental and/or anthropogenic stress, which was conducted on living coastal fauna in the southern coast of Sicily. Distribution and abundance of benthic foraminiferal species were analysed, together with shell's morphology, and their potential relationship with heavy metals concentration in marine sediments (Lea and Martin 1996; Moulfi-El-Houari *et al.*, 1999; Geslin *et al.*, 2000, 2002; Donnici and Serandrei Barbero, 2002; Haley *et al.*, 2005; Albani *et al.*, 2007).

Benthic foraminiferal relations with the oceanographic features and trace elements (Moulfi-El-Houari *et al.*, 1999) were furthermore explored in the Chapter 3, by studying benthic forams tanatocenosis and their coast-wide variations in the Sicily Channel, and analysing the presence of trace elements in shells of dead specimens of *Uvigerina mediterranea*: this species represented the bigger and the most common species of the genus *Uvigerina*, frequently used in numerous studies regarding these issues (Van Geen *et al.*, 1992;

Rosenthal *et al.*, 1997; Martin and Lea, 1998; Marchitto *et al.*, 2000; Tachikawa and Elderfield, 2002; Maréchal-Abram *et al.*, 2004; Ripperger *et al.*, 2008; Katz *et al.*, 2010; Munsel *et al.*, 2010).

State of the Art

To the pioneering works of Zalesny (1959), Resig (1960) and Watkins (1961) several other studies followed that have used forams to monitor marine pollution, especially in coastal areas, with different responses: in presence of heavy metals pollution Sharifi *et al.* (1991) highlighted the abundance of malformed benthic forams, while Geslin *et al.*, (2002) suggested to be careful handling this kind of response. In some cases (Alve, 1991; Schafer *et al.*, 1975) it was also highlighted the correlation between the abundance of some species, such as *Eggerelloides scaber* and *Elphidium poeyanum* (cfr. E. incertum; Williamson, 1858) and heavy metals pollution. Ellison *et al.* (1986), Samir (2000), Samir and El-Din (2001) and Armynot du Châtelet *et al.*, (2004) underlined the decrease of foraminiferal population and species diversity related to the presence of heavy metals, whereas Yanko *et al.*, (1994) have shown the decrease in forams dimentions and the pyritization of many tests. Nagy and Alve (1987) showed an increase of agglutinated forams and the decrease of calcareous species due to the effects of dissolution in presence of pollution sources such as paper mills, farm land and domestic sawage.

The introduction of the scanning electron microscope (SEM) in the 1960s revolutioned the ability of illustrating forams, while, during the same period, the introduction of computers allowed the use of multivariate methods of data analysis. Whereas stable isotope studies of fossil forams became commonplace from the 1960s, it was only in recent years that they have been more widely applied to foraminiferal ecology (Tachikawa and Elderfield, 2002; Rumolo *et al.*, 2009). Biology and ecology are briefly reviewed by Lee and Anderson (1991) and by Murray (2006). Sen Gupta (1999) discussed the role of oxygen and flux of organic matter as ecology controls, the biogeography and the symbiosis in forams; he also investigated their application to monitor pollution. Foraminiferal ecology is also commonly applied in the interpretation of the Quaternary paleoecology (Haslett, 2002). Over recent decades the use of micropaleonthology has shifted from oil geology and basic geological surveying to interpreting paleoecology and paleoceanography and in environmental monitoring (pollution, sea level, climate change; Nigam *et al.*, 2006). Similar works were recently carried out in Italy, appling benthic foraminifera as bioindicators of marine pollution in coastal areas (Di

Leonardo *et al.*, 2007; Valenti *et al.*, 2008; Frontalini and Coccioni, 2008; Ferraro *et al.*, 2009; Frezza and Carboni, 2009) and in transitional environments (Coccioni, 2000; Coccioni *et al.* 2003, 2005; Serandrei-Barbero *et al.*, 2003; Coccioni and Marsili, 2005; Albani *et al.*, 2007; Frontalini *et al.*, 2009).

No doubt foraminiferal ecology will continue to play an important role in the interpretation of the geological record; and despite the geologists' idea that "the present is the key to the past" it is now clear that we can also invert this concept to help predicting future events. There are certainly great challenges for foraminiferal workers in the years to come, and the future of foraminiferal ecology looks extremely exciting.

Study Area and Sediment Sampling Stations

The Sicily Channel is located between Sicily and Tunisia, dividing the Mediterranean Sea into two semi-enclosed basins, Oriental and Occidental (Fig. 1). The Channel basin is on average shallow, with maximum depth value of 1700m, and is characterized by the presence of numerous banks that reduce its depth to a few tens of meters.

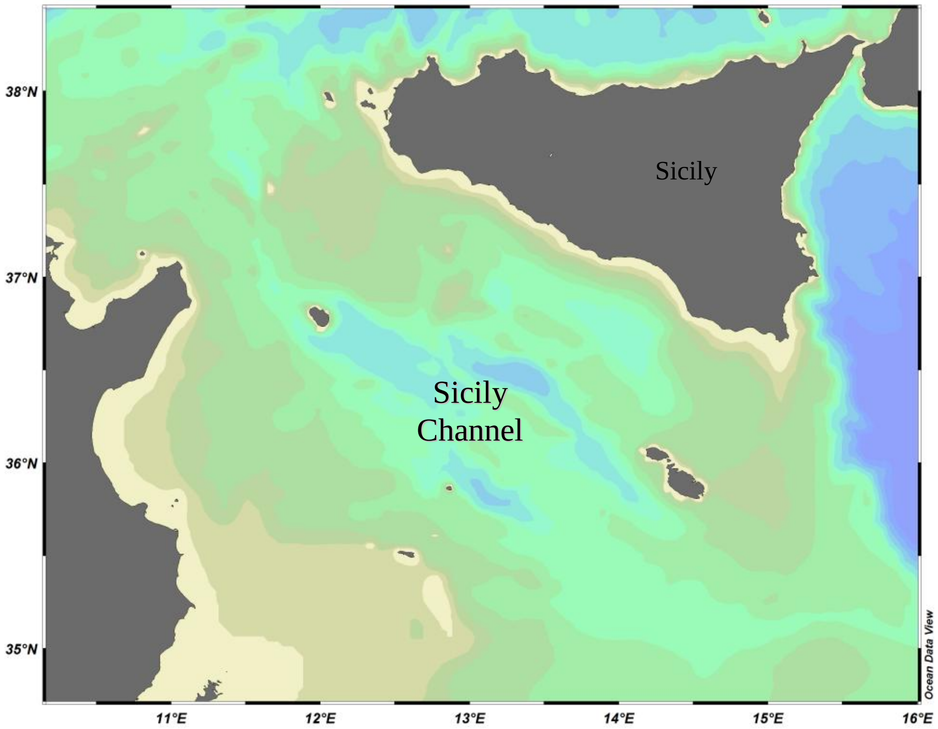


Figure 1. Sicily Channel

Mediterranean water masses move in different directions, depending their chemico-physical features (temperature, salinity and density).

The less dense and salty waters of the Atlantic Ocean flow as shallow current via the Straits of Gibraltar to the Occidental sub-basin of the Mediterranean Sea, and in proximity of the Sicily Channel it gives rise to the *Atlantic Ionian Stream* (AIS). During its flow along the southern coast of Sicily, the shallow current AIS creates two types of cyclonic vortices, one on the *Adventure Bank* (BAV, south of the coast between Mazara del Vallo and Licata), and the other around the Malta's platform (ISVs, south of the coast between Pozzallo and Capo Passero); these movements near the Sicilian coast allow the presence of massive upwelling (Robinson *et al.*, 1999 Fig. 2).

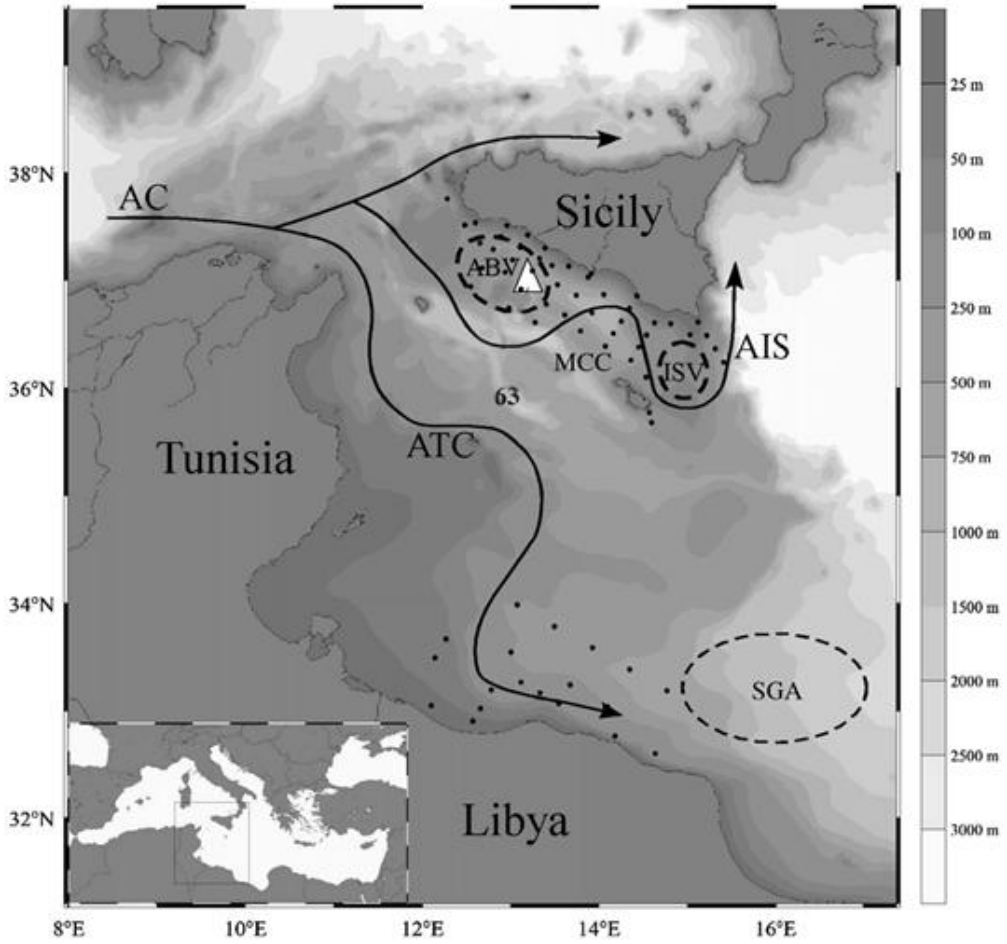


Figure 2. Bathymetric map of Sicily Channel showing surface oceanographic circulation, seasonal and semipermanent features and surface sediment samples (black dots). AC: Algerian Current; ATC: Atlantic Tunisian Current; AIS: Atlantic Ionian Stream; ABV: Adventure Bank Vortex; MCC: Maltese Channel Crest; ISV: Ionian Shelfbreack Vortex; SGA: Syrte Gulf Anticyclone. Insert in figure 2, bottom left, is a map of the Mediterranean region.
(Incarbona *et al.*, 2008).

At the end of these convolutions AIS, which transports warmer and less salt water, moves towards Cyprus in the Levant basin, where the strong evaporation (water reaches a salinity of about 39 ‰) and the winter temperature decrease (up to a maximum of 16 °C) determine its sinking to a depth ranging between 200 and 600 meters, forming the Levantine Intermediate Water (LIW). This water mass subsequently flows along the North African coast, through the Sicily Channel, into the North Atlantic Ocean, in the opposite direction of superficial water (Fig.3 - Cognetti *et al*, 2002). The circulation between the Mediterranean Sea and the Atlantic Ocean is typical of closed, restricted basins in which evaporation exceeds precipitation. This type of circulation pattern is often referred to as Mediterranean circulation.

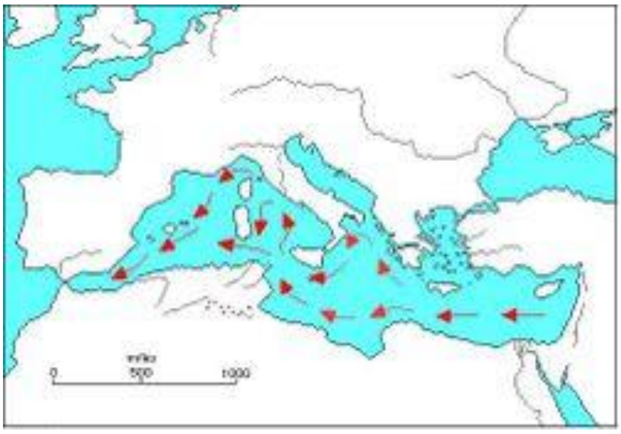


Figure 3 - Representation of the LIW current flow in the Mediterranea Sea.

Close to the Sicilian coasts, the depth range of the LIW waters is strongly influenced by the seafloor morphology of the Sicily Channel (Placenti *et al.*, 2011). Due to the combination of the bottom morphology, and of the thermohaline barrier found by Mazzola *et al.* (2004) the eastward flowing of the AIS surface water in the Malta Shelf damped in strength and speed with a consequent higher particulate setting, which could allow a high deposition leve also of potentially toxic elements.

Anthropization trough the intensive urbanization, the petrochemical plant and the intensive agricultural activities could be the principal sources of contamination of the southern sicilian coast.

A geological study of the Siclily Channel seafloor, concucted by Tranchida *et al.* (2010), highlighted the influence of detrital (riverine and aeolian) input on sediment geochemistry. High Ba contents, used as proxy for primary productivity, confirmed the presence of a massive upwelling system in the Channel, and particularly in the Adventure Bank. Relatively to the origin of trace elements in the sediment of the Sicily Channel, two kind of sources have been identified: the first, mainly lithogenic, for Cr, Cu, Co, V, and Zn and the second, partially deriven from anthropic input, for Sb, Cd, As, Pb, and Hg.

Starting from these assumptions, it has been carried out the study of benthic foraminifera in the Sicily Channel.

Sampling was conducted during the "Bansic" oceanographic cruises in the summers from 2005 to 2011, on board of the R/V Urania. Sediment samples were collected principally by box-corer, in the stations shown in the map of figure 4 (marked with blue points), following the sampling procedures reported in the Chapter 2.

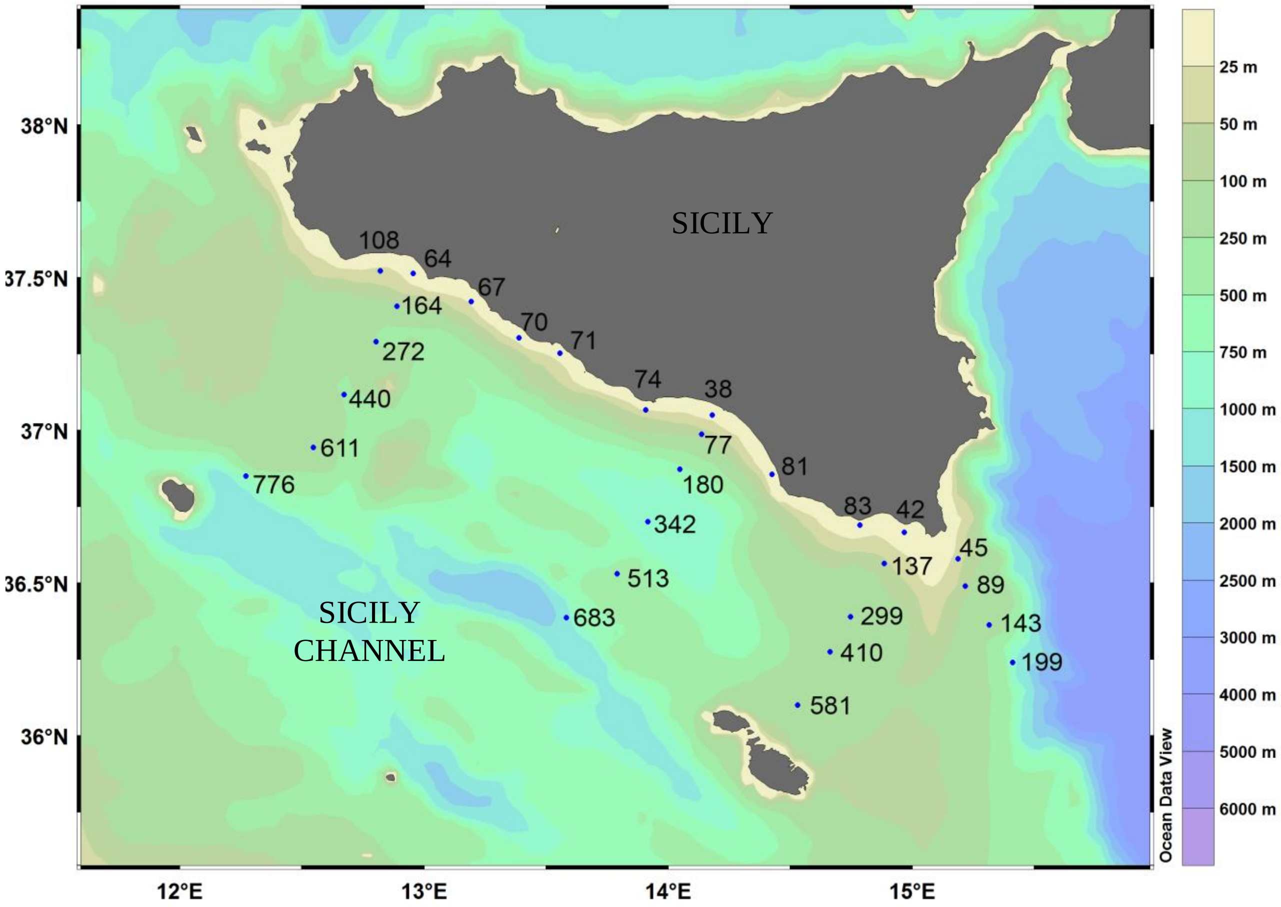


Figure 4. Sampling stations

Coastal stations:

- Capo Granitola (Campobello di Mazara): st.108
- Sciacca: st.64
- Ribera: st.67
- Realmonte: st.70
- Porto Empedocle: st.71
- Licata: st.74
- Gela: st.38
- Vittoria: st.81
- Marina di Modica: st.83
- Pozzallo: st.42
- Capo passero: st.45

Stations in front of Porto Empedocle (port area heavily affected by urban sewage and a thermal power plant) and of Gela (affected by petrochemical industries) were chosen for their proximity to anthropogenic pollution sources. All stations were chosen at an average distance of 7 miles from each other, from the western to the eastern area of the southern Sicilian coast, to evaluate the variation in foraminiferal assemblages, oceanographic variables and/or pollutant concentrations, moving from the stations that precede (Capo Granitola, Sciacca, Ribera, Realmonte) to those that follow (Vittoria, Marina di Modica, Pozzallo and Capo Passero) the pollution sources, along the current flow.

Transects:

Sciacca- Pantelleria 164 – 272 – 440 – 611 – 776

Gela-offshore 77 – 180 – 342 – 513 – 683

Pozzallo-Malta 137 – 299 – 410 – 581

Capo Passero-offshore 89 – 143 – 199

Details on sampling sites and procedures are reported in each chapter.

Two flowcharts are reported below (Figg. 5 and 6) in order to show the research articulation step by step, and the activities carried out, with information about partnerships with Universities or Institutions; activities are subsequently described in detail along different chapters.

Figure 5. Scheme of the Istitutions involved in the Thesis project

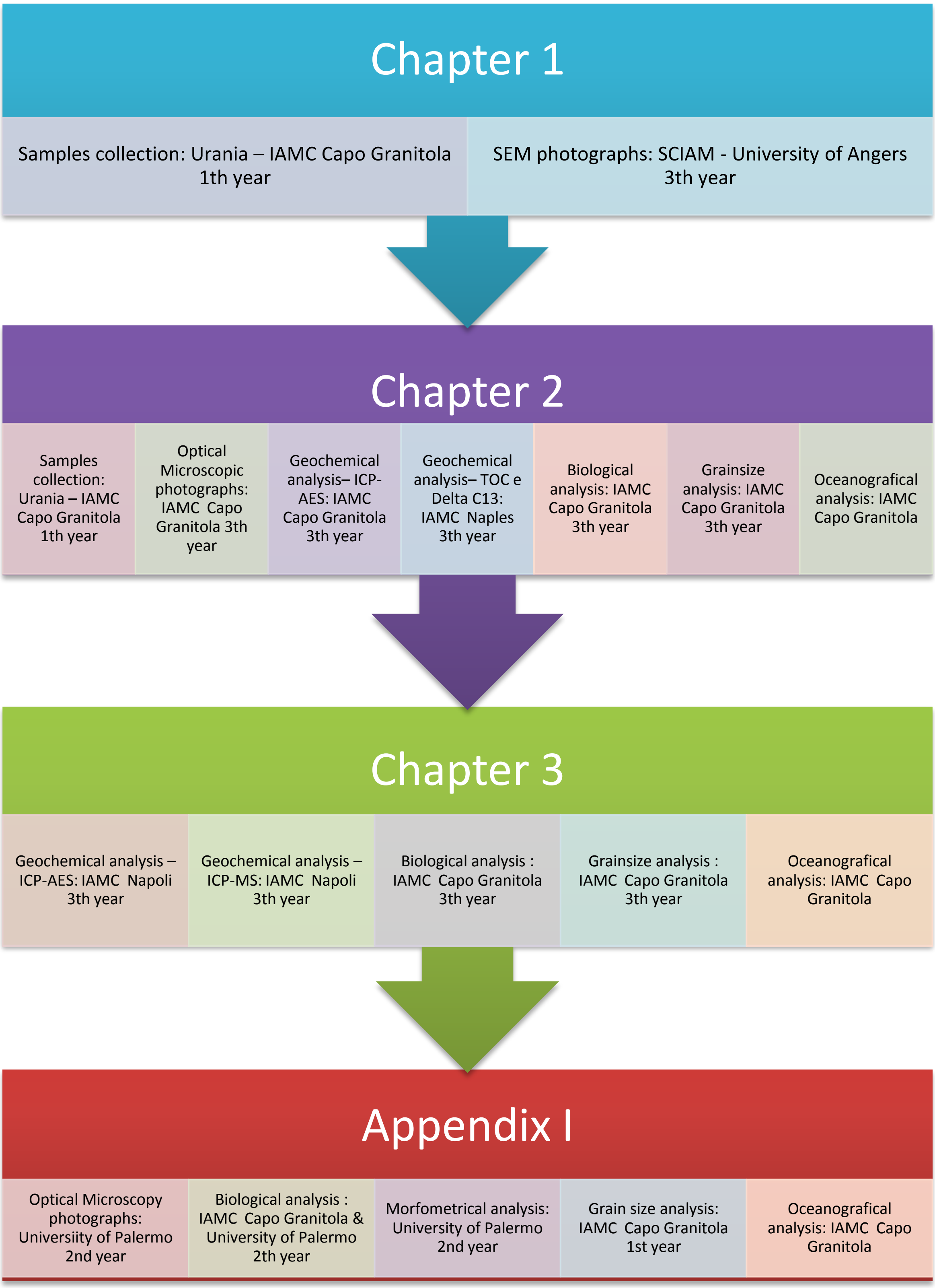


Figure 6. Flowchart of the activities carried out in each Chapters.

Chapter 1: Benthic forams of the Sicily Channel: description and distribution

Introduction

Forams are among the most important shelled protozoa in marine environments, presented in conspicuous numbers in the oceans and salt marshes all over the world since Cambrian (570 Mya).

There are 4000 known living species of foraminifera, which only 40 of them are planktonics; benthic species could have little movement in the sediment, or live as clinging forms in epiphytic or epilithic way.

The most widely used classification of Loeblick and Tappan (1964) placed the Forams group as Order within the Phylum *Sarcomastigophora*, belonging to the Kingdom *Protista*; a recent review of this classification, made by Gross, O. (2001) proposed *Forams* as Phylum belonging to the Subkingdom *Harosa*, Kingdom *Chromista*.

Their organism is composed by a well structured cell, protected by a mineralized chambered test, carbonatic or arenaceous, which easily could fossilize: this structure can have its maximum growth at 100 µm as well as at 15 cm of length, depending from the species. As foraminiferal studies have been started under geological and paleontological interests, foraminiferal species are defined primarily on the basis of wall structure, chamber and test shape and the position of the apertures (“morphospecies”; Murray, 2006).

Benthic forms could made some little movements in the first sediment centimetres through the use of reticulopodia, which are cytoplasmic projections, or live upon sediment (epilitics) or plants (epiphytics). They colonize all marine environments, from intertidal to abyssal zones, and in favorable conditions could develop rich communities.

Environment play a selective role on benthic foraminiferal species distribution: some of them are abundant only in the deep ocean, others are found only on coral reefs, and still other species live only in brackish estuaries or intertidal salt marshes. Moreover species distribution changes in the same habitat due to its physic-chemical, bathymetrical and feeding features.

Benthic foraminiferal studies of western Mediterranean basins have focused on the distribution and ecology of species and assemblages (e.g. Jorissen, 1988; Cimerman and

Langer, 1991; Sgarrella and Moncharmont Zei, 1993; Donnici and Serandrei Barbero, 2002; Frezza *et al*., 2005).

However few studies on benthic forams have been conducted in the Sicily Channel (Cita and Zocchi, 1978; Parisi, 1981; De Rijk *et al.*, 1999; Incarbona *et al.*, 2011), thus the first objective of this Thesis is to provide an overview of the species (live and dead) of benthic forams of the Sicily Channel with their distribution map reference in relation to the sampled stations.

1.1 Atlas of Benthic Dead and Live Forams of the Sicily Channel

The purpose of this Atlas was to give a useful tool for further studies on benthic foraminiferal communities in the Sicilian Channel.

Benthic foraminifera of the Sicilian Channel were classified and listed below, following the review to the Loeblich and Tappan classification (1964, 1988), made by Gross, O. (2001), and supported by the works of Jorissen (1988), Albani and Serandrei Barbero (1990), Cimerman and Langer (1991), and Sgarrella and Moncharmont-Zei (1993). All families were briefly described, while a deeper description was made for species which were more abundant than 5% of the assemblage, principally following the same authors listed above, with the addition of the pubblications of Jorissen (1987), Alve (1991, 1995), Murray (1991, 2006), Sen Gupta (1999), Armynot du Châtelet (2003) and Frontalini and Coccioni (2008).

For all the species more abundant than 5% of the assemblage of at least one station, it was also realized a distribution map, performed with the Ocean Data View software (ODV - http://www.awi-bremerhaven.de/GE/ODV, Schlitzer, 2003), relating to the coastal (living – in red) or offshore (dead – in green) fauna; each map compares spatial variations of species densities (number of forams per 28,26 cm^3). Moreover for almost all these species (>5%) it was acquired a photo with the SEM (*Scanning Electron Microscope*), at the SCIAM (*Service Commun d'Imageries et d'Analyses Microscopiques*) of the University of Angers (France), within the collaboration with the BIAF (Bio-Indicateur Actuels et Fossiles) Laboratory of the University of Angers.

Unfortunately, some specimens were irremediably damaged during the preparation and image acquisition processes, so it was not possible to include their SEM photos in the Atlas.

Phylum: Foraminifera - **Class** Polythalamea

Order Astrorhizida

Superfamily Astrorhizoidea

Family Astrorhizidae: agglutinated wall with particles attached to a proteinaceous or mineralized matrix; single chambered, branching tubular, or irregularly multichambered with incomplete septa. Test free or attached.

Genus *Bigenerina*

Species: *nodosaria* (Orbigny, 1826)

Family Rhabdamminidae: test free or attached, simple or branching, tubular to slightly inflated, interior non-septate; wall agglutinated; apertures terminal, at ends of branches or chamber.

Genus *Rhabdammina*

Species: *abissorum* (Sars, 1869)

Family Saccaminidae: test free or attached, globular to elongate; wall agglutinated; aperture single to multiple.

Genus *Lagenammina*

Species: *difformis* (Brady, 1879)
Species: *fusiformis* (Williamson, 1858)

Order Lituolida

Superfamily Ammodiscoidea

Family Ammodiscidae: wall agglutinated; two-chambered test, with a globular proloculus followed by a non-septate tubular (coiled or uncoiled) second chamber; terminal aperture.

Genus *Ammodiscus*

Species: s*p.* (Reuss, 1862)

Genus *Glomospira*

Species: *charoides* (Jones and Parker, 1860)

Species: *gordialis* (Jones and Parker, 1860)

Superfamily Ataxophragmoidea

Family Globotextulariidae: test high trochospiral throughout or with triserial or biserial later part; aperture interior-marginal or areal.

Genus *Globotextularia*

Species *anceps* (Brady, 1884)

Superfamily Haplophragmioidea

Family Discamminidae: wall coarsely agglutined on an inner organic layer; elongate shape, early stage planispirally coiled, later uncoiled and rectilinear. Straight and thin septa. Aperture terminal, rounded, at the end of the neck.

Genus: *Ammoscalaria*

Species: *sp.* (Hoglund, 1947)

Genus *Discammina*

Species: *compressa* (Goës, 1882)

Species *sp.* (Lacroix, 1932)

Superfamily Hormosinoidea

Family Hormosinidie: test free, chambers arranged in rectilinear to arcuate series; wall agglutinated, interior simple; aperture terminal, single or multiple.

Genus *Reophax*

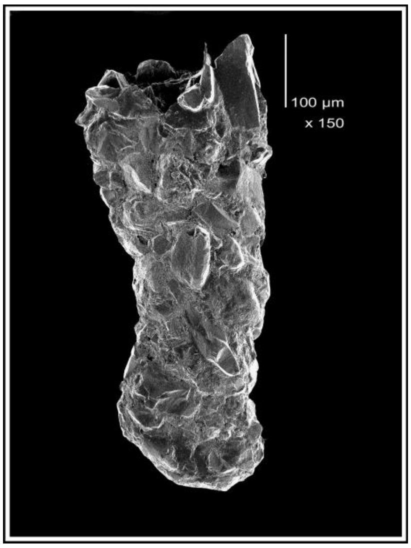
Species: *scorpius* (de Montfort, 1808)

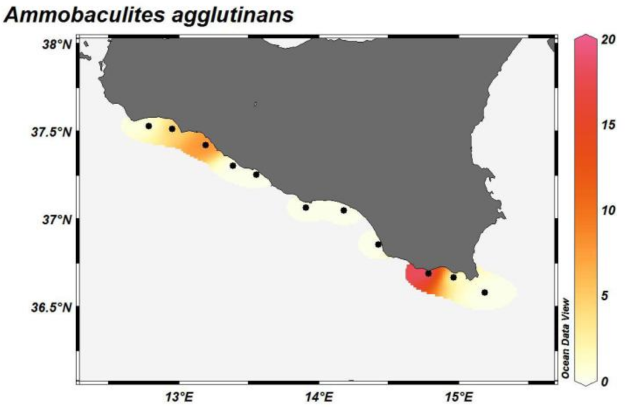
Superfamily Lituoloidea

Family Lituolidae: wall agglutinated; test imperforate with multiple chambers; planispirally coiled throughout or in early stage. Aperture terminal single, or multiple.

Genus *Ammobaculites*

Species: *agglutinans* (d'Orbigny, 1846)





- morphology: wall coarsely agglutinated; test free, elongate; early portion close coiled, later uncoiling and rectilinear; interior simple. Aperture terminal, sub-rounded.

- distribution: cosmopolitan species; brackish-marine; found from the inner shelf to upper bathial zone (Murray, 2006).

- ecology: infaunal, free, in muddy sediments.

Species: *sp.* (Cushman, 1910)

Genus *Cribrostomoides*

Species *jeffreyssii* (Williamson, 1858)

Species: *sp.* (Cushman, 1910)

Species *subglobosum* (Cushman, 1910)

Superfamily Lituotuboidea

Family Trochamminoidae: wall agglutinated; test enrolled, discoidal, irregularly coiled; planispiral to evolute. Aperture large, equatorial, may have a thickened lip.

Genus *Trochamminoides*

Species: *sp.* (Cushman and Renz, 1948)

Superfamily Spiroplectamminoidea

Family Nouriidae: wall agglutinated; chambers in high spiral or biserial; aperture terminal and ovate, may be produced on a neck.

Genus *Nouria*

Species: *polimorphinoides* (Heron-Allen and Earland, 1914)

Family Spiroplectamminidae: wall agglutinated; test elongate, planispiral or streptospiral in early stage, and biserial or uniserial in later part.

Genus *Spiroplectinella*

Specie: *wrighii* (Silvestri, 1903)

Superfamily Verneulinoidea

Family Verneuilinidae: test triserial in the early stage, later may be biserial or uniserial; aperture interiomarginal, may become slitlike, oval, or rounded and areal in biserial and uniserial taxa.

Genus *Connemarella*

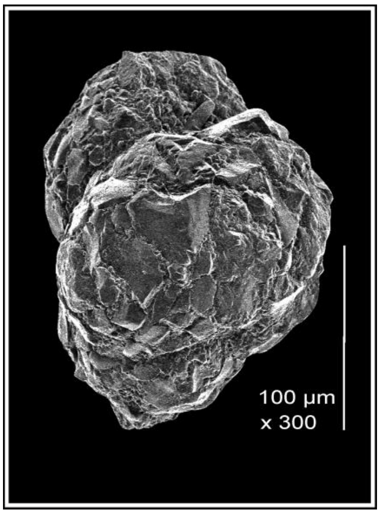
Species: *rudis* (Wright, 1900)

Order Textulariida

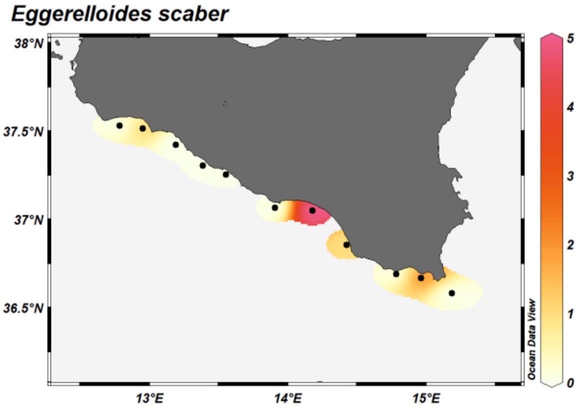
Superfamily Textularioidea

Family Eggerellidae: wall canaliculate, agglutinated commonly of calcareous particles, on a thick organic layer; test trochospirally enrolled or triserial in the early stage, later may be triserial, biserial, or uniserial. Aperture an interiomarginal slit to areal; single to multiple.

Genus *Eggerelloides*



Species: *scaber* (Williamson, 1858)



- morphology: wall coarsely agglutinated; test shape subconical – subfusiformis, trochospiral early stage with 3 chambers per whorl. Chambers increasing in size as added. Aperture a semilunate arch in the center of apertural face and bordered by a lip.

- distribution: widespread all around the Mediterranean; infralittoral and circalittoral zone, with the highest concentrations at about 15-18 m (Sgarrella and Moncharmont-Zei, 1993); tipically marine, it is also present in estuarine and in transitional environments (Albani and Serandrei Barbero, 1990).

- ecology: infaunal; fine sand to sandy-muddy bottoms; detritivore.

Family Pseudogaudrynidae: wall agglutinated; test free, elongate; aperture terminal, a semicircular to circular opening.

Genus *Pseudoclavulina*

Species: *crustata* (Cushman, 1936)

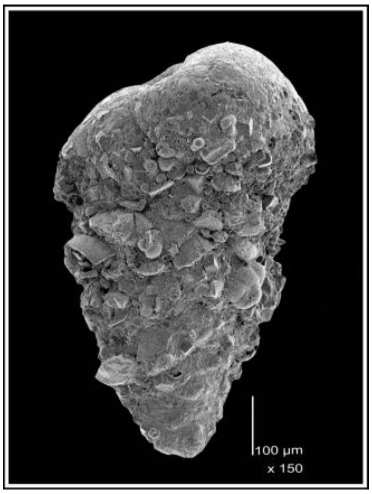
Family Textulariidae: wall agglutinated, test biserial, triangular in lateral view.

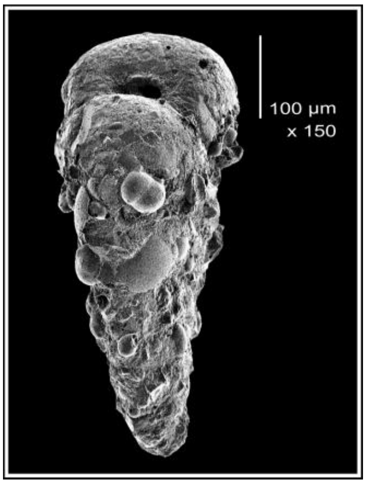
Genus *Siphotextularia*

Species: *concava* (Karrer, 1868)

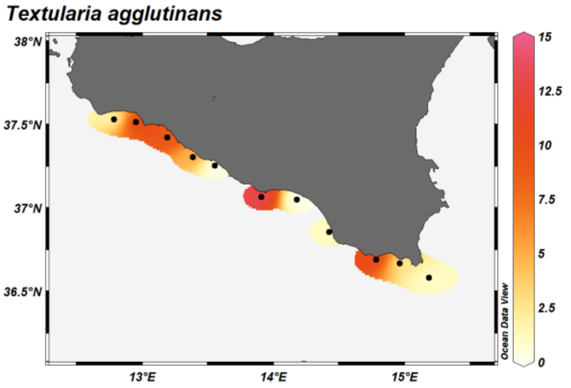
Species: *rolshauseni* (Phleger and Parker, 1951)

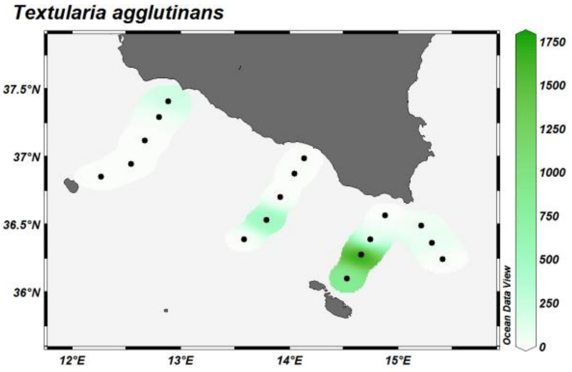
Genus *Textularia*





Species: *agglutinans* (d'Orbigny, 1839)


Textularia agglutinans


Textularia agglutinans

- morphology: wall agglutinated; test biserial, with sutures shightly depressed. Last chambers increasing in size an slightly inflated. Aperture a low arch at the base of the apertural face.

- distribution: from sandy and detrital bottoms (Blanc-Vernet, 1969). Widespread in Mediterranean, mostly abundant at the depth of 18 m (Albani and Serandrei Barbero, 1990), was also found at different depth ranges (5-10 m, 27-75 m, 70-90 m) (Sgarrella and Moncharmont-Zei, 1993).

- ecology: infaunal, resistant to strong currents.

Species: *calva* (Lalicker, 1940)

Species: *conica* (d'Orbigny, 1839)

Order Miliolida

Superfamily Cornuspiroidea

Family Cornuspiridae: free or attached, proloculus followed by undivided planispiral to streptospiral tubular second chamber, that may show later zigzag growth.

Genus *Cornuspira*

Species: *involvens* (Reus, 1850)

Superfamily Milioloidea

Family Cribrolinoididae: test of high-Mg calcite, adult chambers imperforate; multichambered; surface texture porcelaneous; surface pitted in some genera. Coiled in one or several planes; aperture terminal.

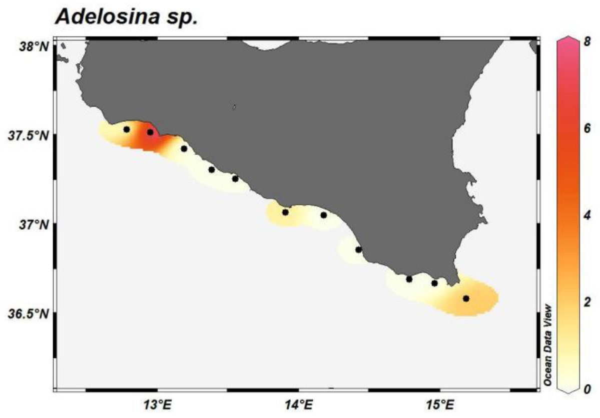
Genus *Adelosina*

Species: *italica* (Terquem, 1878)

Species: *mediterranensis* (Le Calvez J. and Y., 1958)

Species: *pulchella* (d'Orbigny, 1826)

Species: *sp.* (d'Orbigny, 1826)



- morphology: wall porcellanaceous and imperforate; megalospheric proculus followed by a completely embracing and planispirally enrolled second chamber. Surface ornamented by thick, acute ribs and small costae. Aperture rounded produced on a neck, bordered by a weakly developed lip and provided with a T-shaped tooth.

distribution: widespread all around the Mediterranean.

- ecology: infaunal, detritivore.

Family Hauerinidae: chambers arranged in one or several planes, later part of test may be uncoiled; aperture terminal, toothed or partly covered. The test may have an outer agglutinated layer.

Genus *Biloculinella*

Species: *cylindrica* (Todd, 1958)

Species: *labiata* (Schlumberger, 1891)

Genus *Cycloforina*

Species: s*p.* (Luczkowska,1972)

Genus *Cribromiliolinella*

Species: *sp.* (Saidova, 1981)

Genus *Miliolinella*

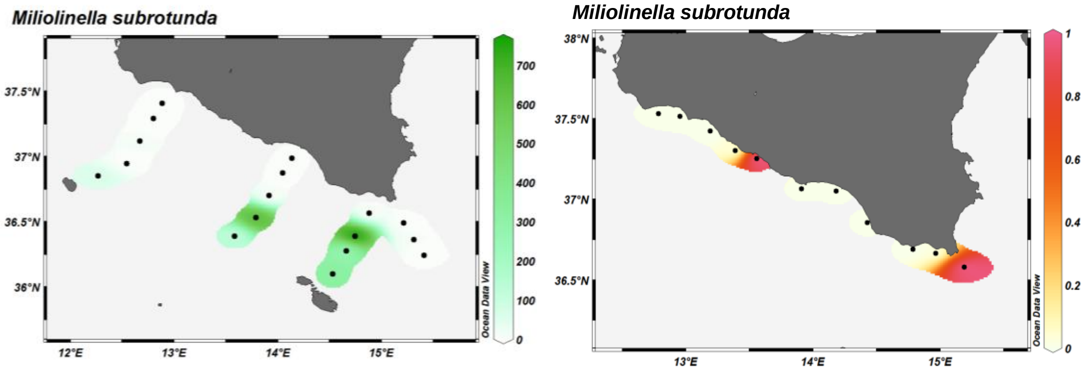
Species: *dilatata* (d'Orbigny, 1839)

Species: *elongata* (Krult,1955)

Species: *sp.* (Wiesner, 1931)

Species: *semicostata* (Wiesner, 1923)

Species: *subrotunda* (Montagu, 1803)



- morphology: test porcelaneous, with smooth surface, and ovate in lateral view; periphery margin broadly rounded; chambers initially arranged in a quinqueloculine pattern, later nearly planispirally arranged, inflated and increasing in size as added. Three chambers are visible from the exterior. Aperture is provided with an apertual flap.

- distribution: ubiquitous in Mediterranean; from infralittoral down to the bathyal mud. Parisi (1981) recorded its presence in the deep-wathers of the Sicily Channel and of the Tyrrhyenian Sea (Sgarrella and Moncharmont-Zei, 1993), while Albani and Serandrei Barbero (1990), highlighted its salutary presence in all the Adriatic Sea.

- ecology: epifaunal; clinging, epiphital; herbivore.

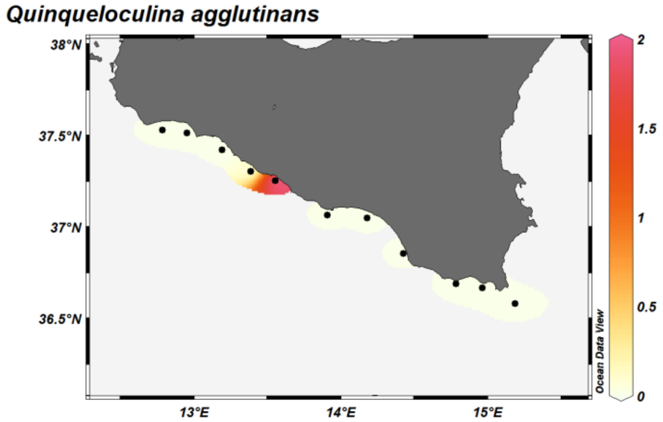
Genus *Pyrgo*

Species: *denticulata* (Brady, 1884)

Species: *elongata* (d'Orbigny, 1826)

Genus *Quinqueloculina*

Species: *agglutinans* (d'Orbigny, 1839)

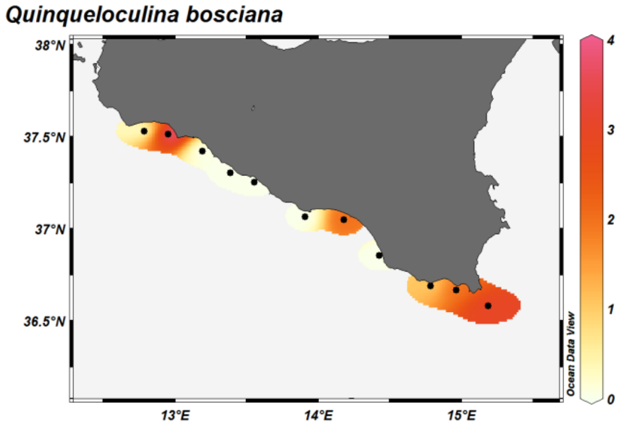


- morphology: small test, lenticular in outline, with a quinqueloculine chamber arrangement. The wall is porcelaneous and imperforate with a smooth and slightly arenaceous surface. Five chambers are visible from the exterior. The oval aperture is terminal, provided with a short bifite tooth.

- ecology: epifaunal; clinging, epiphital; herbivore.

Species: *badanensis* (D'Orbigny, 1826)

Species: *bosciana* (d'Orbigny, 1839)



- morphology: wall porcelaneous and imperforate; test subcircular in lateral view and ovate in apertural view, with a quinqueloculine chamber arrangement. The oval aperture is terminal, provided with a short bifite tooth.

- ecology: epifaunal; clinging, epiphital. Herbivore.

Species: *ferussacii* (d'Orbigny, 1826)

Species: *laevigata* (d'Orbigny, 1839)

Species: *lamarkiana* (d'Orbigny, 1839)

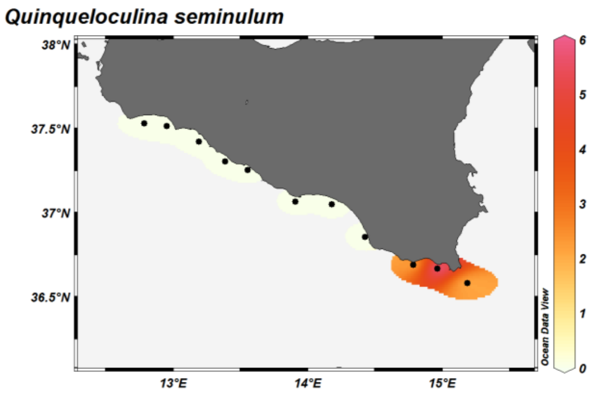
Species: *lata* (Terquem, 1876)

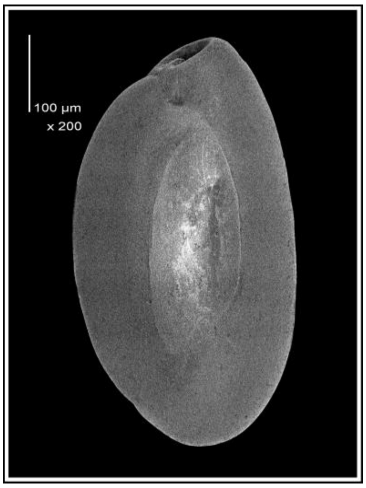
Species: *neapolitana* (Sgarrella Moncharmont Zei, 1993)

Species: *polygona* (d'Orbigny, 1839)

Species: *pygmaea* (d'Orbigny, 1826)

Species: *seminulum* (Linnaeus, 1758)



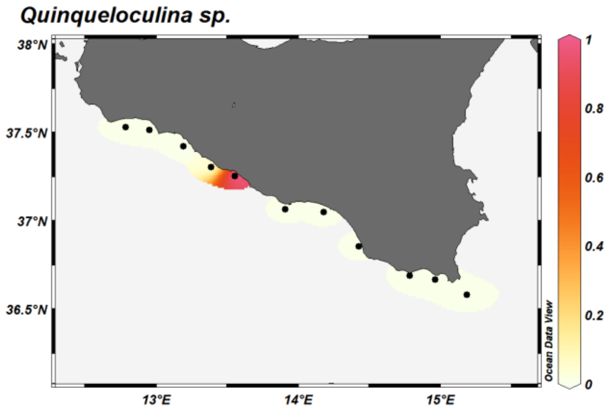


- <u>morphology</u>: wall porcelaneous and imperforate; elongated test; chambers increasing in size in the basal portion; The oval aperture is terminal, provided with a short tooth (Albani and Serandrei Barbero, 1990).

- <u>distribution</u>: widespread all around the Mediterranean; particularly abundant in the infralittoral zone, occasionally in the circalittoral zone (Sgarrella and Moncharmont-Zei, 1993).

- <u>ecology</u>: epifaunal; on sediment and firm substrate; occasionally found as infaunal.

Species *sp.* (d'Orbigny, 1826)



- morphology: wall calcareous, porcellanaceous, imperforate, with a smooth face. Quinqueloculine chamber arrangement; five chambers are visible from the exterior, increasing in size as added. Aperture oval and terminal, provided with a short bifite tooth.

- distribution: widespread all around the Mediterranean; typical marine, it is also present in ipersaline environments. Rarely bathial.

- ecology: epifaunal, free or clinging, plants or sediment; herbivore.

Species: *stelligera* (Schlumberger, 1893)

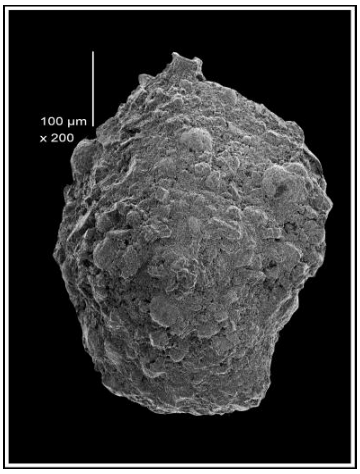
Genus *Sigmoilina*

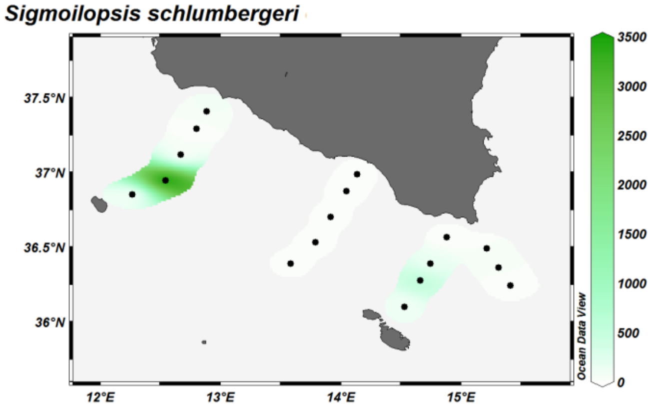
Species: *sp.* (Schlumberger,1887)

Species: *tenuis* (Czjek, 1882)

Genus *Sigmoilopsis*

Species *schlumbergeri* (Silvestri, 1904)





- morphology: wall porcellanous with agglutined coating. Test ovate in outline with sigmoidal form, lateral planispirally arranged chambers. Apertured rounded and provided with a little neck and a very small tooth.

- distribution: widespread species in the Mediterranean Sea typical of muddy sediments, in circalittoral and bathyal bottoms (about 1,000 m depth in the Eastern Mediterranean; Parker, 1958). In the Adriatic Sea mostly on muddy bottoms rich in organic matter in the depth- range of 60-100 m (Jorissen, 1987).

Genus *Siphonaperta*

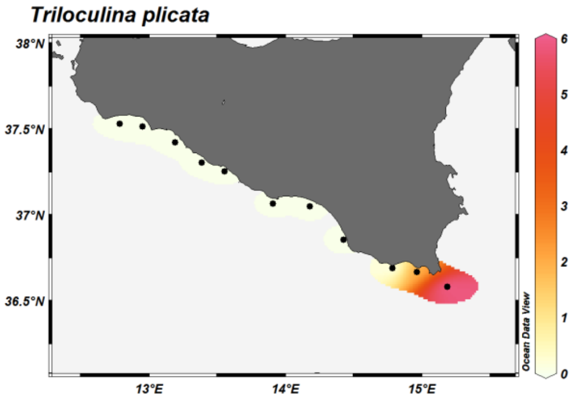
Species: *sp*. (Vella, 1957)

Family Miliolidae: chambers one-half coil in length, added in one or more regular planes; thick wall calcareous, porcelaneous, imperforate, with numerous pseudopores; aperture terminal.

Genus *Triloculina*

Species: *marionii* (Schlumberger, 1893)

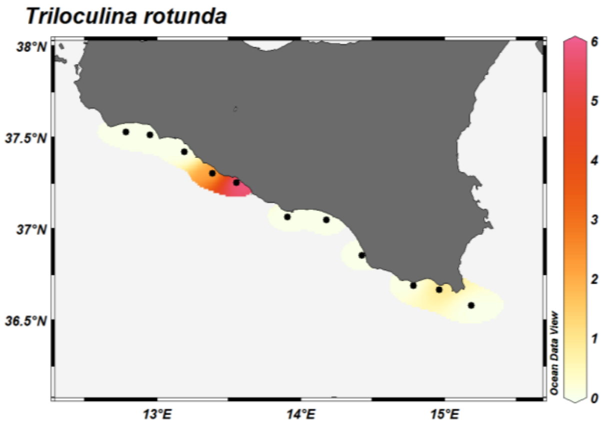
Species: *plicata* (Terquem, 1878)



- morphology: wall porcellanous, egg-shaped in peripheral view and triangular in end view; chambers gradually increasing in size and slightly inflated. Aperture ovate bordered by a peristomal lip.

- ecology: epifaunal, free of clinging, herbivore, detritivore.

Species: *rotunda* (d'Orbigny, 1893)

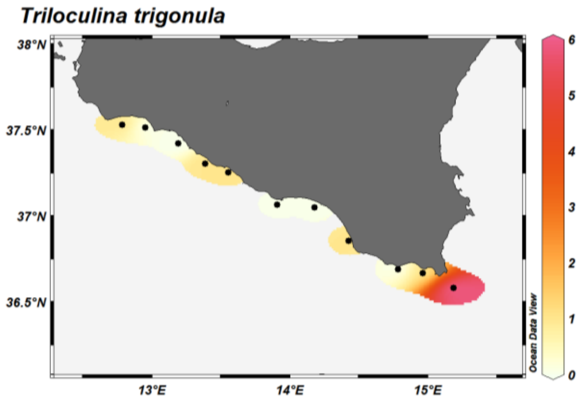


- morphology: wall porcellanous, inperforate, sub-rounded shaped in peripheral view and sub-triangular in section; triloculine chambers arrangement in the adult stage, with 3 visible chambers; chamber one-half coil in length, gradually increasing in size and slightly inflated. Aperture subrounded, terminal, provided with a short bifite tooth.

- ecology: epifaunal, free of clinging, herbivore, detritivore.

Species *tricarinata* (d´Orbigny, 1826)

Species *trigonula* (d´Orbigny, 1826)



- morphology: wall porcellanous; generally big test, triangular in transversal section, ovate in outline; smooth wall. Apertured rounded, provided with a bifite tooth (Albani and Serandrei Barbero, 1990).

- distribution: widespread species; well represented in the infralittoral bottoms of the Mediterranean Sea (depth range 30-35 m); abundant in areas with vegetation; it is reported also in the upper circalittoral zone (Sgarrella and Moncharmont-Zei, 1993).

- ecology: epifaunal, free of clinging, herbivore, detritivore.

Family Spiroloculinidae: initial chamber rounded, socound chamber coiled tubular, adult chambers one-half coil in extent; aperture terminal, toothed or partly covered.

Genus *Spiroloculina*

Species: *communis* (Cushman and Todd, 1944)

Species: *dilatata* (d'Orbigny, 1846)

Species: *excavata* (d'Orbigny, 1846)

Species: *henbesti* (Thalman, 1955)

Species: *lucida* (Cushman and Todd, 1944)

Species: *rostrata* (Reuss)

Order Lagenida

Superfamily Nodosarioidea

Family Lagenidae: test unilocular; wall calcareous, hyaline, radial in structure; aperture terminal, rounded, or radiate, may be produced on a neck.

Genus *Lagena*

Species: *striata* (d’Orbigny, 1939)

Species: *laevis* (Montagu, 1803)

Species: *sp.* (Morch, 1853)

Family Nodosariidae: wall calcareous, hyaline, finely perforate, monolamellar or orthomonolamellar; test multilocular, or rarely single chambered, chambers uniserial or less commonly biserial in part, arcuate to rectilinear Aperture terminal, radiate or rounded, slitlike, or multiple.

Genus *Dentalina*

Species: *inflexa* (Reuss, 1866)

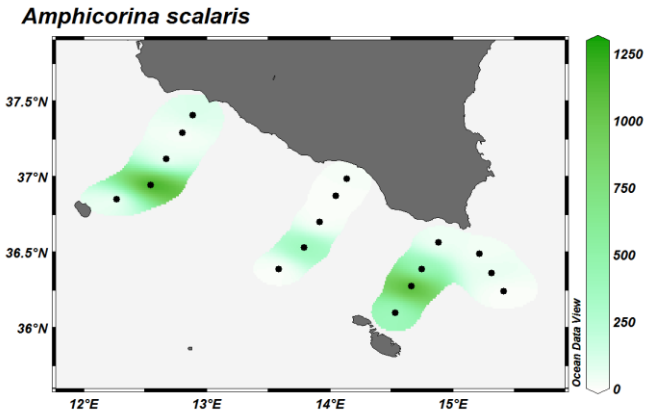
Species: *communis* (d'Orbigny, 1826)

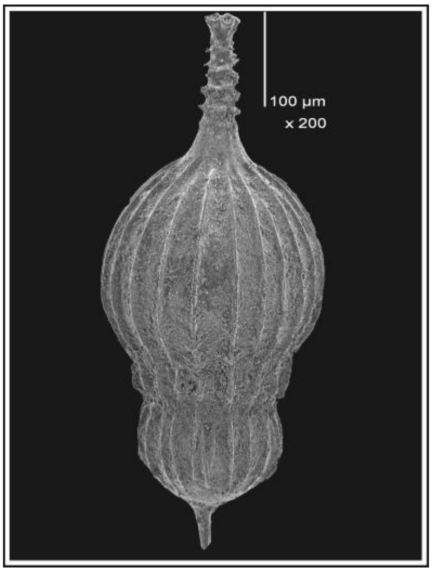
Species: *sp.* (d'Orbigny, 1826).

Family Vaginulinidae: test calcareous, enrolled throughout or with early stage partially enrolled or arcuate, and later stage uncoiled and rectilinear; ovate in section.

Genus *Amphicoryna*

Species: *scalaris* (Batsch,1791)





- morphology: test elongate at the base with an apiculate spine; in megalospheric specimens the proloculus is followed by rectilinearly arranged, uniserial globular chambers, whereas in the microspheric generation at first the chambers are arranged in an astacoline coil. Aperture terminal, radiate, on a long neck, which is ornamented with several ringlike concentric ridges.

- distribution: very widespread species in the Mediterranean; well represented in the circalittoral and bathyal mud; it is reported also in the infralittoral zone, and occurs in the deep-wather assemblages of the Tyrrhenien Sea and of the Sicily Channel (Parisi, 1981; Sgarrella and Moncharmont-Zei, 1993).

- ecology: epifaunal, free of clinging, herbivore, detritivore.

Genus *Astacolus*

Species: *crepidulus* (Fichtel and Moll, 1798).

Genus *Lenticulina*

Species: *calcar* (Linnaeus, 1767)

Species: *cultrata* (Montfort, 1808)

Species: *gibba* (d'Orbigny, 1826)

Species: *orbicularis* (d'Orbigny, 1826)

Species: *sp.* (Lamarck, 1804)

Genus *Neolenticulina:*

Species: *peregrina* (Schwager, 1866)

Genus *Vaginulinopsis*:

Species*: tasmanica* (Parr, 1950)

Superfamily Polymorphinoidea

Family Ellipsolagenidae: wall hyaline and finely perforate. Test unilocular, flasklike and lenticular in horizontal section. Aperture with an internal tubular extension. Periphery carinate and thickened. Surface smooth except for the slightly irregular neck. The neck makes up about one third of the length of the specimen. The aperture is ovate, produced on the neck and bordered by a thickened rim.

Genus *Favulina*

Species: *hexagona* (Williamson, 1848)

Genus *Fissurina*

Species*: castanea* (Flint, 1899).

Species: *eburnea* (Buchner, 1940).

Species: *lucida* (Williamsoni, 1848)

Species*: neptuni* (Buchner, 1940).

Species: *orbignyana* (Seguenza, 1862).

Species: *sp*. (Reuss, 1850)

Species*: sidebottomi* (Buchner 1940).

Genus *Oolina*

Species: *compressa* (d'Orbigny, 1839)

Family Polymorphinidae: test with chambers spirally arranged on a vertical axis, strongly overlapping toward the early part of the test; rounded. Slitlike or radiate aperture at the distal side.

Genus *Polymorphyna*:

Species: *sp.* (d’Orbigny, 1826)

Genus *Pyrulina*

Species: *sp.* (d'Orbigny, 1839)

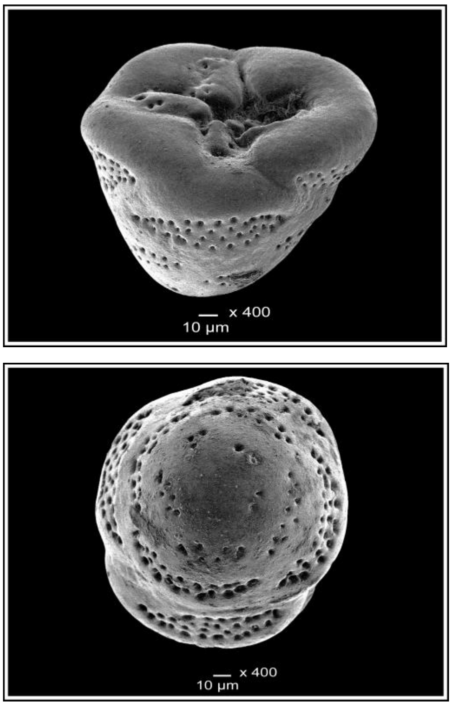
Order Rotaliida

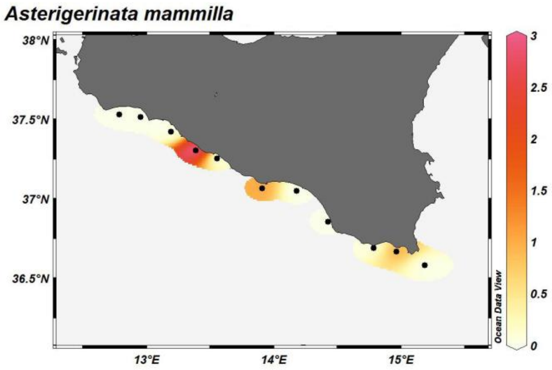
Superfamily Asterigerinoidea

Family Asterigerinatidae: test trochospiral; numerous chambers and chamberlets with sinuous sutures; primary apertures sutural or areal; wall structure optically radial.

Genus *Asterigerinata*

Species: *mammilla* (Williamson, 1848)





- morphology: test large, spherical to hemispherical or some-what irregular. Early spiral stage followed by numerous layers of alternating chamberlets. Septa thick, raised and imperforate; chambers perforate. Test pianocvonvex, conical in peripheral view. Communication to outside only by the murail; umbilical aperture. Evolute on the spiral side, involute on that umbilical.

- distribution: very widespread; infralittoral bottoms with vegetation cover, mostly on Posidonia (Sgarrella and Moncharmont-Zei, 1993).

- ecology: epifaunal, free, herbivore.

Family Epistomariidae: test trochospiral, primary aperture interiomarginal, supplementary sutural and areal apertures also may be present.

Genus *Pseudoeponides*

Species: *falsobeccarii* (Rouvillois, 1974)

Superfamily Chilostomelloidea

Family Chilostomellidae: test trochospiral to planispiral, chambers without an internal partition.

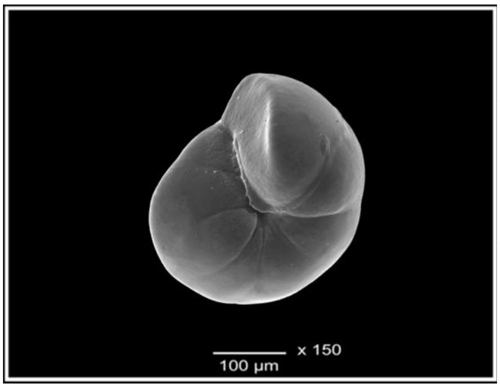
Genus *Chilostomella*

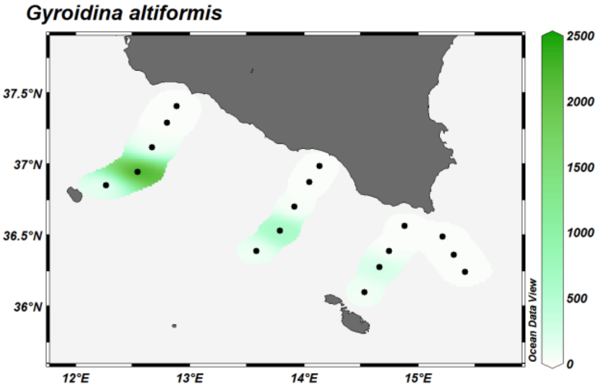
Species: *oolina* (Schwager, 1878)

Family Gavelinellidae: test low to high trochospiral; aperture interiomarginal, usually bordered by a narrow or wide extension of chamber wall.

Genus *Gyroidina*

Species: *altiformis* (R.E.and K.C. Stewart, 1930)





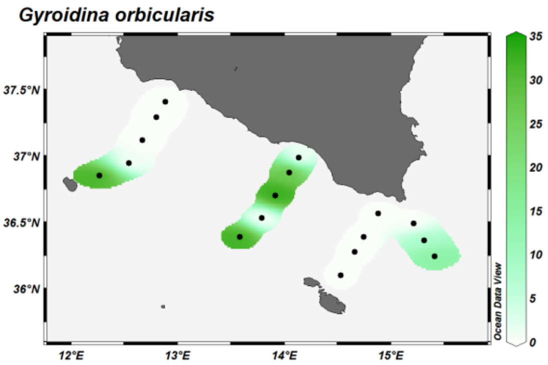
- morphology: test trochospiral, spiral side evolute, flattened or slightly convex; oblique sutures curved back to the periphery; umbilical side strongly convex, involute, with acute periphery; aperture a low interiomargial slit.

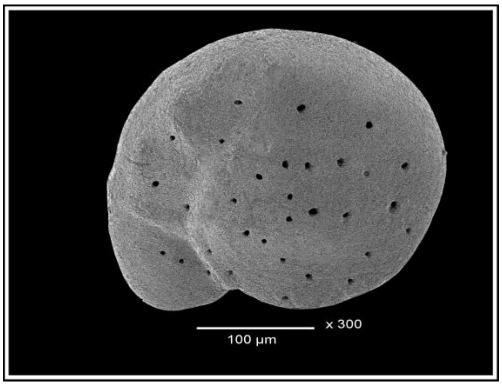
- distribution: generally recorded from 100 m depth downwards, it is reported in the Sicily Channel by Cita and Zocchi (1978) and by Parisi (1981); (Sgarrella and Moncharmont-Zei, 1993).

- ecology: epifaunal, free, detritivore.

Species: *neosoldanii* (Brotzen, 1936)

Species: *orbicularis* (d´Orbigny, 1826)





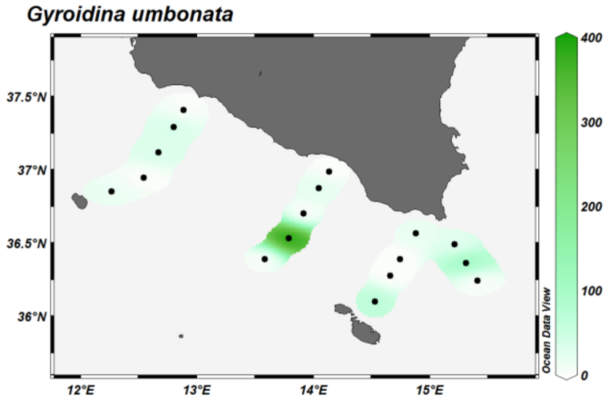
- <u>morphology</u>: test trochospiral, spiral side evolute, flattened in the last whorls, slightly convex in the early chambers; right sutures curved back to the periphery; umbilical side convex, involute; aperture a low interiomarginal slit.

- <u>distribution</u>: in the Mediterranean, this species is generally referred to as bathyal by Blanc-Vernet (1969).

- <u>ecology</u>: epifaunal, free, detritivore.

Species: *sp.* (d'Orbigny,1826)

Species: *umbonata* (Silvestri, 1898)



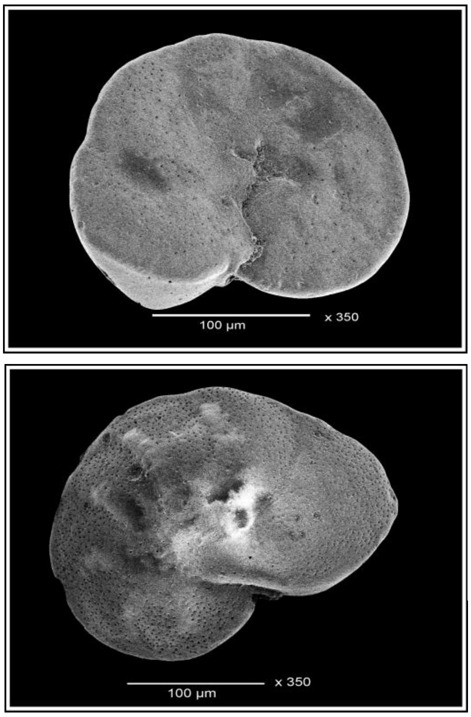
- morphology: test trochospiral, flattened; slight sutures curved back to the periphery; umbilical side slightly convex, involute; chambers gradually increasing in size as added. Aperture a low interiomargial slit.

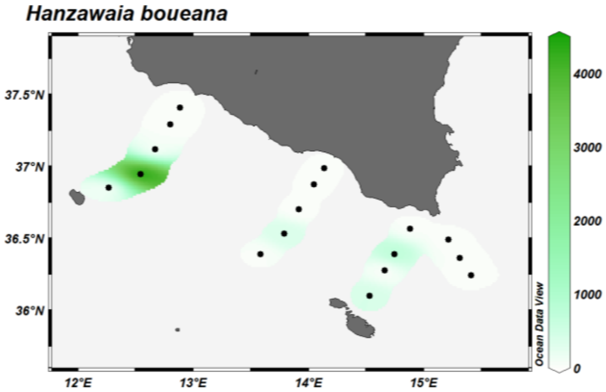
- distribution: this species is widespread in the Mediterranean Sea, generally reported at different depth ranges, from 50m to the bathyal Plane (Blanc-Vernet, 1969; Sgarrella and Moncharmont-Zei, 1993).

- ecology: epifaunal, free, detritivore.

Genus *Hanzawaia*

Species: *boueana* (d'Orbigny, 1846)





- morphology: test trochospiral, planoconvex, whorls enlarging rapidly; chambers numerous, sutures thickened and strongly curved back at the periphery, convex side involute with clear central umbilical boss, flattened side partially evolute. Umbilical apertural flap from each chamber extending over the umbilical region and chambers of earlier whorls; periphery subangular may be carinate. Wall calcareous, optically granular, moderately coarsely perforate; thickened sutures.

- distribution: this species is common in outer neritic environments in the Mediterranean and is a frequent element in displaced faunas.

- ecology: epifaunal, clinging clinging hard substrates; passive suspension feeder; temperate-warrn; inner shelf.

Family Oridorsalidae: wall calcareous, finely perforate; test lenticular, chambers in low trochospiral coil; aperture at base of the apertural face, extending from near the periphery to the umbilical region, small secondary sutural openings on spiral side near junction of spiral and septal sutures.

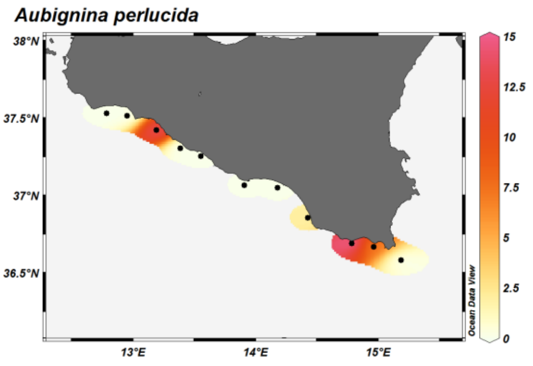
Genus *Oridorsalis:* epifaunal.

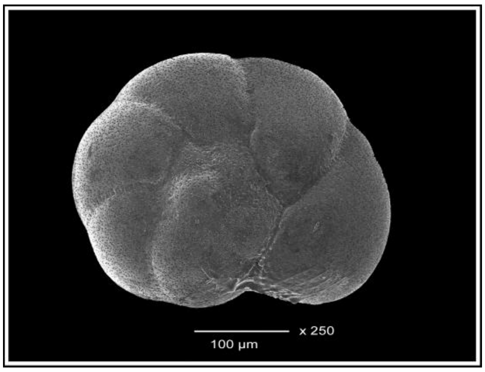
Species: *umbonatus* (Reuss, 1851)

Family Trichohyalidae: test trochospiral, umbilical side partly or wholly obscured by secondary growth of shell material.

Genus *Aubignyna*

Species: *perlucida* (Heron-Allen and Earland, 1913)





- morphology: wall calcareous, hyaline, perforate surface smooth except for numerous beadlike granules in the apertural face. A low trochospiral coil of one and a half to two gradually enlarging whorls; eight chambers in the final whorl; sides flattened, periphery rounded and sutures weakly depressed. Aperture interiomarginal, extending from the umbilicus to the periphery; supplementary sutural apertures occur on the umbilical side.

- distribution: innershelf and brackish lagoons.

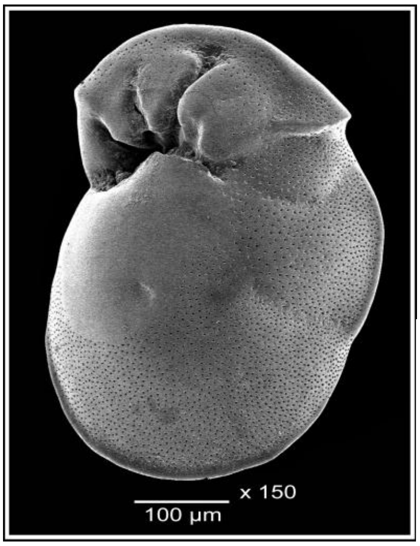
- ecology: infaunal, free.

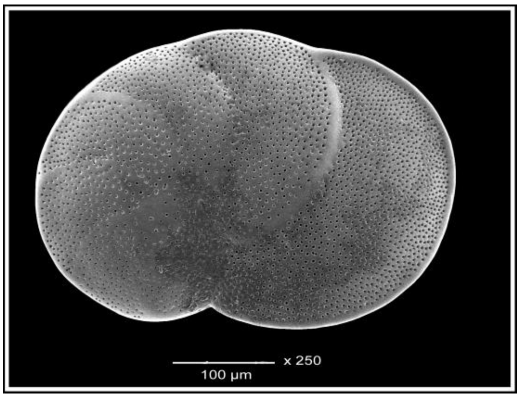
Superfamily Discorboidea

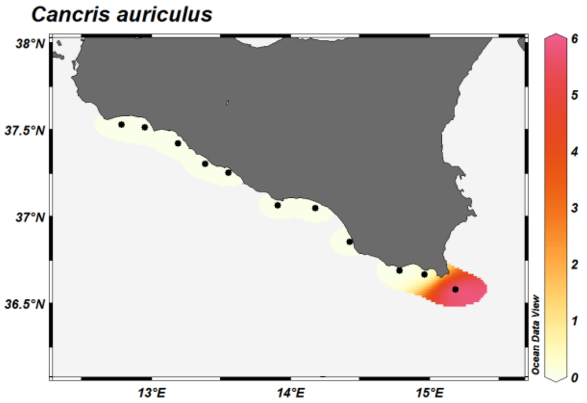
Family Bagginidae: trochospiral, test calcareous, finely perforate but with imperforate area near aperture and umbilicus on ventral side.

Genus *Cancris*: epifaunal; prefers high organic flux.

Species: *auriculus* (Fichtel and Moll, 1798)







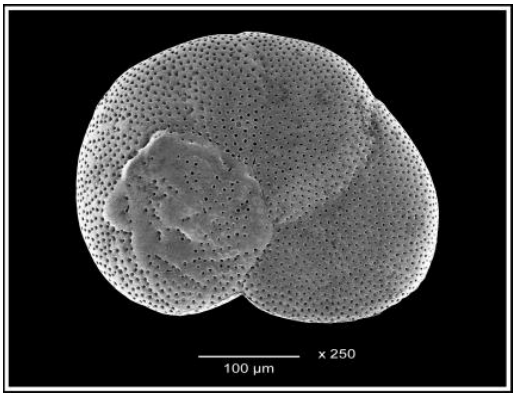
- <u>morphology</u>: wall calcareous, perforate, but with an imperforate area above the aperture, continuing into the imperforate umbilical apertural flap; surface smooth other than the peripheral keel. Test elongate ovate to auriculate in outline, lenticular in section; periphery angled to carinate. Chambers increasing rapidly as added; flaring trochospiral coil; sutures depressed. Aperture a low interiomarginal opening on the umbilical side, with a broad apertural flap.

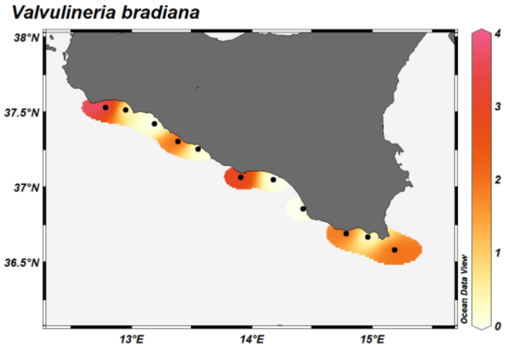
- <u>distribution</u>: very rare in the Mediterranean; depth range of 25-200 m (Sgarrella and Moncharmont-Zei, 1993).

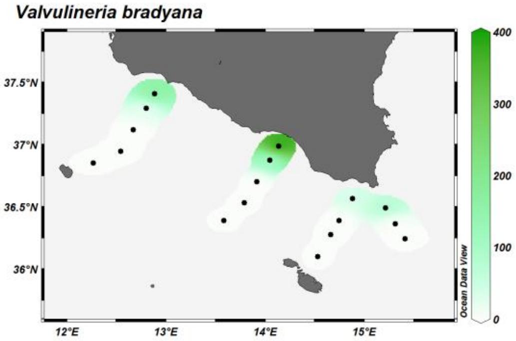
- <u>ecology</u>: epifaunal, free, detritivore.

Genus *Valvulineria*

Species: *bradyana* (Fornasini, 1900)




Valvulineria bradiana


Valvulineria bradyana

- morphology: wall calcareous, hyaline; test trochospiral with subrounded periphery; surface smooth and finely perforate, apertural face imperforate. Spiral side advolute, slightly convex with a weakly depressed initial stage; umbilical side involute, with depressed umbilicus. Two and a half whorls are visible; chambers are inflated, increasing in size as added. Aperture an interiomarginal arch with a large flap covering the umbilicus.

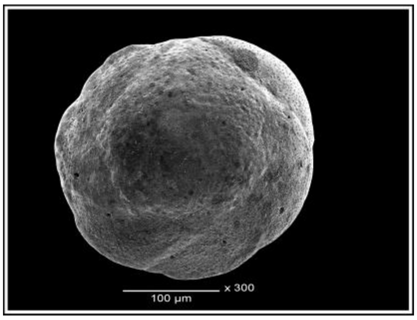
- distribution: very widespread all around the Mediterranean; abundant from circalittoral and epibathyal mud; depth range 30-100 m (Sgarrella and Moncharmont-Zei, 1993).

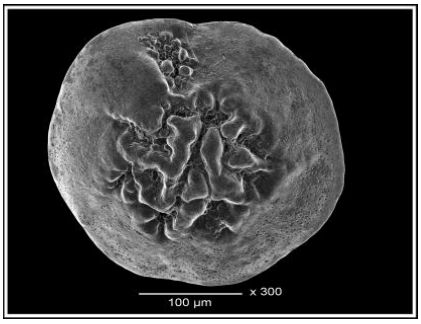
- ecology: shallow infaunal, tolerating dysoxia.

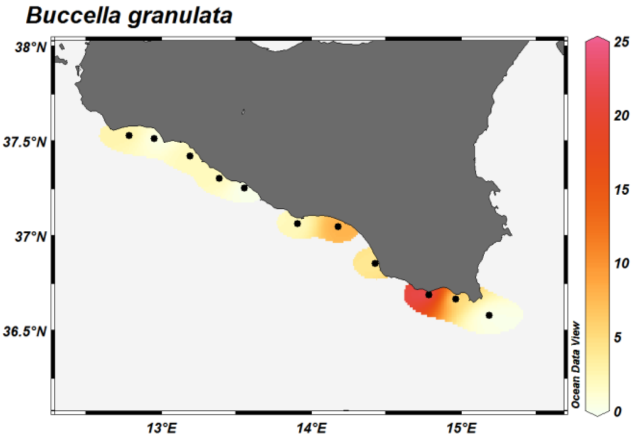
Family Discorbidae: test a low trochospiral; chamber partly divided by an imperforate wall; aperture umbilical with distinct flap extending over the umbilical region, may have additional openings at opposite end of the flaps.

Genus *Buccella*

Species: *granulata* (di Napoli Alliata, 1952)







- morphology: small biconvex test, wall coarsely agglutinated; test trochospiral, lenticular in peripheral view with 5-6 crescentic chambers in the final whorl; in the umbilical side is heavly ornamented by calcareous material, which covers the aperture. Aperture interiomarginal (Albani and Serandrei Barbero, 1990).

- distribution: very widespread in the Mediterranean; abundant in infralittoral fine sands; bottoms with vegetation cover, mostly Cymodocea and Posidonia (Blanc-Vernet, 1969; Sgarrella and Moncharmont-Zei, 1993).

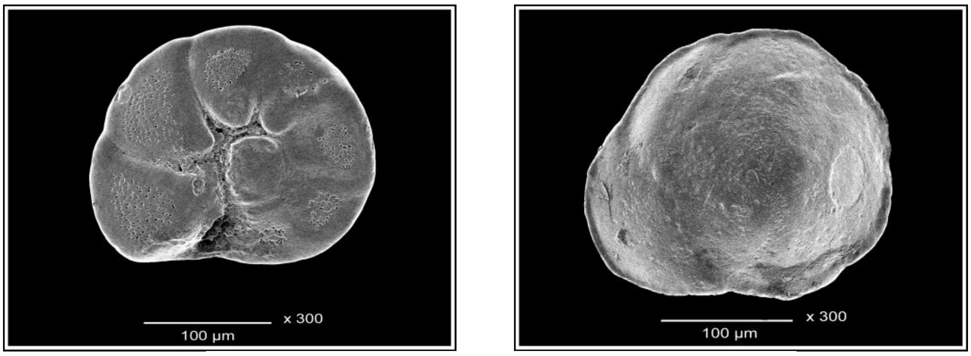
- ecology: infaunal, free, detritivore.

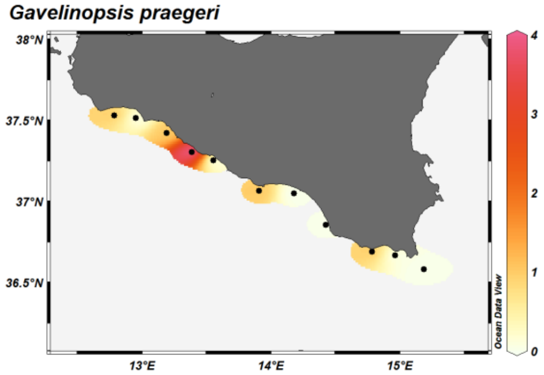
Genus *Discorbis*

Species: *sp.* (Lamarck, 1804)

Genus *Gavelinopsis*

Species: *praegeri* (Heron-Allen and Earland, 1913)





- <u>morphology</u>: wall calcareous; test trochospiral and planoconvex with about three whorls; spiral side evoiute and convex, umbilical side involute, strongly fiattened with six chambers in the final whorl; sutures oblique. Chambers nearly trianguiar in outline on the umbilical side, peripheral margin carinate; umbilical side perforate and within the umbilicus a rounded umbilical knob is present. Aperture an interiomarginal, extraumbilical arched slit.

- <u>distribution</u>: widespread in the Mediterranean; frequent in the circalittoral zone, it is present also in the infralittoral zone; depth range 60 - 100 m; recorded by Parisi (1981) from the Tyrrhenian Sea (down to 3,588 m) and from the Sicily Channel at deeper bathymetry (Sgarrella and Moncharmont-Zei, 1993).

- <u>ecology</u>: epifaunal, clinging.

Species: *sp.*(Hofker, 1951)

Family Eponididae: test trochospiral, at least in early stage: aperture interiomarginal, extending from periphery to umbilicus on umbilical side, or may be cribrate and areal.

Genus *Eponides*

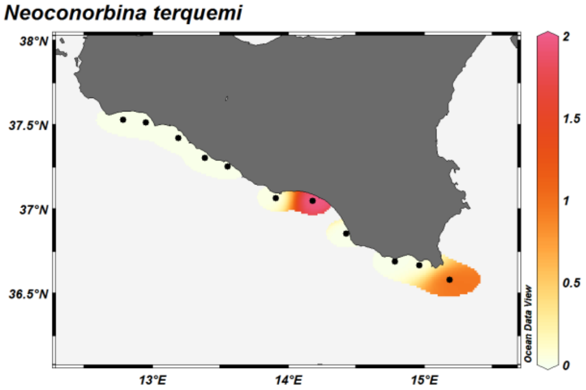
Species: *repandus* (Fichtel and Moll, 1798)

Species: *repandus concamerata* (Montagu, 1808)

Family Rosalinidae: test trochospiral, may have closed umbilicus or umbonal boss; chamber interior simple; aperture a low arch at the base of the final chamber on the umbilical side.

Genus *Neoconorbina*

Species: *terquemi* (Rzehak, 1888)



- morphology: test trochospiral, planoconvex, triangular in peripheral view. Spiral side perforate along the chamber margins, umbilical side perforate. Involute, flat ventral side; spiral side evolute with about 3.5 whorls and long crescentic chambers. Chambers with subtriangular to rectangular folia on the umbilicai side. Aperture an elongated, interiomarginal, extraumbilical slit extending around the folium.

- distribution: exclusively marine species (Albani and Serandrei Barbero, 1990) frequent in the infralittoral zone; deph range of 30-60 m. Parker (1958) has found it to a depth of 799 m, more frequently shallower than 117 m (Sgarrella and Moncharmont-Zei, 1993).

- ecology: epifaunal, clinging, herbivore.

Genus *Rosalina*

Species*: bradyi* (Cushman, 1915)

Species: *sp*. (d'Orbigny, 1826)

Family Sphaeroidinidae: chambers variously enrolled; aperture an arched slit just above the base of the chamber or primary aperture may be replaced by a series of sutural supplementary openings.

Genus *Sphaeroidina*

Species: *bulloides* (d'Orbigny, 1826)

Superfamily Glabratelloidea

Family Glabratellidae: test a low trochospiral coil, umbilical side commonly with radial ornamentation and granules around umbilicus.

Genus *Conorbella*

Species: *patelliformis* (Brady, 1884)

Superamily Nonionoidea

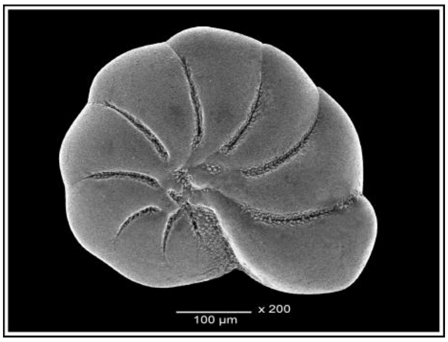
Family Nonionidae: test planispiral throughout or at least in the early stage; aperture interiomarginal and equatorial or a series of small equatorial pores.

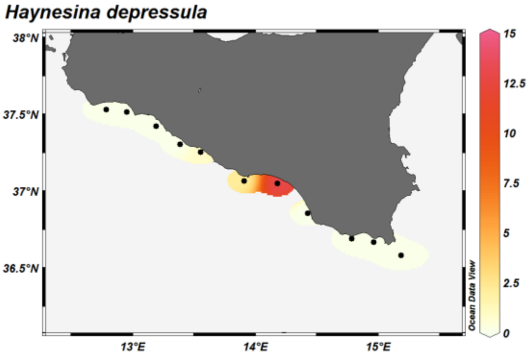
Genus *Astrononion*

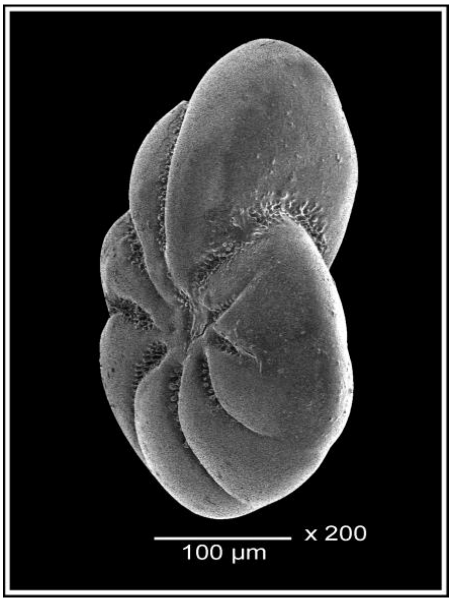
Species: *stelligerum* (d'Orbigny, 1839)

Genus *Haynesina*

Species: *depressula* (Walker and Jacob 1798)







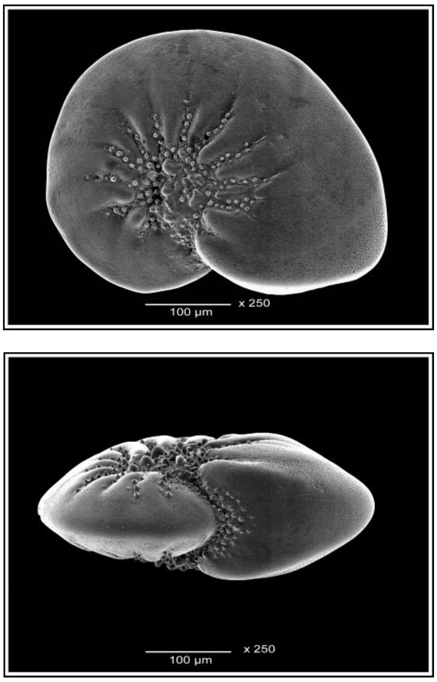
- morphology: wall calcareous, finely perforate, with a smooth surface. test planispiral, biumbilicate, sub-circular with involute coiling and somewhat compressed; the periphery is sub-rounded. Sutures slightly backwards curved and depressed. Chambers with short folia and foliar apertures, gradually increase in size as added; up to twelve weakly inflated chambers visible in the final whorl. The umbilicus is depressed and the interlocular spaces are densely covered by tubercles. Aperture a low interiomarginal arch obscured by the surrounding tuberculation.

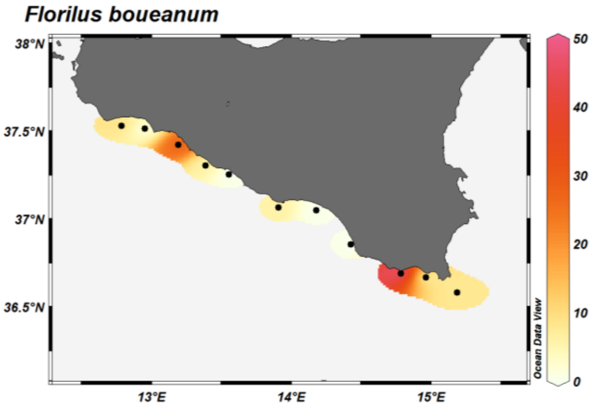
- distribution: inner shelf and transitional environments.

- ecology: infaunal, free, mudd and silt substrates; herbivore.

Genus *Florilus*

Species: *boueanum* (Rasheed and Ragothaman, 1997)



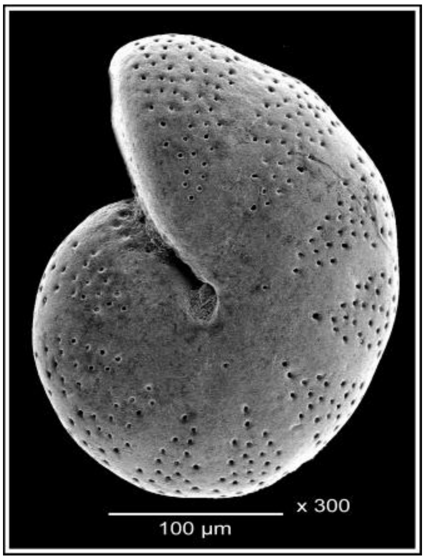


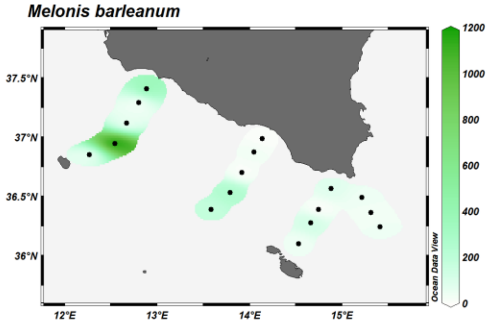
- morphology: wall calcareous, optically granular, surface smooth except for the granules; test planispiral ovate to circular and smooth in outline; coiling involute to slightly evolute, laterally compressed and biumbilicate; umbilici filled with granules on the inner margins of the chambers. Chambers increasing in size as added. Sutures depressed near the umbilici. Aperture a low interiomarginal and equatorial slit at the base of the apertural face, extending laterally nearly to the umbilici, and covered by numerous granules.

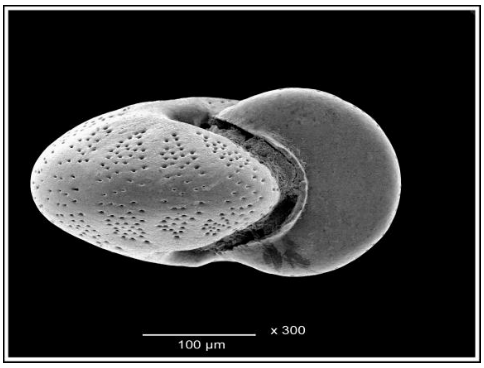
- ecology: shallow infaunal.

Genus *Melonis:*

Species*: barleanum* (Williamson, 1858)







- morphology: wall calcareous, hyaline; test planispiral, involute, symmetrical, biumbilicate with rounded, peripheral margin; surface without ornamentation. About ten chambers in the final whorl, increasing in length, breadth and in thickness. Sutures radial and slightly curved. Chamber wall densely perforate, sutures and apertural face imperforate. Aperture a low interiomarginal and equatorial slit extending to the umbilici and remaining open around the umbilical margin, bordered with a distinct and protruding lip.

- distribution: widespread all around the Mediterranean; frequent and abundant from circalittoral and bathyal mud; depth-range of 60-100 m (Sgarrella and Moncharmont-Zei, 1993).

- ecology: deep-infaunal, tolerant of degraded organic matter; tolerating dysoxia.

Species*: pompilioides* (Fichtel and Moll, 1798)

Genus *Nonion*

Species: s*p.* (de Montfort, 1808)

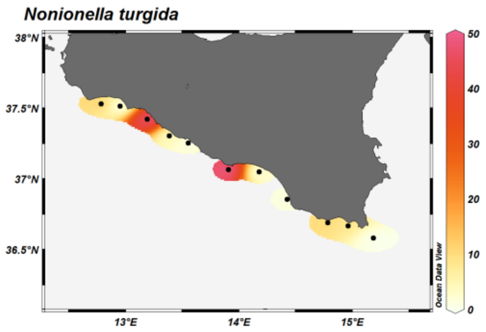
Genus *Nonionella*

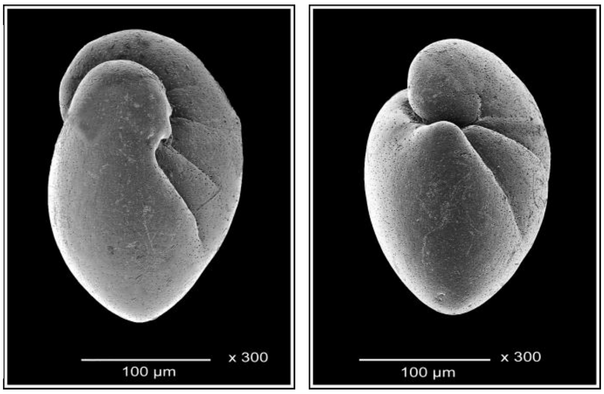
Species: *opima* (Cushman, 1947)

Species: *sp.* (Rhumbler, 1949)

Species: *stella* (Cushman and Moyer, 1930)

Species: *turgida* (Williamson, 1858)





- morphology: wall calcareous and hyaline; trocospiral coiled with primary torsion chamber and next chambers are spiral and perforated; radial and deep suture lines.

- distribution: very widespread species in the Mediterranean; depth-range of 40-100 m (Sgarrella and Moncharmont-Zei, 1993).

- ecology: typical species of muddy bottoms, infaunal, free; tolerate temporary dysoxia and high organic matter content.

Genus *Pullenia*

Species: *bulloides* (d’Orbigny, 1826)

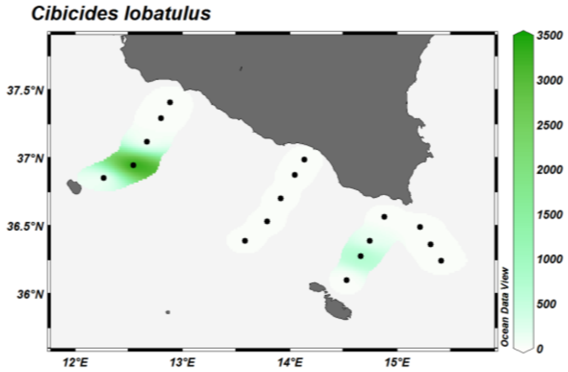
Species: *quinqueloba* (Reuss, 1851)

Superfamily Planorbulinoidea

Family Cibicididae: chamber arrangement low trochospiral throughout, or uniserial or biserial in the lateral part, or planispiral or annular; test attached by spiral side: primary aperture a low equatorial arch that may extend from ventral to dorsal side.

Genus *Cibicides*

Species: *lobatulus* (Walker and Jacob, 1798)

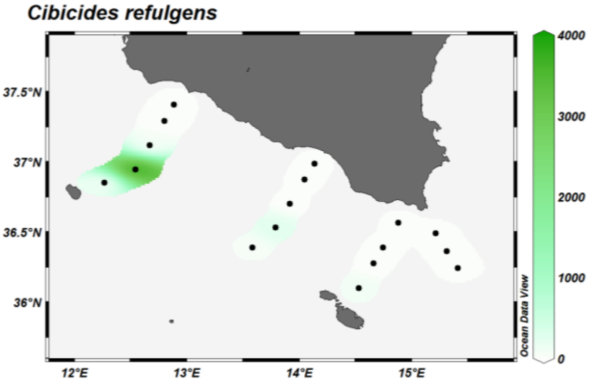


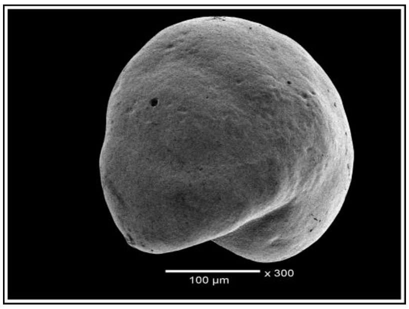
- morphology: wall calcareous and hyaline, coarsely perforate; trocospiral coiled; convex ventral side and spiral side flat; sutures thickened, depressed and radial around the shallow umbilicus. Seven or eight chambers in the last whorl. Aperture an interiomarginal, equatorial arch bordered by a small lip: apertural lip and area bordering the aperture are imperforate (Albani and Serandrei Barbero, 1990).

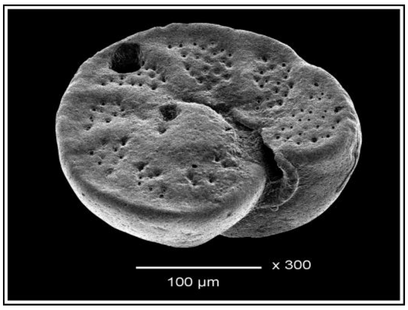
- distribution: very widespread species in the Mediterranean; abundant in the infralittoral zone, it is present also from circalittoral zone, down to 100 m; (Sgarrella and Moncharmont-Zei, 1993).

- ecology: epifaunal, usually attached to vegetable leaves or on detritus; high energy environments.

Species: *refulgens* (De Montfort, 1808)







- morphology: wall calcareous and hyaline, coarsely perforate; test trochospiral and biconvex, periphery angular and carinate; convex ventral side and spiral side flat; sutures thickened, depressed and radial around the shallow umbilicus. The apertural face is angular, and the periphery is subcarinate. Eight chambers that increase in size when added, are visible in the final whorl. Aperture an interiomarginal, equatorial arch bordered by a small lip: apertural lip and area bordering the aperture are imperforate.

- distribution: widespread species in the Mediterranean (Sgarrella and Moncharmont-Zei, 1993).

- ecology: epifaunal, usually attached; high energy environments.

Family Planulinidae: test trochospiral to nearly planispiral, partially evolute on both sides; aperture a low interiomarginal, equatorial arch.

Genus *Planulina*

Species: *sp.*(d'Orbigny, 1826)

Superfamily Discorbinelloidea

Family Parrelloididae: wall calcareous, test trochospiral, biconvex; spiral side coarsely perforate, opposite side with closed umbilicus and central boss. Aperture a low interiomarginal and equatorial opening bordered by a narrow lip.

Genus *Cibicidoides*

Species: *pachyderma* (Rzehak, 1886)

Superfamily Planorbulinoididae

Family Planorbulinidae: test free or attached, early stage trochospiral, later may have chamber proliferation resulting in discoid. Cylindrical or conical tests; single or multiple aperture.

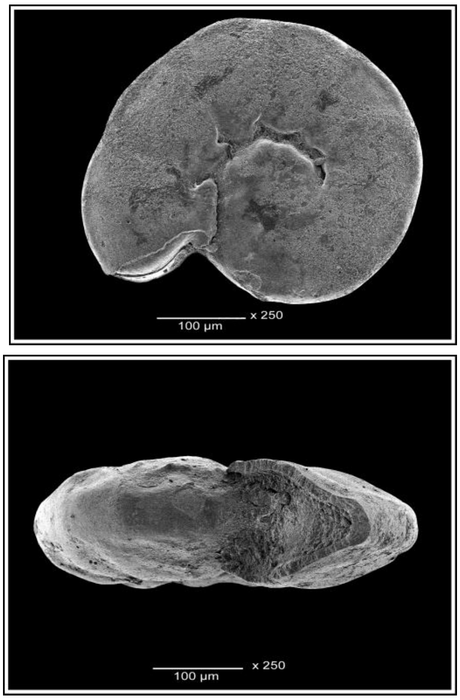
Genus *Planorbulina*

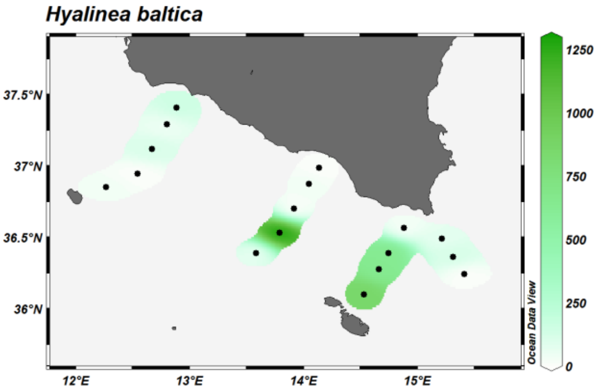
Species*: mediterranensis* (d'Orbigny, 1826)

Family Planulinidae: test trochospiral to nearly planispiral, partially evolute on both sides; aperture a low interiomarginal equatorial arch.

Genus *Hyalinea*

Species: *baltica* (Schroeter, 1783)





- morphology: wall calcareous and hyaline, surface smooth; test discoidal, very low trochospiral, flat, semievolute on both side; eight to ten chambers in the final whorl; sutures curved, grading into the broad imperforate peripheral carina, periphery angular; finely perforate except for the elevated imperforate septa and keel. Ubilical margin of the chambers with a small umbilical flap or folium. Aperture a low equatorial and interiomarginal arch, bordered above by a narrow lip, a low slit continuing laterally beneath the folium in the umbilical region and around the spiral suture on both sides of the test.

- distribution: very widespread species in the Mediterranean; circalittoral and especially epibathyal mud (Sgarrella and Moncharmont-Zei, 1993).

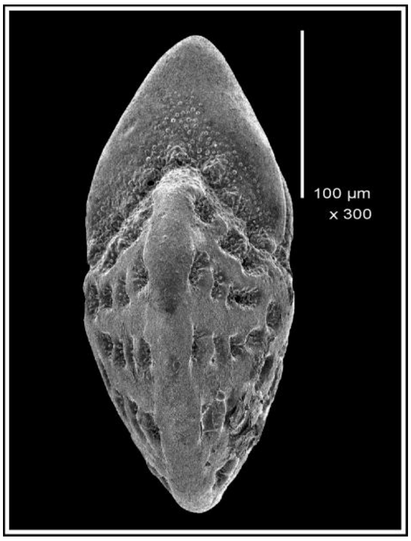
- ecology: epifaunal, free, detritivore.

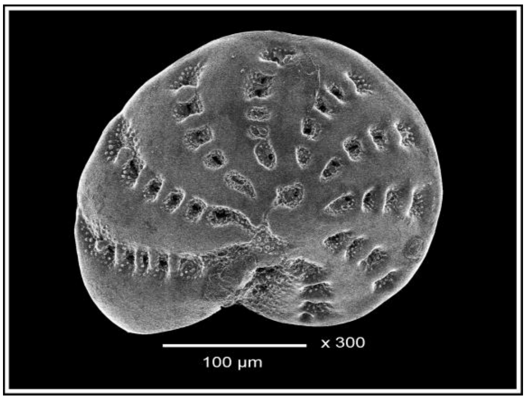
Superfamily Rotalioidea

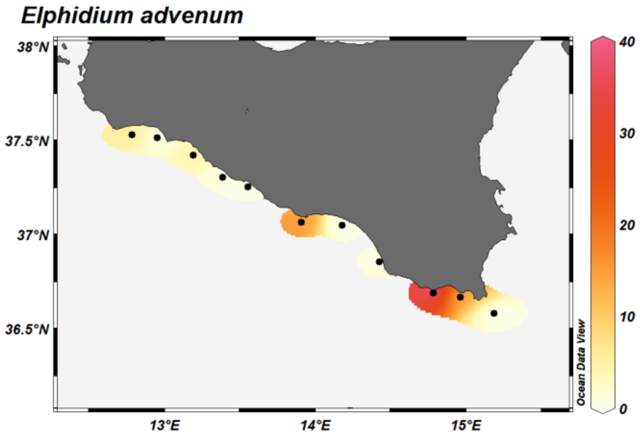
Family Elphidiidae: test planispiral to trochospiral, or may uncoil in later stage; sutural canal system opening into sutural pores; aperture interiomarginal or areal, single or multiple.

Genus *Elphidium*

Species: *advenum* (Cushman, 1922)







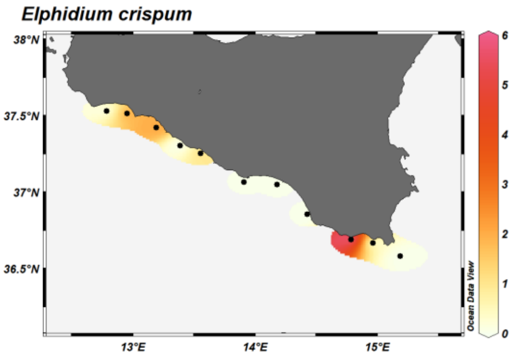
- morphology: test pianispiral, involute and flat. Peripheral outline subcircular, peripheral margin acute and carinate. 21-24 chambers in the final whorl all backwards curved. The small folia of the chambers fuse in the umbilical region and develop a somewhat irregular structure, with small openings resulting from vertical canals piercing the umbilicus. Chambers are inflated and sutures are depressed, presenting many retroseptal ponticuli. The primary aperture is composed of a single row of openings at the lower base of the final chamber in interiomarginal position.

- distribution: widespread species in the Mediterranean, reported in shallow waters. (Albani and Serandrei Barbero, 1990).

- ecology: epifaunal, free, herbivore.

Species: *complanatum* (d´Orbigny, 1839)

Species: *crispum* (Linneaus, 1758)

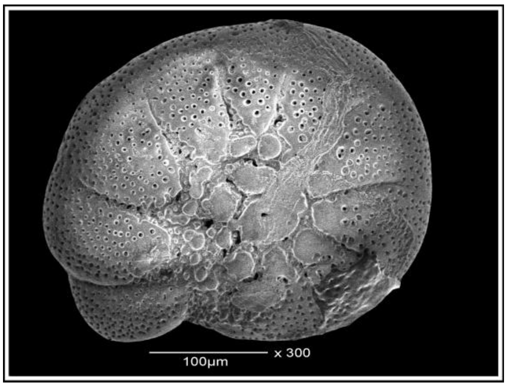


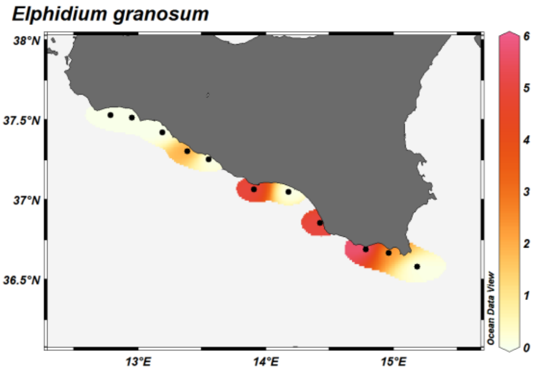
- morphology: planispiral, involute and compressed; big dimensioned test. Peripheral outline subcircular, peripheral margin acute and carinate. More than 20 chambers in the final whorl all backwards curved in a sigmoid form; chambers are inflated, presenting many retroseptal ponticuli; the umbilical region presents a perforated and smooth knob. The primary aperture is composed of a single row of openings at the lower base of the final chamber in interiomarginal position (Albani and Serandrei Barbero, 1990).

- distribution: species typically marine; very widespread in the Mediterranean, abundant in infralittoral sand and in circalittoral detritic sand. (Sgarrella and Moncharmont-Zei, 1993).

- ecology: epifaunal, free, herbivore; rarely on the Posidonia leaves.

Species: *granosum* (d´Orbigny, 1826)





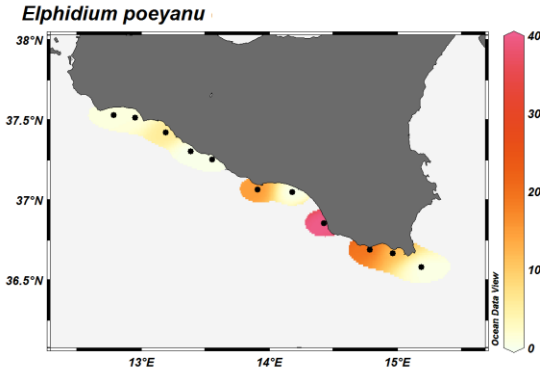
- morphology: planispiral, involute and compressed; generally big dimensioned test. Peripheral outline and margin subcircular. Chambers are inflated and densely perforated. The umbilical region is covered by numerous granules and presents a knob. The primary aperture is composed of a single row of openings at the lower base of the final chamber in interiomarginal position (Albani and Serandrei Barbero, 1990).

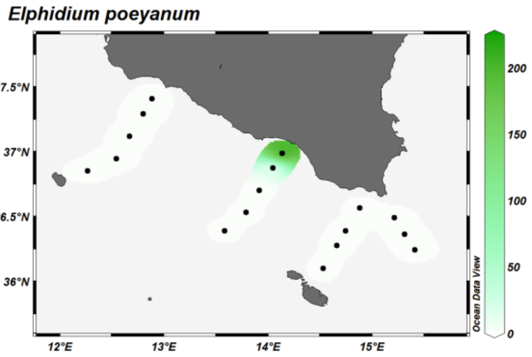
- distribution: species typically marine, very widespread in the Mediterranean; abundant in infralittoral fine sediments and in circalittoral mud, down to about 100 m (Sgarrella and Moncharmont-Zei, 1993).

- ecology: epifaunal, free, herbivore.

Species: *macellum* (Fichtel and Moll, 1798)

Species: *poeyanum* (d'Orbigny, 1839)





- morphology: planispiral, involute and lamellar; subcircular in lateral view, and broadly lenticular in profile view; generally big dimensioned test. Peripheral outline and margin subcircular. Deep sutures particulary in the later stage. Chambers are inflated, presenting many retroseptal ponticuli, and densely perforated, excepted the smooth and flat umbilical region consisting of the fuse small folia of the chambers. The primary aperture is composed of a single row of openings at the lower base of the final chamber in interiomarginal position.

- distribution: abundant in the Mediterranean, present in infralittoral sands and in the circalittoral zone (Sgarrella and Moncharmont-Zei, 1993).

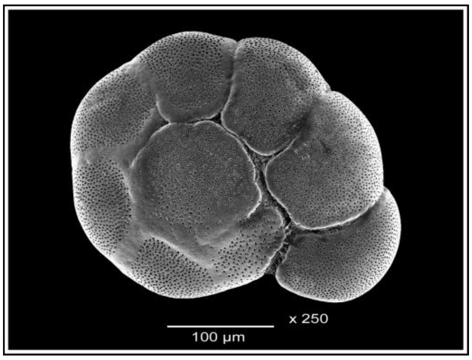
- ecology: epifaunal, free, herbivore.

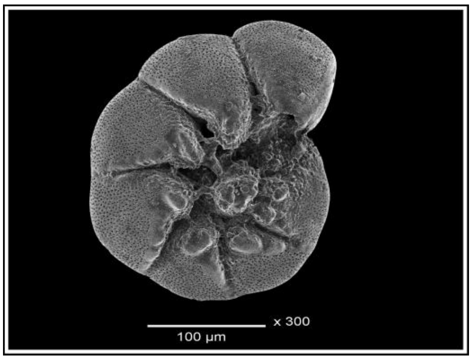
Species: *sp.* (de Montfort, 1808)

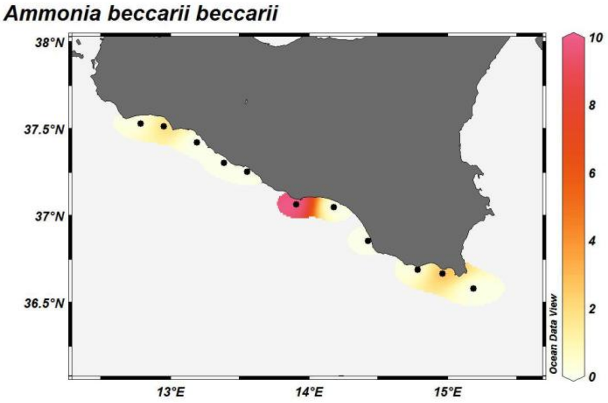
Family Rotaliidae: test low trochospiral throughout, with radial canals or fissures and intraseptal and subsutural canals.

Genus *Ammonia*

Species: *beccarii beccarii* (Linnaeus, 1758)





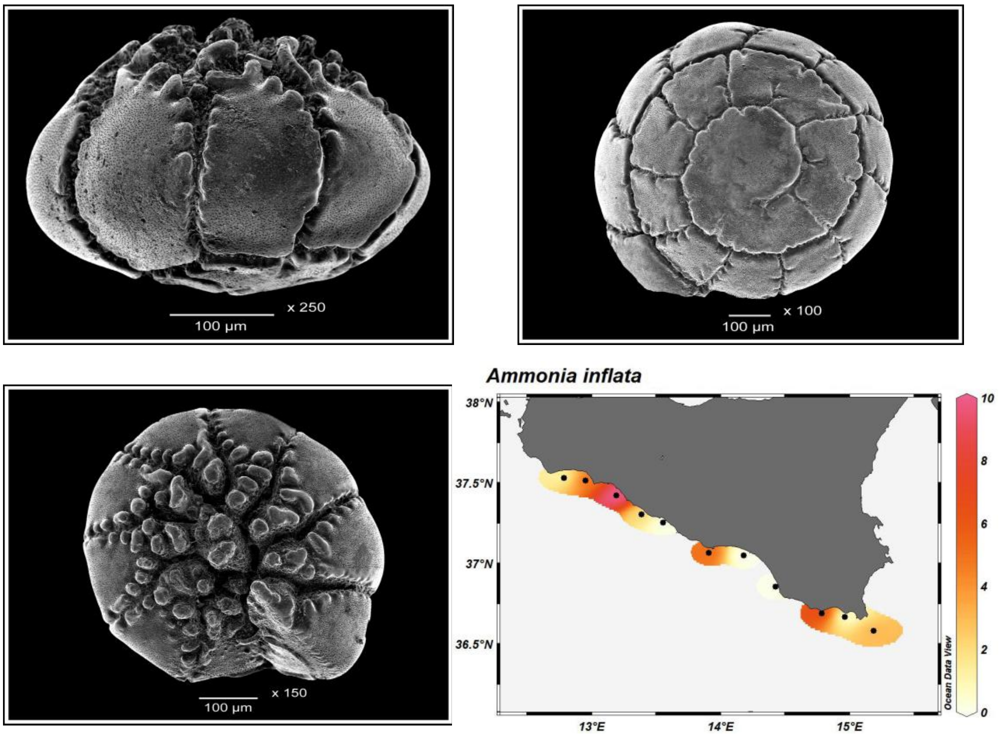


- morphology: wall calcareous, hyalinus; large dimensioned species; the spiral side is flattened presents deeply incised sutures in the last whorl, and thickened among the earlier chambers; large pores; rectangular shaped chambers. Ventral side presents a well developed umbilical knob, with pointed and imperforate chamber flaps and knobby ornamentations. Nine to ten chambers in the last whorl (Jorissen,1988).

- distribution: widespread in the Mediterranean, abundant in the whole infralittoral zone in the first 30 m, mostly on sandy bottom (Sgarrella and Moncharmont-Zei, 1993).

- ecology: epifaunal, free, herbivore, common in sediments with highly variable mood and TOC contents, salinity and oxygen.

Species: *beccarii inflata* (Seguenza, 1862)



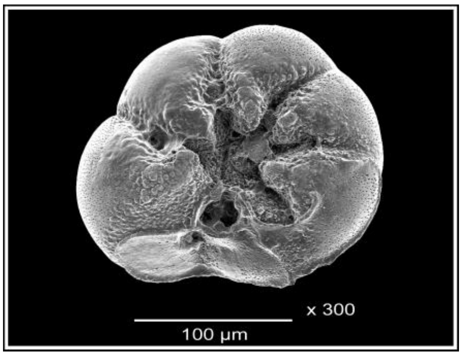
- <u>morphology</u>: wall calcareous, hyalinus; large dimensioned species. The chambers of the umbilical side and the knob region are densly covered by a knobby ornamentations; the spiral side, is low convex, presents deeply incised sutures among all the chambers in at least the last whorl (Jorissen,1988); the chambers edges may appear more or less jagged. Periphery rounded. Aperture an interiomarginal, extraumbilical arch.

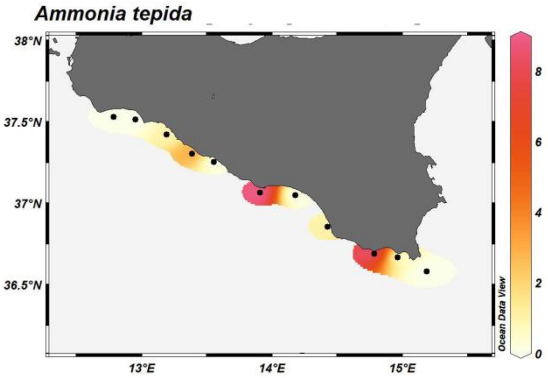
- <u>distribution</u>: (cfr. *A. gaimardi*) abundant in the infralittoral and upper circalittoral zone; muddy-sands and detritic bottoms (Sgarrella and Moncharmont-Zei, 1993).

- <u>ecology</u>: epifaunal, free, herbivore, common in sediments with highly variable TOC contents, salinity and oxygen.

Species: *parkinsoniana parkinsoniana* (d'Orbigny, 1839)

Species: *parkinsoniana tepida* (Poag,1978)





- morphology: wall calcareous, hyalinus; test relatively small and thin, lobate in outline; umbilical knob is not developed; the chambers of the last whorls are inflated and presents deep septa; the spiral side, is low convex and the periphery is rounded (Jorissen,1988).

- distribution: widespread in the Mediterranean, abundant in the whole infralittoral zone in the first 30 m, mostly on sandy bottom (Sgarrella and Moncharmont-Zei, 1993).

- ecology: epifaunal, free, herbivore, common in sediments with highly variable mood and TOC contents, salinity and oxygen.

Superfamily Siphoninoidea

Family Siphoninidae: test trochospiral in early stage, later may be nearly planispiral. streptospiral, uncoiled or biserial. Aperture rounded or oval, at the end of a neck and bordered by a lip.

Genus *Siphonina*

Species: *reticulata* (Czjzek, 1884)

Order Buliminida

Superfamily Bolivinoidea

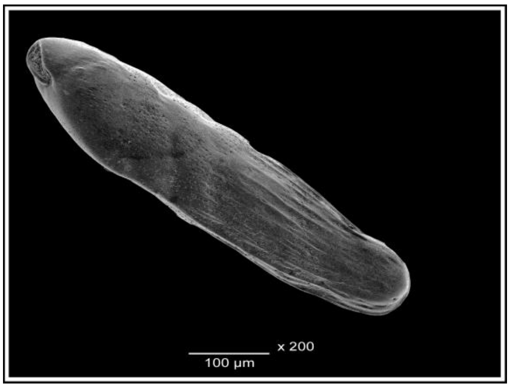
Family Bolivinidae: test biserial throughout or only in the early stage. Aperture a high loop-shaped opening, provided with a tooth-plate.

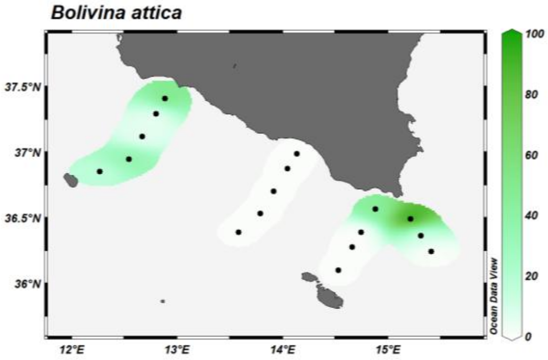
Genus *Bolivina*

Species: *alata* (Seguenza,1862)

Species: *albatrossi* (Cushman, 1922)

Species: *attica* (Parker, 1958)



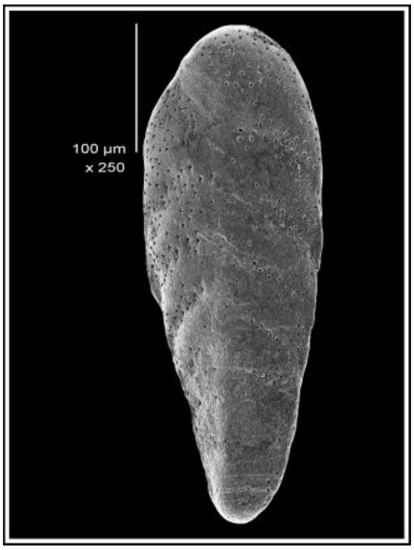


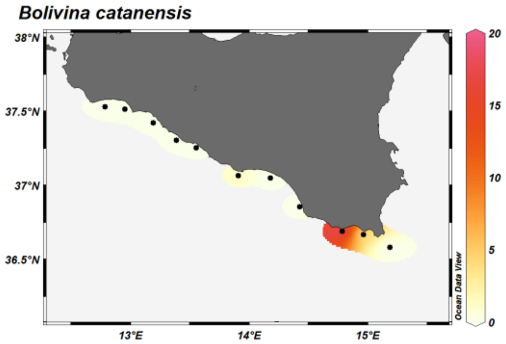
- morphology: wall calcareous, hyalinus and perforated; the periphery is acute and the test is compressed in lateral view and could terminate with a short spine. The ratio of length/width is about 1/3. Periphery sharply rounded, often with a narrow keel; wall ornamented with 10-12 low costae on the lower half of the tests (Parker, 1958).

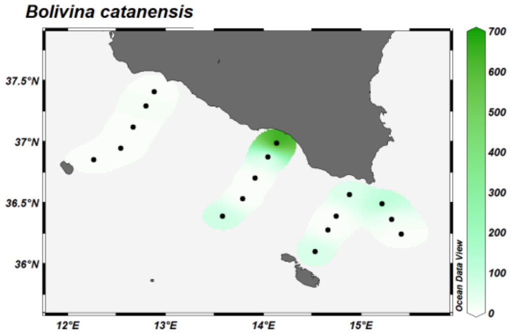
- distribution: rare in Mediterranean; depth range of 82-383 m (Parker, 1958).

- ecology: infaunal

Species: *catanensis* (Seguenza, 1862)







- morphology: wall calcareous, hyalinus and perforated; the test is elongate, compressed, with a sub-arcuate periphery; the sutures are distincted and oblique but not so depressed. The wall is irregularly perforated (Albani and Serandrei Barbero, 1990).

- distribution: very common in the western Mediterranean, from 70 down to 1000 m of depth (Parker, 1958). It occurs from infralittoral to epibathyal mud (Sgarrella and Moncharmont-Zei, 1993).

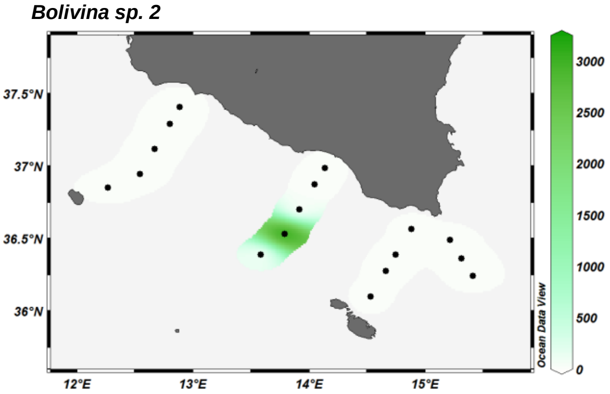
- ecology: infaunal

Species: *difformis* (williamson, 1858)

Species: *dilatata dilitatissima* (Reuss, 1850)

Species: *sp.* 1 (d'Orbigny, 1843)

Species: *sp.2* (d'Orbigny, 1843)



- morphology: wall calcareous, hyalinus and perforated; test, small, large, biserial throughout, triangular and acute in the early chambers. Wall perforated; sutures depressed. The aperture consists of an ovate interiomarginal opening with a toothplate, bordered by a lip.

Species: *spathulata* (Williamson, 1858)

Species: *subaenariensis* (Cushman, 1922)

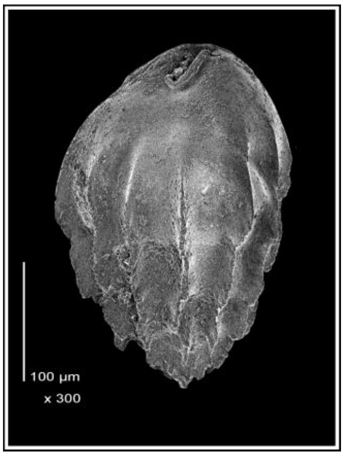
Species: *subspinescens* (Cushman, 1922).

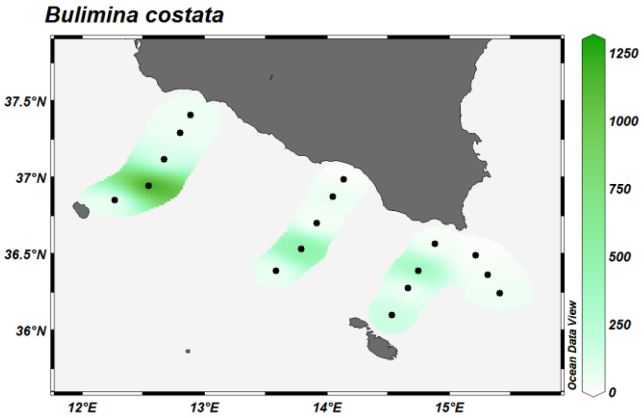
Superfamily Buliminoidea

Family Buliminidae: test highly trochospiral, consisting of not more than three chambers per whorl, but could be reduced to biserial. Aperture a loop in the apertural face, with distinct plate like toothplate that connects the aperture to the foramen.

Genus Bulimina

Species: *costata* (d'Orbigny, 1852)



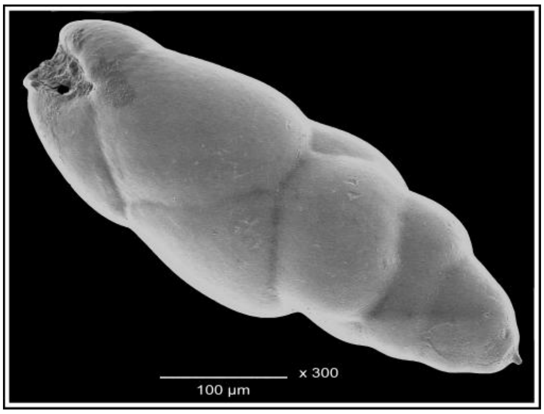


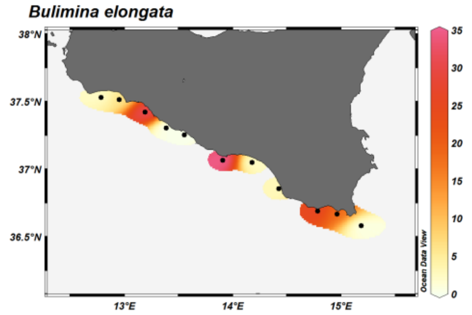
- morphology: wall calcareous; test small, triserial throughout and triangular in side view; trochospiral coiled. Chambers with acute basal, rapidly increasing in size as added. All the chambers are ornamented with numerous costae, arranged parallel to each others, which terminate with a spine at the end of the chambers. Aperture typical buliminid loop, extending from the base of the apertural face and provided internally with a toothplate.

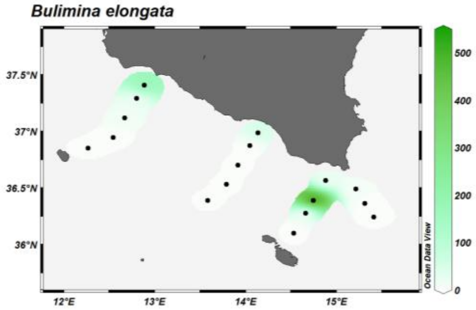
- distribution: very widespread in the western Mediterranean, from the circalittoral zone (50-70 m) and becomes abundant deeper than 90-100 m and in bathyal mud. Parisi (1981) found this species in the Sicily Channel and in the Tyrrhenian Sea, down to 2,239 m (Sgarrella and Moncharmont-Zei, 1993).

- ecology: infaunal, free.

Species: *elongata* (d´Orbigny, 1826)




Bulimina elongata

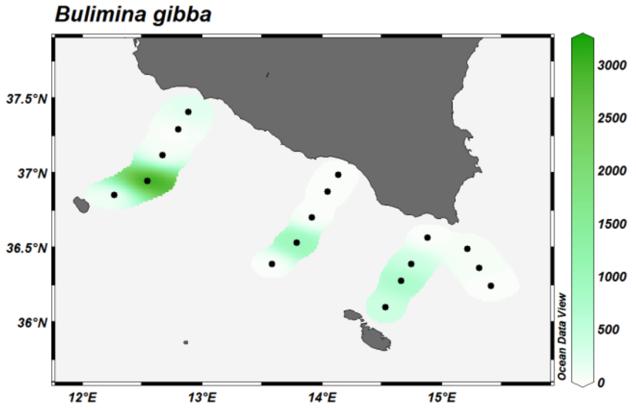

Bulimina elongata

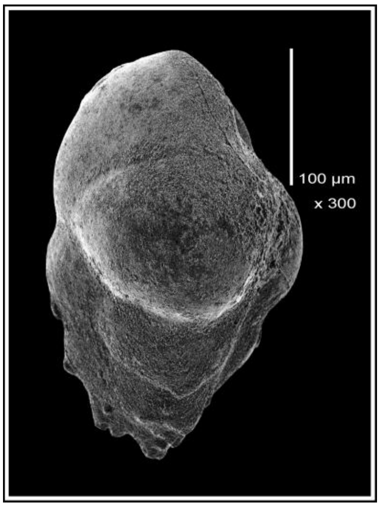
- morphology: wall calcareous; elongated test, triserial, could be uniserial in the early chambers; chambers slightly inflated; there is often present one basal spines. Aperture typical buliminid loop, extending from the base of the apertural face and provided internally with a toothplate (Albani and Serandrei Barbero, 1990).

- distribution: this species occurs in infralittoral and upper circalittoral muddy sediments from about 15 to 80 m. (Sgarrella and Moncharmont-Zei, 1993).

- ecology: infaunal, free, detritivore.

Species: *gibba* (Fornasini, 1902)



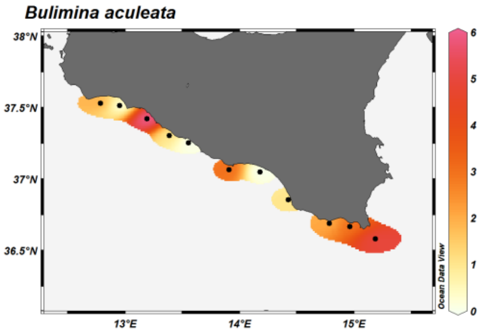


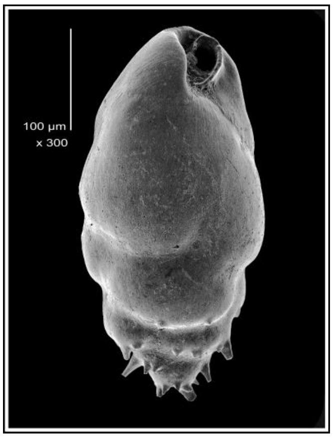
- morphology: wall calcareous; test elongated and large, triserial; chambers inflated, increasing as added; the early chambers terminate with a short spine, in aboral position; there are often present one or few basal spines. Aperture typical buliminid loop, extending from the base of the apertural face and provided internally with a toothplate (Albani and Serandrei Barbero, 1990). All the chambers are perfectly lined with those of the precedent whorl.

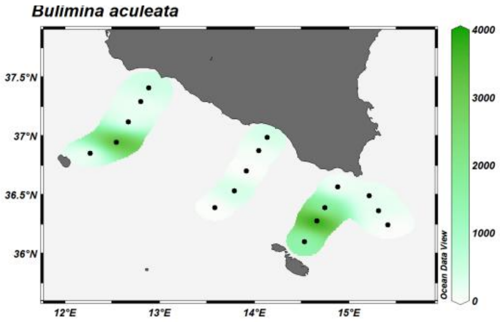
- distribution: exclusively marine species; is frequent in the Adriatic Sea; occurs at a depth of 15-18 m (Albani and Serandrei Barbero, 1990).

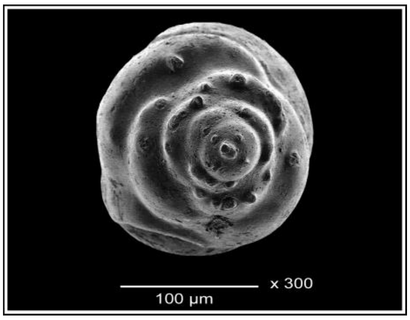
- ecology: infaunal, free.

Species: *marginata aculeata* (d´Orbigny, 1826)


Bulimina aculeata




Bulimina aculeata

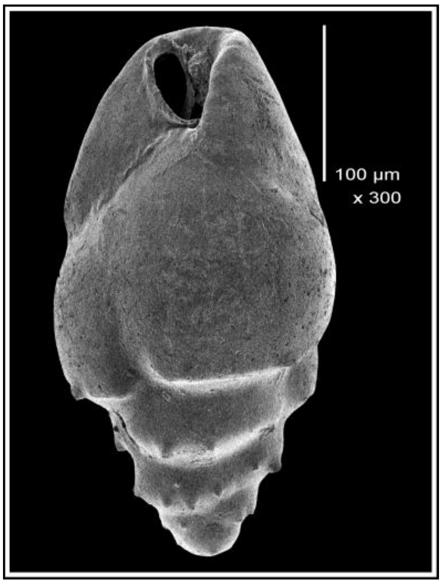


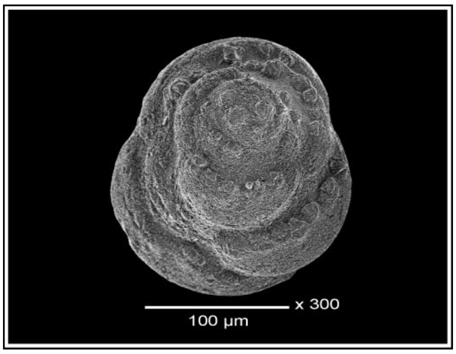
- morphology: wall calcareous; test elongated and large, triserial; chambers inflated, increasing as added; the early chambers terminate with at least one short spine, in aboral position; there are often present few basal spines. Aperture typical buliminid loop, extending from the base of the apertural face and provided internally with a toothplate Chambers are not lined with those of the precedent whorl.

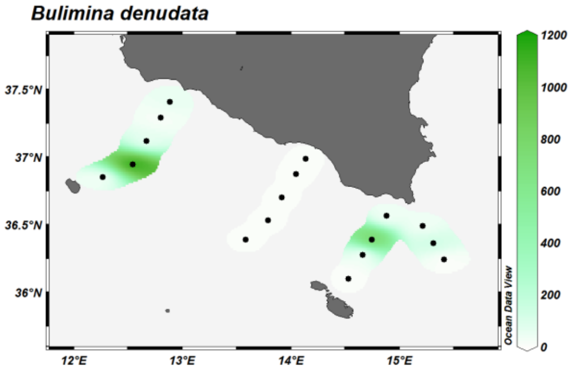
- distribution: widespread species, frequent in the infralittoral but also in the circalittoral and epibathyal zone (Sgarrella and Moncharmont-Zei, 1993).

- ecology: infaunal, muddy sediments, free, detritivore

Species: *marginata denudata* (Cushman and Parker, 1938)





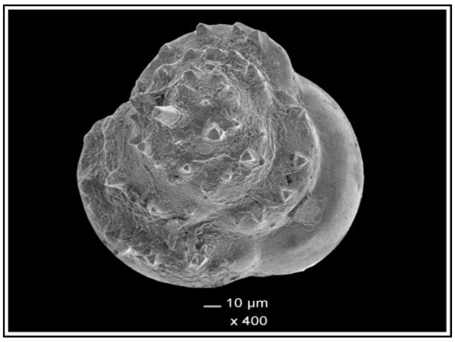


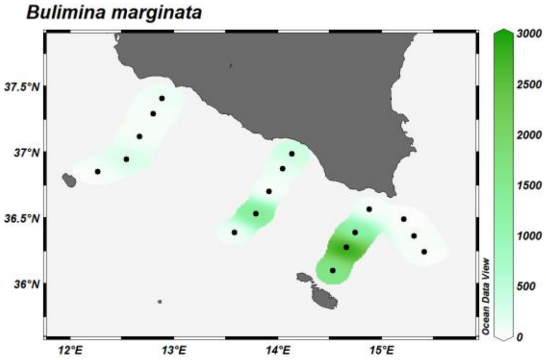
- <u>morphology</u>: wall calcareous; test elongated and large, triserial; the aboral side of the chambers presented a rounded angle; reduced ornamenration than the species *B. aculeata* and *B. marginata*; chambers inflated, increasing as added; there are often present few basal spines. Aperture typical buliminid loop, extending from the base of the apertural face and provided internally with a toothplate (Jorissen, 1988).

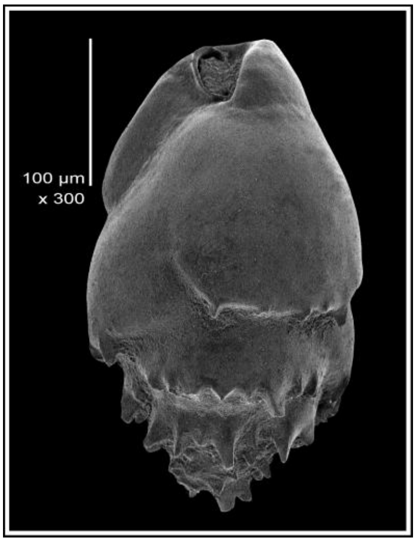
- distribution: widespread species, frequent in the infralittoral but also in the circalittoral and epibathyal zone (Sgarrella and Moncharmont-Zei, 1993).

- ecology: infaunal, free, detritivore.

Species: *marginata marginata* (d´Orbigny, 1826)







- morphology: wall calcareous; test small and large, triserial; tests characterized by the presence of angled undercuttings at the base of each chamber and numerous and developed spines along the chamber margin; Aperture typical buliminid loop, extending from the base of the apertural face and provided internally with a toothplate (Jorissen, 1988).

- distribution: very widespread species in the Mediterranean; frequent at the depth range of 15-18 m. It is present down to 30 m (Albani and Serandrei Barbero, 1990).

- ecology: infaunal, free, muddy sediment, detritivore.

Genus *Globobulimina*

Species: *affinis* (d'Orbigny, 1839)

Genus *Stainforthia*

Species*: complanata* (Egger, 1893)

Family Reussellidae: test triserial throught or changing to biserial or uniserial in later part; periphery angular; aperture interiomarginal or terminal, slitlike or cribrate.

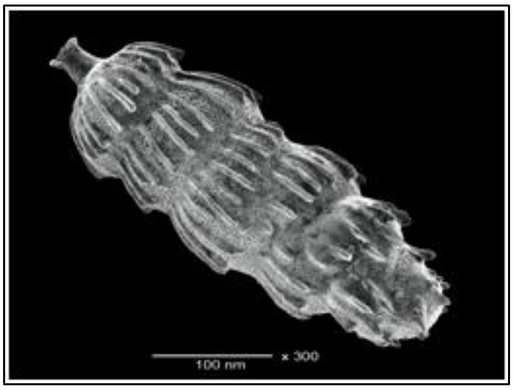
Genus *Reussella*

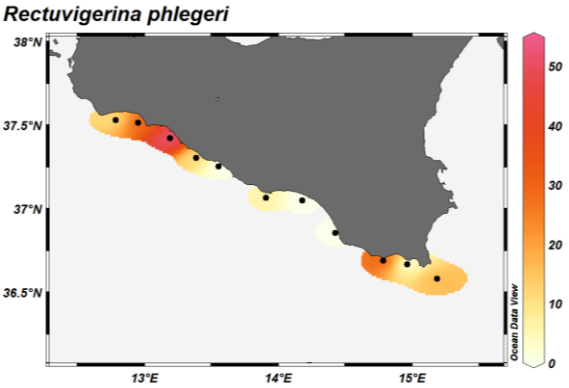
Species: *spinulosa* (Reuss, 1850)

Family Uvigerinidae: test triserial to biserial in the early stage, later may be biserial or tend to become uniserial; oblique sutures; aperture terminal extended into a neck, with internal toothplate connecting aperture and foramina of succesive chambers.

Genus *Rectuvigerina*

Species: *phlegeri* (Le Calvez, 1958)





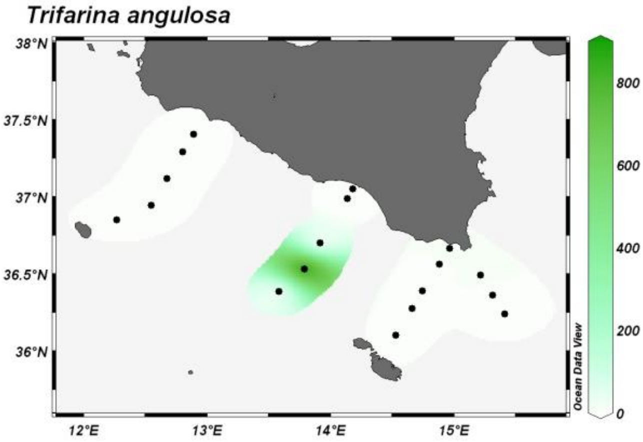
- morphology: wall calcareous, perforate, elongated and rounded in section; triserial in the early stage with oblique sutures, then uniserial with horizontal and straight sutures; surface with longitudinal costae, usually discontinuous, termining in short spines. Aperture rounded and terminal bordered with a lip; neck with internal toothplate connecting aperture and foramina of succesive chambers.

- distribution: species reported in the Mediterranean at a bathymetric range of 27- 90 m (Sgarrella and Moncharmont-Zei, 1993).

- ecology: infaunal; muddy bottoms; sensitive to low organic matter content in the sediment.

Genus *Trifarina*

Species: *angulosa* (Williamson, 1858)



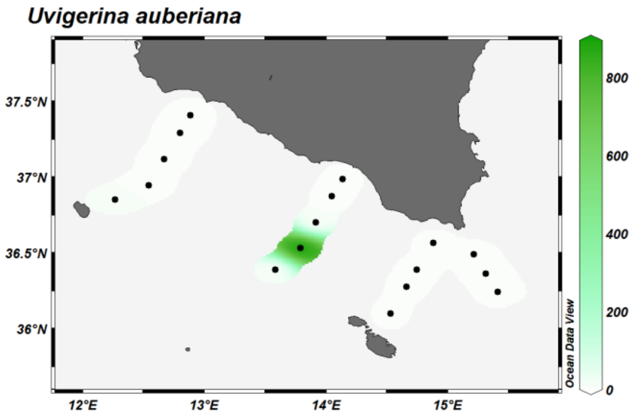
- morphology: wall calcareous, perforate; elongated test, triserial in the early stage tending to the uniseriality; apical part is rounded, with the chambers slightly compressed. The chambers of the later stage are elongated, presenting numerous longitudinal, subrounded costae. Sutures are oblique and depressed. Aperture produced on a neck and provided with an internal, strongly folded toothplate (Albani and Serandrei Barbero, 1990).

- distribution: in Mediterranean this species was recorded from bathyal and circalittoral zones; Parker (1958) reported it presence in the deep water of the Sicily Channel (Sgarrella and Moncharmont-Zei, 1993). In the Adriatic Sea it was mostly abundant at the depth of 15-18 m (Albani and Serandrei Barbero, 1990).

- ecology: epifaunal, is present in strong current environments, detritivore.

Genus *Uvigerina*

Species: *auberiana* (d'Orbigny, 1839)



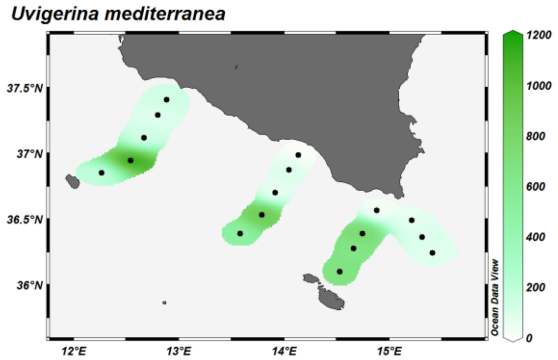
- morphology: wall calcareous, perforate; elongated test, triserial in the early stage, later more loosely triserial; apical part is rounded, with the chambers slightly compressed. The chambers of the later stage are slightly inflated, presenting depressed and oblique sutures; surface ornamented by granules. Aperture produced on a neck bordered by a lip and provided with a hemicylindrical toothplate.

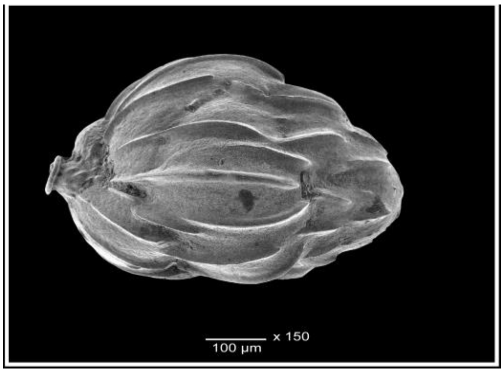
- distribution: species reported in the Mediterranean, at a bathymetric range of 150 down to 2800 m (Sgarrella and Moncharmont-Zei, 1993).

- ecology: infaunal, free; muddy sediment; detritivore.

Species: *costata* (d'Orbigny, 1839)

Species: *mediterranea* (Hofker, 1932)



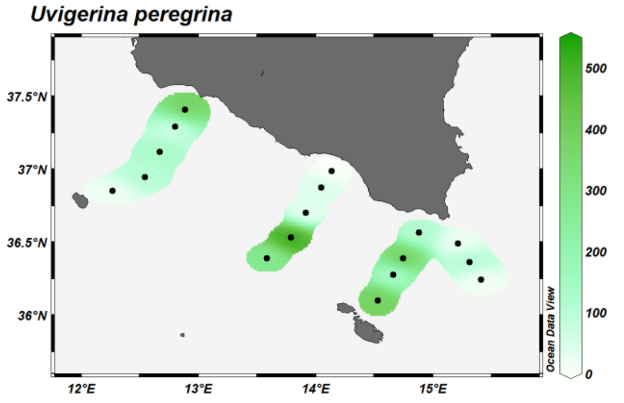


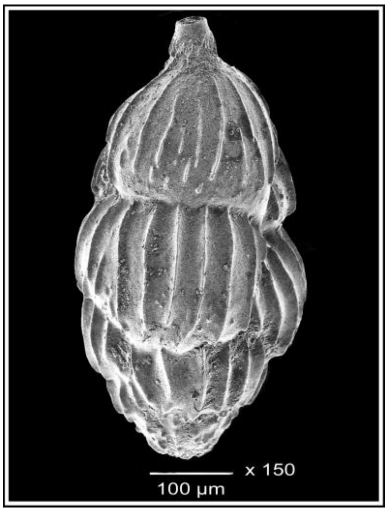
- morphology: wall calcareous, perforate; test elongated and large, triserial in the early stage, later more loosely triserial. Apical part is rounded; adult chambers are slightly inflated, with longitudinal non-continuous ribs, very large and marched. Sutures are oblique. A short neck slightly wedged within the apertural face terminate in the aperture bordered by a lip and provided with a hemicylindrical toothplate.

- distribution: this species is very widespread in the Mediterranean; it is recorded from the circalittoral zone (50-70 m) downwards, and very abundant in bathyal mud; in the Sicily Channel, Parisi (1981) registered this species as very abundant at about 1000 m of depth (Sgarrella and Moncharmont-Zei, 1993).

- ecology: shallow infaunal, abundant in environments rich in organic matter.

Species: *peregrina* (Cushman, 1923)





- morphology: wall calcareous, perforate; test elongated, triserial in the early stage, later more loosely triserial. Apical part is slightly rounded; adult chambers are more inflated, with longitudinal non-continuous ribs, thinner and less marched than in *U. mediterranea*. Sutures are oblique. It presents a neck bringing the terminal aperture, which is bordered by a lip and provided with a hemicylindrical toothplate.

- distribution: this species is widespread in the Mediterranean; less frequent than *U. mediterranea*, but with similar distribution (Sgarrella and Moncharmont-Zei, 1993).

- ecology: shallow infaunal, abundant in environments rich in organic matter, and a high concentration of bacteria.

Species: *sp.* (d'Orbigny, 1826)

Family Siphogenerinoididae: test tiserial or biserial to uniserial; aperture with toothplate.

Genus *Saidovina*

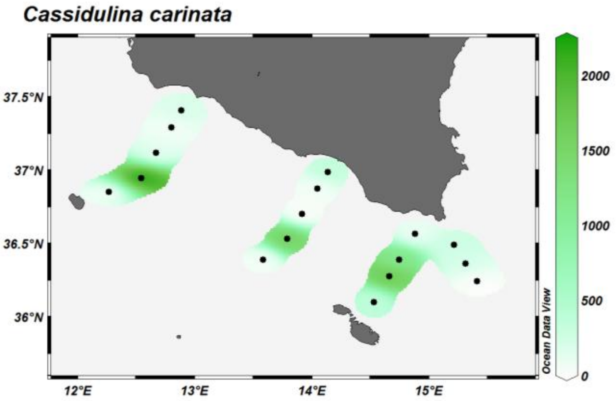
Species: *karrieriana* (Brady, 1881)

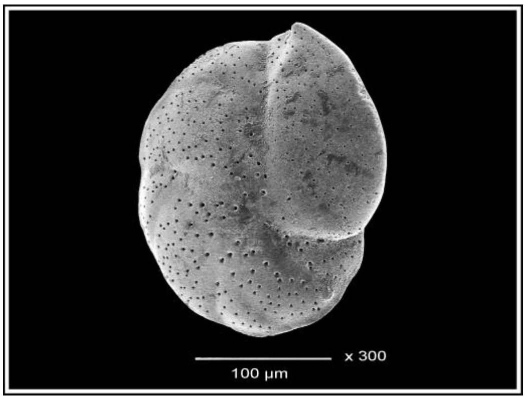
Superfamily Cassidulinoidea

Family Cassidulinidae: test with biserially arranged chambers; axis of biseriality enrolled in a planispiral coil at least in early stage, later may uncoil.

Genus *Cassidulina*

Species: *carinata* (Silvestri, 1896)



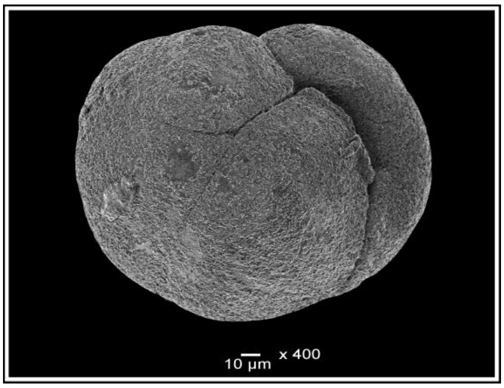


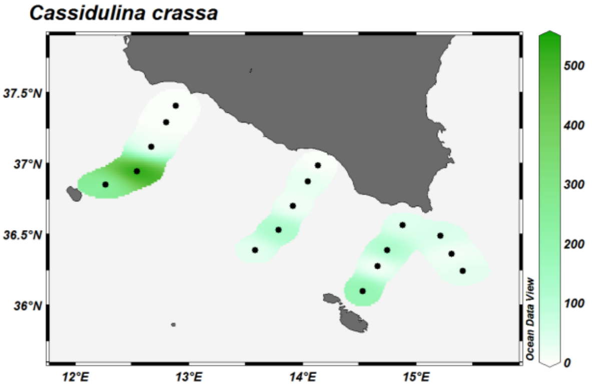
- morphology: wall calcareous, hyaline, perforate; test sub-circular, planispirally, thin and compressed, lenticular or biconvexed. The last whorl is composed by four chambers and bordered by a thin and slight keel; surface smooth; wall densely perforate, sutures and carinate margin imperforate. Acute edge; aperture is a basal slit partially closed by a weakly perforate apertural plate.

- distribution: widespread species, mostly from circalittoral and bathyal mud. Parisi (1981) reported this species in the deep-assemblages of the Sicily Channel (Sgarrella and Moncharmont-Zei, 1993).

- ecology: epifaunal; moderate to high organic flux.

Species: *crassa* (d´Orbigny, 1839)



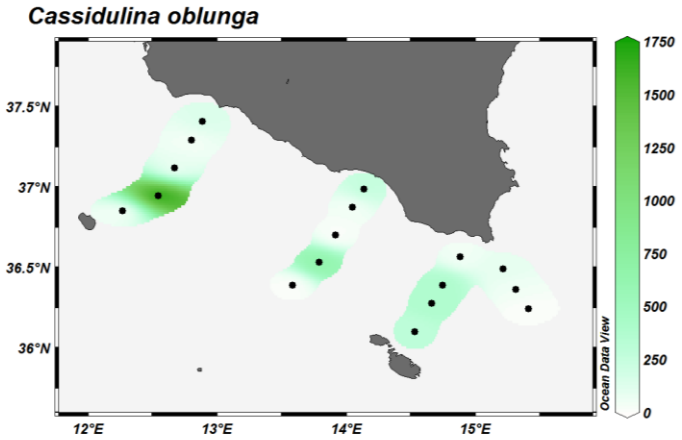


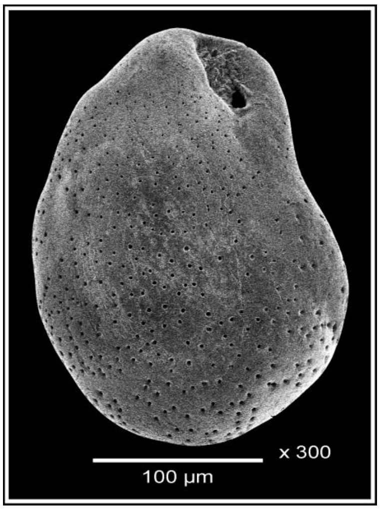
- morphology: wall calcareous, hyaline, perforate; test sub-circular; surface smooth, wall densely perforate. Oval outline, periphery sub-rounded and chambers biserially arranged; aperture is a basal slit partially closed by a weakly perforate apertural plate.

- distribution: very widespread species, mostly from circalittoral and bathyal mud (deeper than 100 m). In the Sicily Channel as well as in the Thyrrenian Sea, Parisi (1981) reported this species as abundant at about 1060 m (Sgarrella and Moncharmont-Zei, 1993).

- ecology: epifaunal-shallow infaunal, free, detritivore.

Species: *oblonga* (Egger, 1857)





- morphology: wall calcareous, hyaline, perforate; test sub-ovate; surface smooth, wall densely perforate. This species differs from C. crassa because of the obtuse peripheral edge, the number and size of the visibile segments (chambers) and the aperture more subelliptical.

- distribution: this species was found from the Adriatic Sea, at a bathymetric range of 50-700 m, with low frequency (Jorissen, 1988).

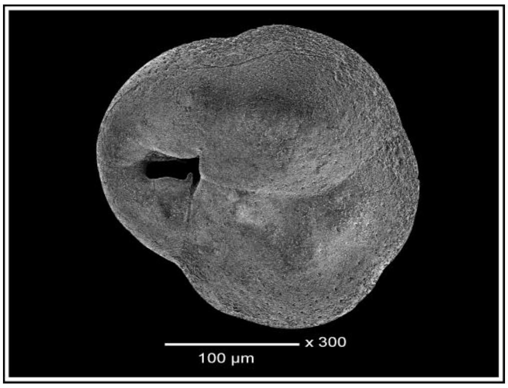
- ecology: epifaunal-shallow infaunal, free, detritivore.

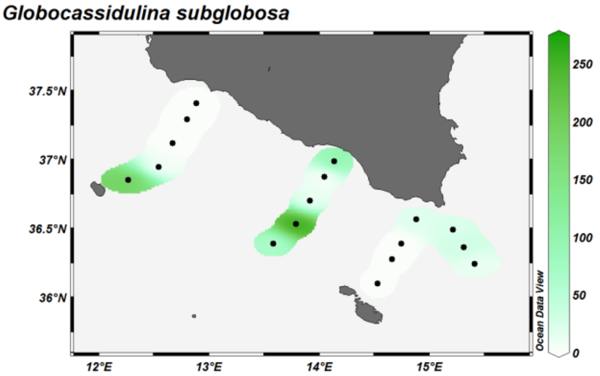
Genus *Cassidulinoides*

Species: *bradyi* (Norman, 1881)

Genus *Globocassidulina*

Species*: subglobosa* (Brady, 1881)





- morphology: wall calcareous, hyaline, densely and finely perforate; test globular to ovate with broadly rounded periphery. Surface smooth, sutures oblique and flush with the surface. Aperture a rounded opening in the center of the large apertural face, partially bordered by a thickened, hook-shaped rim.

- distribution: species widespread in the Mediterranean; frequent from circalittoral and bathyal. Parisi (1981) found this species in deep-water assemblages in the Sicily Channel and in the Tyrrhenian Sea (at about 1,000 m) (Sgarrella and Moncharmont-Zei, 1993).

- ecology: infaunal, free; muddy sediment; detritivore.

Superfamily Fursenkoinoidea

Family Fursenkoinidae: test biserial, resulting in a sigmoid or twisted biserial appearance, later may become uniserial. Aperture loop-shaped in biserial stage and terminal in uniserial stage.

Genus *Cassidella*

Species: *complanata* (Egger, 1893)

Genus *Fursenkoina*

Species: *acuta* (d'Orbigny, 1846)

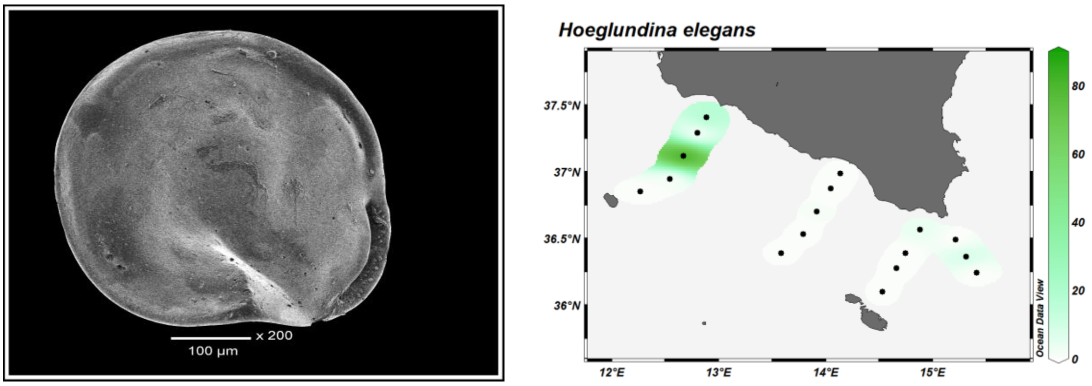
Order Robertinida

Superfamily Ceratobuliminacea

Family Epistominidae: test with predominantly sinistral trochospiral coiling; chambers subdivided by an internal partition; aperture a slit on peripheral margin, closed by clear shell material in older chambers.

Genus *Hoeglundina*

Species: *elegans* (d´Orbigny, 1878)



- morphology: test trochospiral and unequally biconvex, with smoothed surface finely perforated. Spiral outline subcircular and acute, carinate periphery sutures on the spiral side backwards curved. Aperture a slitlike, latero-marginal opening parallel to the keel.

- distribution: very common and widespread species in the Mediterranean; frequent from circalittoral and epibathyal. In the Sicily Channel, Parisi (1981) found this species down to 1,744 m (Sgarrella and Moncharmont-Zei, 1993).

- ecology: epifaunal-shallow infaunal, muddy sediment.

Superfamily Robertinoidea

Family: Robertinidae: test with chambers in trochospiral coil, or may be nearly planispiral: interior of chambers divided by double transverse partition; aperture interiomarginal or elongate loop-shaped or both and may have additional areal or sutural supplementary openings, septal foramen homologous with part of the primary aperture.

Genus *Robertinoides*

Species: *bradyi* (Cushman and Parker, 1936)

Chapter 2: Coastal Benthic Forams as possible bio-indicators of environmental stress or pollution along the southern coasts of Sicily

2.1 Introduction and objectives

As other living organisms, forams are strictly dependent to environments where they live. Although they could survive for few days to the effects of some factors that exceeded their expected critical thresholds (Bernanrd and Sen Gupta, 1999), several variations of the environment in which they live could limit their distribution in both time and space (Murray, 2006).

According to Iserentant and De Sloover (1976), who describe a bioindicator~~s~~ as an organism or a biological system applied to assess any environmental modifications, forams are largely used as bioindicators both in coastal and in deep marine environments.

Forams are good indicators of pollution because they are often among the last organisms to disappear completely from a stressed or impacted site (Schafer, 2000). In areas exposed to different types of stress, numeros studies have been carried out since early 1960s, appling benthic forams as bioindicators of pollution, although the effects of pollution on forams were earlier recognized (see reviews by Alve, 1995; Yanko *et al.*, 1999; Schafer, 2000). Similar works were conducted in Italy in coastal marine areas and in transitional environments (see for a review Frontalini and Coccioni, 2011).

Organisms need small amounts of some heavy metals (Fe, Co, Cr, Cu, Mn, Ni, Se, Zn) for the explication of multiple biological functions; unlike these so called “essential” elements, other “non-essential” metals, such as Cd, Hg, Pb, and As, don’t partecipate to the organisms biochemistry. Above a specific threshold, both of these categories are extremely toxic, due to their bioaccumulation within the organisms (Cognetti et al., 2002; Kennish, 1992).

The responses of benthic foraminifera to adverse ecological conditions, as well as to heavy metals pollution, include assemblage modifications (changes in diversity, abundance and composition), local extinctions, riduction in the test-size, and development of malformed tests (e.g. Alve, 1991, 1995; Yanko *et al.*, 1994; Geslin *et al.*, 1998). As well as in polluted environment, test malformations also occur in presence of other environmental factors such as variations in salinity and temperature, high oscillation in food abundance, low dissolved oxygen content (Boltovskoy *et al.*, 1991); however, it should be considered that stressor effects, such as the effects of salinity variations, may cause abnormalities in one place but not in another (Sharifi *et al.*, 1991; Yanko *et al.*, 1998).

Samir and El-Din (2001), Triantaphillou *et al.* (2005) and Frontalini and Coccioni (2008) corroborated the use of deformation of the shell as biomarker of heavy metals pollution, while Geslin *et al.* (2002), Bergin *et al.* (2006), and Albani *et al.* (2007) showed the correspondence between distribution of benthic forams and the concentration of heavy metals in sediments. Moreover, Naidu *et al.* (1985), Sharifi *et al.*, (1991) and Armynot du Châtelet *et al.* (2004) highlighted as total densities and species richness tend to decrease in areas of elevated heavy-metal concentrations.

In this work the use of benthic forams as bio-indicators in the Sicily Channel, along the southern Sicilian coast, is assessed by evaluating how and whether different concentrations of heavy metals in the top sediment could affect their assemblages.

2.2 Study Area

Study area covers the Southern coast of Sicily, extending for about 350 km^2 between Campobello di Mazara (Trapani) to the west and Capo Passero (Siracusa) to the east (Fig. 2.1).

The coast is interested by the shallow AIS (*Atlantic Ionian Stream*) current, which creates two vortexes near the coast of Sciacca and Licata, inducing transportation of nutrients and elements, and favouring the instauration of upwelling currents (Fig. 2.2 - Robinson *et al.*, 1999).

The main coastal pollution sources are the Petrochemical Industry adjoining the city of Gela (Fig. 2.1), placed within the homonymous Gulf and the Thermoelectrical Industry of Porto Empedocle (which also holds a touristic port; Fig. 2.1).

A previous study conducted in the Gulf of Gela (SOGESID S.P.A., 2007) highlighted the presence of benthic populations typical of environments subjects to high organic matter input in correspondance of the areas with the highest degree of anthropic pression. This was presented as possible result of the environmental pression produced on the coastal marine ecosystem by petrochemical and agricultural activities, together with urbanization.

A large number of studies have been carried out on metal levels and oceanographic characteristics of the Sicily Channel, including the gulf of Gela (Béthoux, 1980; Grancini and Michelato, 1987; Manzella *et al.*, 1988; Robinson *et al.*, 1999; Tranchida *et al.*, 2010), but few data are known regarding the distribution of benthic foraminiferal assemblages and their possible relation to anthropogenic impacts in this area (Valenti *et al.*, 2008; Musco *et al.*, 2011).

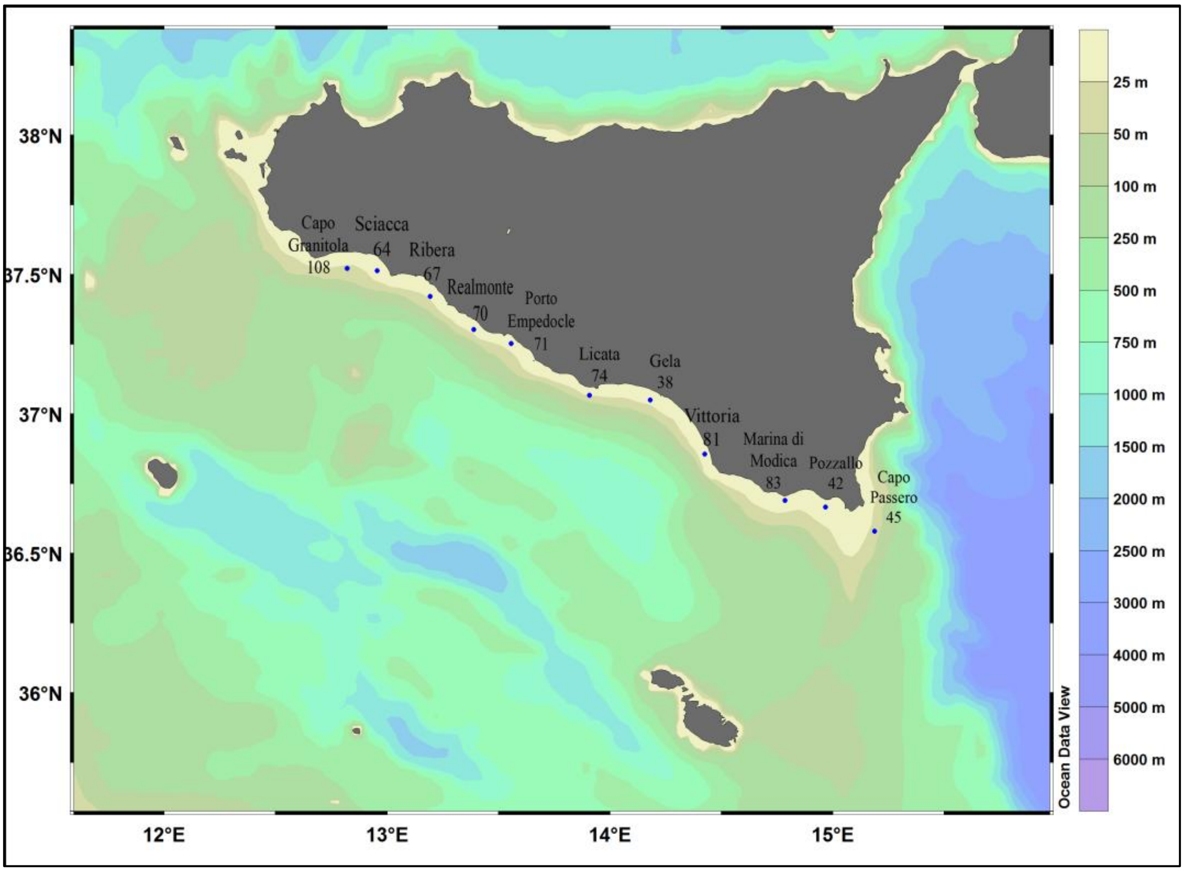


Figure 2.1. Location of sampled stations along the Sicily Channel

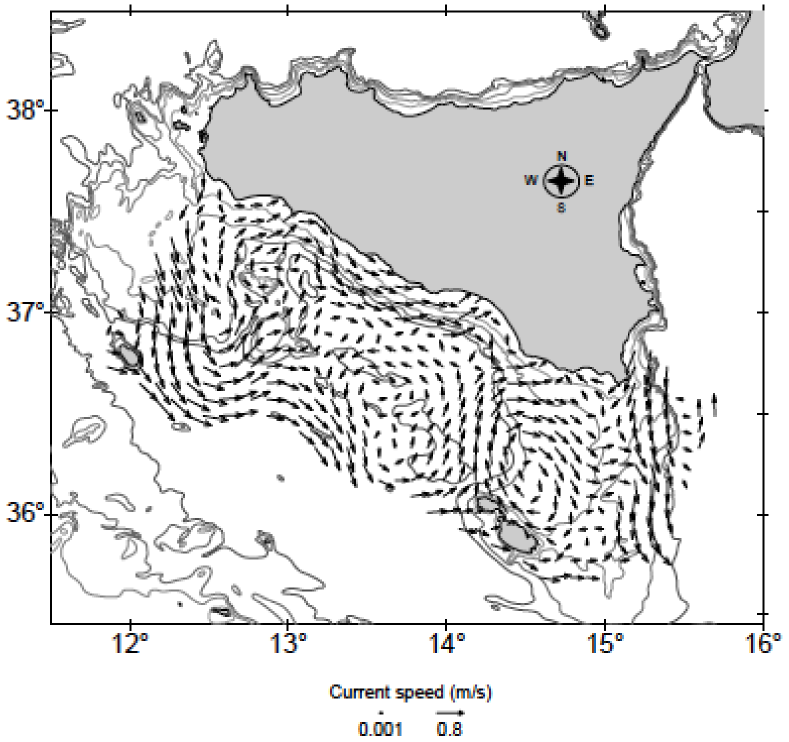


Figure 2.2. Surface geostrophic current pattern during July 2005 (Final Report Project AMECO, 2006)

2.3 Materials and Methods

2.3.1 SAMPLING METHODS

Samples were collected during the “Bansic” oceanographic cruises on board of the C.N.R.’s R/V URANIA (during July and August from 2005 to 2011) in eleven stations located along the southern Sicilian coast and identified with a code number indicating their relative position inside a sampling grid: 108 – 67 – 64 – 70 – 71 – 74 – 38 – 81 – 83 – 42 – 45 (Fig. 2.1). Selection criteria included the relative position from polluted sources, distance from the coast, bathymetry and, at last, sampling requirements of the oceanographic cruises. All stations were located near the coast (distance from the coast is about 800 m), with an average depth of -30 m, (station 45 represented the deeper station at -75 m depth; tab. 2.1).

Table 2.1. Coordinates (Decimal Degree) and depth (m) of sampling stations.

Station	Longitude E (DD)	Latitude N (DD)	Depth [m]
108	12.786	37.531	-48
64	12.955	37.513	-31
67	13.193	37.422	-32
70	13.387	37.302	-25
71	13.556	37.253	-15
74	13.908	37.066	-24
38	14.18	37.05	-14
81	14.425	36.855	-20
83	14.785	36.689	-25
42	14.966	36.666	-27
45	15.187	36.579	-75

2.3.2 HYDROLOGY

Physical-chemical parameters of bottom water or along the water column were acquired by using the multiparametric probe *CTD SBE 9plus* (Underwater Unit) and the form *SBE 11plus V2* (Deck Unit) of the SEA-BIRD ELECTRONICS, Inc. The multiparametric probe has sensors to measure pressure, temperature, conductibility, oxygen, light transmission and fluorescence. Data were polished and recorded by using the software *SEASOFT-Win32* (SBE Data Processing – CTD Data Processing and Plotting Software). Only the downcast data were acquired and used during the data processing (Mazzola *et al.* 2004). Data interpolation was performed using the software Ocean Data View (http://www.awi-bremerhaven.de/GE/ODV, Schlitzer, 2003).

2.3.3 SEDIMENT FEATURES

2.3.3.1 SEDIMENT SAMPLING

Sediment samples were collected by *box-corer* and subsamples were taken using five PVC tubes (25 cm x 63 mm Ø). The use of box corer was strongly influenced from the hardness of the sediment: it need a muddy sediment (silt and clay) and moderate angles of the seafloor.

For that reason, before the sampling, it was conducted an explorative analysis of the sediment through the acoustic signals of the system of seismic reflection *Sub-bottom Profiler 3,5 kHz* (Chirp), which gives information on the morphological nature of the seabottom.

When the hardness of the sediment did not allow the use of box-corer, it was used a grab sampler, paying attention to take the top of the sediment with a small tube (2 cm x 63 mm Ø; Annin 2001). Each tube was immediately frozen (-20°C) on board to preserve the organic matter and maintain sediment stratification. Only 2 of the 5 sediment tubes could be used to perform all the analyses. In laboratory, samples were cut in slices 1 cm thick, and the top-first cm, corresponding approximately to the last 2 years of sedimentary disposal (average data extracted from Tranchida *et al.*, 2010), was taken from each of the 2 small tubes available and used for all the analysis.

2.3.3.2 GRAIN-SIZE

Approximately 10 g of sediment from each sampling station were treated with a solution of hydrogen peroxide in order to tarnish organic substance, and subsequently analysed by using a laser diffraction instrument (*Horiba Partica LA-950V2 laser granulometer*).

Samples were then divided in grain-size classes (tab 2.2) using the Wentworth scale (Wentworth, 1922).

Table 2.2 Grain-size classes

Class	Diameter (mm)
Gravel	> 2
Sand	0,063 – 2
Silt	0,004 - 0,063
Clay and Colloids	< 0,004

The distinction of the principal dimensional classes applied to the sediments classification was based on the triangular diagram of Shepard (1954). Even if the original scheme of Shepard did not take in account the gravel component, it was still applied in this work because of the low gravel content (<6%) of the sampled sediment. Anyway, gravel content was however taken in account by adding it at the sand percentage.

2.3.3.3 TOC AND Δ^{13}C

Nutrient content was investigated as TOC within the sediment (Donnici and Serandrei Barbero, 2002).

Whole sediments were dried at 60°C and then shell's fragments greater than 0.5cm in size were removed before the sediment was homogenized by mortal and pestle. The samples were then stored at room temperature in a dryer until analysis. In order to determinate the TOC percentage and $\delta^{13}C$ in marine sediment, the aqueous method (HCl_{aq}) was used (Nieuwenhuize *et al.*, 1994; Schubert and Nielsen, 2000; Ryba and Burgess, 2002). Through contact between sample and acid, the aqueous method ensures that any trace of carbonate is entirely eliminated from the sample. To avoid the loss of the sample, commercially available 12 mm silver cups were used rather than 7-8 mm laboratory-made tin cups (high container walls reduced possible sample loss).

Samples of 12-20 mg were accurately weighed into Ag capsules (5 mm diameter and 12.5 mm tall). To minimize sample loss, capsules were filled to no more than about a third full. The capsules were held in sample trays. The acidification was started with a small volume of acid (5-10 µL 1M HCl prepared from concentrated HCl). To prevent sample loss from heat-induced effervescence, the samples were allowed to react at room temperature for 5-10 min before being placed to dry (~20 min) in a 40°C oven. Over the course of several acidifying drying cycles, the amount of acid added per cycle was gradually increased (up to 50 µL) - as it was done for the oven temperature - to speed drying process (up to 60°C). To confirm the complete removal of inorganic carbon, samples were acidified until the effervescence was not detected in two consecutive cycles. Once the process was completed, the samples were dried either in a 50°C oven for a minimum of 3h to overnight, or under vacuum, to drive off excess moisture and HCl.

Values of TOC (%) and $\delta^{13}C$ in sediments were determined by a Thermo Electron Flash EA 1112, coupled to a Thermo Electron Delta Plus XP mass spectrometer, tuned to carry out high sensitivity analyses.

The standard used for EA was acetanilide (C_8H_9ON), available from Thermo, and internal standard used for the spectrometer was urea (CH_4N_2O mw=60, C=20% N=46%) with a certificated isotopic composition ($\delta^{13}C$ (‰)= -47,37 vs. Vienna Pee Dee Belemnite [VPDB]). Data quality control was checked by running the internal reference standard after every six samples. Routine replicated by international standard IAEA (reference samples CH-

7 for $\delta^{13}C$) were also analysed. Uncertainties were lower than 0.2‰. Samples were also run with blank cups. Stable isotopes values were reported in ‰ delta notation (1):

$$\delta(\text{‰}) = \left[\frac{R_{sample}}{R_{reference}} - 1\right](1000) \qquad (1)$$

where δ(‰) stands for $\delta^{13}C$ (‰) and R_{sample} and $R_{reference}$ are the isotopic carbon ratios ($^{13}C/^{12}C$) of sample and reference, respectively. The reference standard for carbon is VPDB and atmospheric N_2 for nitrogen. Reproducibility value based on triplicate analyses of a sample was ± 0.1‰ for $\delta^{13}C$.

2.3.3.4 HEAVY METAL CONTENTS

Heavy metals, major and minor elements contents (Ca, Al, Fe, Mg, Sr, Cr, Co, Cu, V, Pb, Mn, Ni and Zn) were measured in sediment samples by ICP-AES, using a Thermo iCap 6000, after total digestion in a microwave oven (Anton Paar Multiwave 3000), following US EPA 3050b, 3052, 6010c protocols.

About 0.25 g of dry sample were placed in an acid mixture (2 ml H2O2, 8 ml HNO3, 3 ml HCl, 1.5ml HF) at T=220 °C for 90 min. Obtained acid solution were introduced in ICP-AES by a microflow nebulizer, and analyses were performed after instrument parameters optimization, using an external calibration curve. ”Reference Standard Materials (PACS-2, BCR-2), reagent blanks and duplicated samples (about 20% of the total number of samples) were prepared and measured in order to assess accuracy (estimated between 90 and 110%), detection limits, precision (>95%, n=3) and reproducibility (about 93% for all elements) of analytical method.

spectrophotometer, Milestone, Wesleyan University, Middletown, CT, USA), fully compliant with US EPA method 7473 (Mercury in solids and solutions by thermal decomposition, amalgamation, and atomic absorption spectrophotometry) and with ASTM method D-6722-01 (Standard test method for total mercury in coal and coal combustion residues by direct combustion analysis).

DMA80 was equipped with optical path spectrophotometer, achieving a mercury detection limit of 0.0015ng. Dried sediment (50 mg) were loaded in nickel boats and thermally decomposed, and mercury was selectively trapped by gold amalgamation and released via the carrier gas along the optical path of the spectrophotometer, where it was quantitatively measured by atomic absorption at 253.65 nm. The calibration range used for Total Hg analysis was 0.5÷20 ng per 100 mg of sample.

The method used require the decomposition temperature of 700°C, amalgamator heating time of 150s, purge time of 120s .

A certified reference material (PACS-2: 3.04±0.20) was used at the beginning and at the end of each analysis to check method accuracy.

Metals from natural and anthropogenic sources normally accumulate together mostly in the fine sediment fractions; for that reason the analysis of the potential enrichment first requires normalization to the grain size and mineralogical effects on metals variability. Usually the normalization method consist of ratios of element concentrations to a proxy of the fine sediment fractions, normally Al, because its content is not perturbed by biogenic activity or diagenetic mobilization (Calvert and Pedersen, 1993; Wedepohl, 1995; Angelidis *et al.*, 2011). According to Yanko *et al.* (1999) heavy metals concentrations were normalized to Al, in order to evidence effects of real contamination of sediments. This approach directly enables the identification of element anomalies not related to the lithological variability.

Moreover to highlight the heavy metal enrichment in the sediment, it was performed the Enrichment Factor (EF) analysis (2), which represents the element's value (TE) measured in relation to its background, both normalized to Al (Acevedo-Figueroa *et al.*, 2006):

$$EF = (TE/Al)campione / (TE/Al)background \qquad (2).$$

The average data relative to a previous study on heavy metals content in the sediment in the Sicily Channel by Tranchida *et al.* (2010) were assumed as background values (tab. 2.3).

Table 2.3. Average values of Al-normalized trace elements (mg/Kg) in the top sediment of the Sicily Channel.

As	Cd	Co	Cr	Cu	Mn	Ni	Pb	V	Zn	Hg
0.000426829	2.9E-06	0.00013	0.00074	0.00022	0.00972	0.00057	0.00046	0.00116	0.00126	9.8E-07

2.3.4 FORAMINIFERAL BIODIVERSITY

A constant volume of 28.26 cm^3 (slice of 1 cm thick) of the top-soft sediment was analyzed from each station in order to study living benthic forams.

The sediment was stained for at least 48hrs with a double volume of Rose Bengal solution (1-2 g/l ethyl alcohol), which conferred a pink colour to the organic matter, allowing the identification of live specimens (Walton, 1952; Lutze and Altenbach, 1991; Alve and Bernhard, 1995; Geslin *et al.*, 2002; Frontalini and Coccioni, 2008): in order to highlight the correlation among benthic foraminiferal assemblages and abiotic compartment (represented by environmental features and heavy metals concentrations), only living specimens were taken into account.

After sieving through 125 µm meshes in order to remove fine grain fraction and exclude all juvenile individuals (Donnici and Serandrei Barbero, 2002), stained forams were picked, identified and counted under a binocular microscope, following the Loeblich and Tappan classification (1988; 1992) and the publications of Jorissen (1988), Albani and Serandrei Barbero (1990), Cimerman and Langer (1991), and Sgarrella and Moncharmont-Zei (1993); the ecological characterization of species was carried out principally following Jorissen (1987, 1988), Alve (1991, 1995), Murray (1991, 2006), Sen Gupta (1999), Armynot du Châtelet (2003) and Frontalini and Coccioni (2008).

Only the individuals who presented a bright colour were considered "living" forams (de Stigter *et al.* 1998). Additionally, tests that appeared broken or that had clearly suffered partial dissolution or diagenesis phenomena were not taken in account.

Individual density was calculated per top-core (6 cm^2 surface area, 1cm long) which represented a costant volume of 28.26 cm^3.

There were analysied benthic forams richness as number of species (S), species diversity using the Shannon-Weaver index (H'- Shannon and Weaver, 1949) (3) and equitability using the Pielou index (J - Pielou, 1966) (4) by the software *Past*.

$$H' = -\sum_{j=1}^{s} p_j \log p_j \qquad (3)$$

were p_j is the population of the j^{th} species ($\Sigma p_j = 1$) and s is the species number;

$$J = \frac{H'}{log_2 S} \qquad (4)$$

2.3.5 MALFORMATIONS OF FORAMINIFERAL TESTS

Morphological abnormalities of foraminiferal tests may be caused by physical (predators or hydrology), ecological (substrate nature) influences (Boltovskoy and Wright, 1976) or environmental stress conditions (e.g. high salinity variations, heavy metals pollution; review in Geslin *et al*., 2000).

Forams could regenerate their tests, but regeneration processes often result in morphological abnormalities (Stouff *et al*., 1999), which generally include protuding chamber, reduced size chamber, gemellar (dubble or triple) tests, and complex forms by fusing of juvenile stages.

Living forams were observed under binocular microscope and all deformed tests, whenever present, were picked up and photographed. Moreover, percentage of abnormal specimens within the assemblage was calculated for each sample.

2.3.6 STATISTICAL ANALYSES

Only the living species with a relative abundance exceeding 5% of the assemblage in at least one sample (Bergin *et al*., 2006) were taken in account to conduct statistical analyses.

A nMDS was realized taking into account the rank of (dis-)similarities among samples relatively to species density (using Bray-Curtis distance).

Q-mode cluster analysis was performed on living benthic forams as well as on Al-normalized heavy metals, using the Ward's method and the Euclidean distance (Fontanier *et al*., 2008), in order to highlight similarities among the stations in relation to these parameters.

Trace elements (in mg/l, normalized to Al), grain-size fractions (%), TOC (%), forams absolute abundance of species more abundant than 5% and diversity indices were analyzed together in a Correlation Matrix, using the Pearson's correlation coefficient r, which gives a value between -1 and +1 and measures the strength of the linear relation between two variables; only significative r values (95% of probability), equal to or greater than |0.6|, were taken in account.

Benthic foraminiferal thanatocenosis were examined using Redundancy Analysis (RDA) after the Hellinger transformation (Legendre and Gallagher, 2001). Redundancy

Analysis (RDA) is a multivariate direct gradient analysis in which species composition data are constrained to selected environmental parameters.

The number of canonical axes corresponds to the lowest value among the number of abiotic parameters (trace elements and environmental variables), the number of species, or the number of stations -1 (Legendre and Birks, 2012).

BIOENV analysis (Clarke & Ainsworth, 1993; Clarke & Warwick, 1994), was carried out to find the combination of abiotic variables (among grainsize fractions, TOC and trace elements) that best explained community patterns. It is performed calculating the Mantel test correlation with a stepwise routine: Mantel test (Mantel, 1967) examines the correlation between two triangular matrices, represented in this case by a dissimilarity matrix of given abiotic parameters (euclidean distance on standardized abiotic variables) and a dissimilarity matrix calculated among stations in terms of thanatocenosis (Bray-Curtis distance on forams abundances).

Statistical analyses were conducted using the software R, *Statistica 8.0* and *Past*.

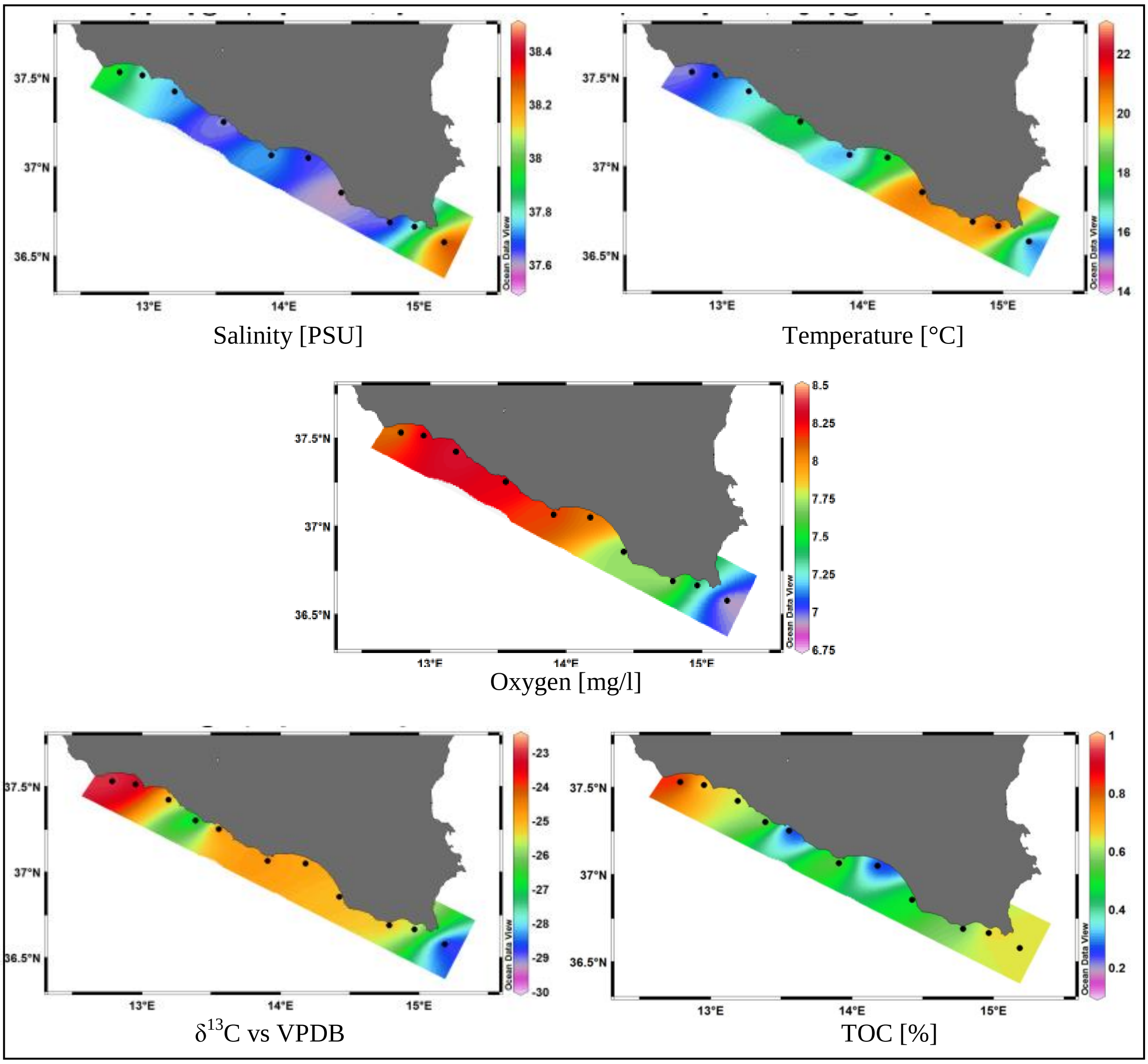
2.4 Results

2.4.1 HYDROLOGY AND SEDIMENT FEATURES

The following table (2.4) reports the temperature, salinity and dissolved oxygen data for all stations, acquired at the bottom by CTD sampling, and $\delta^{13}C$ and TOC values measured in the sediment. For each station, temperature, salinity and dissolved oxygen data presented small variation within the different years, from 2005 to 2011 (Project Report: AMECO, 2006); it is for this reason that they are plotted together in the horizontal interpolated profile of figure 2.3.

Table 2.4. Physical-chemical data of sampled stations.

Station	Temperature [°C]	Salinity [PSU]	Oxygen [mg/l]	$\delta^{13}C$	TOC (%)
108	14.8399	38.0114	7.9904	-22.8748	0.90827245
64	15.9095	37.7301	8.35763	-23.1038	0.60421681
67	16.5085	37.7312	8.35271	-25.3698	0.63336527
70	17.0642	37.6765	8.30695	-27.7138	0.64491326
71	17.62	37.6218	8.2612	-24.2838	0.1787013
74	15.8906	37.7405	8.16049	-24.7808	0.58018988
38	23.8812	38.2398	7.69911	-24.9368	0.21480434
81	20.7553	37.5919	7.70051	-25.1228	0.48296875
83	19.5824	37.5649	7.8849	-25.1118	0.53900528
42	22.4333	37.7375	7.26131	-25.0768	0.69043642
45	14.6831	38.4079	6.81669	-29.6238	0.63985956



Salinity [PSU]

Temperature [°C]

Oxygen [mg/l]

$\delta^{13}C$ vs VPDB

TOC [%]

Figure 2.3. Horizontal profiles of salinity, temperature, dissolved oxygen, TOC and $\delta^{13}C$.

Salinity profile showed homogeneous values for all the stations, ranging from 37 to 38 PSU. Dissolved oxygen values decreased in the W-E direction (from 8 to 6.8 mg/l), while temperature values increased in the E-W direction (from about 16 to 22 °C). The lowest temperature and dissolved oxygen values were found in the stations 108 and 45, sampled at deeper bathymetries (-48 and -75 m).

The lowest $\delta^{13}C$ values, typical of marine environments, were found in the stations 108 and 64 (-22.8 and -23.1‰, respectively). All the other stations presented higher $\delta^{13}C$ values (about -25‰), with lower values close to the Gulf of Gela (stations 71, 74 and 38, with a mean value of -24.6‰) and two peaks in stations 70 and 45 (-27.7 and -29.6‰ respectively).

TOC values showed a discontinuous distribution pattern: values ranged from 0.18% and 0.21%, at stations 71 (Porto Empedocle) and 38 (Gela) respectively, to 0.91% at station 108 (Capo Granitola) (tab. 2.4; Fig. 2.4).

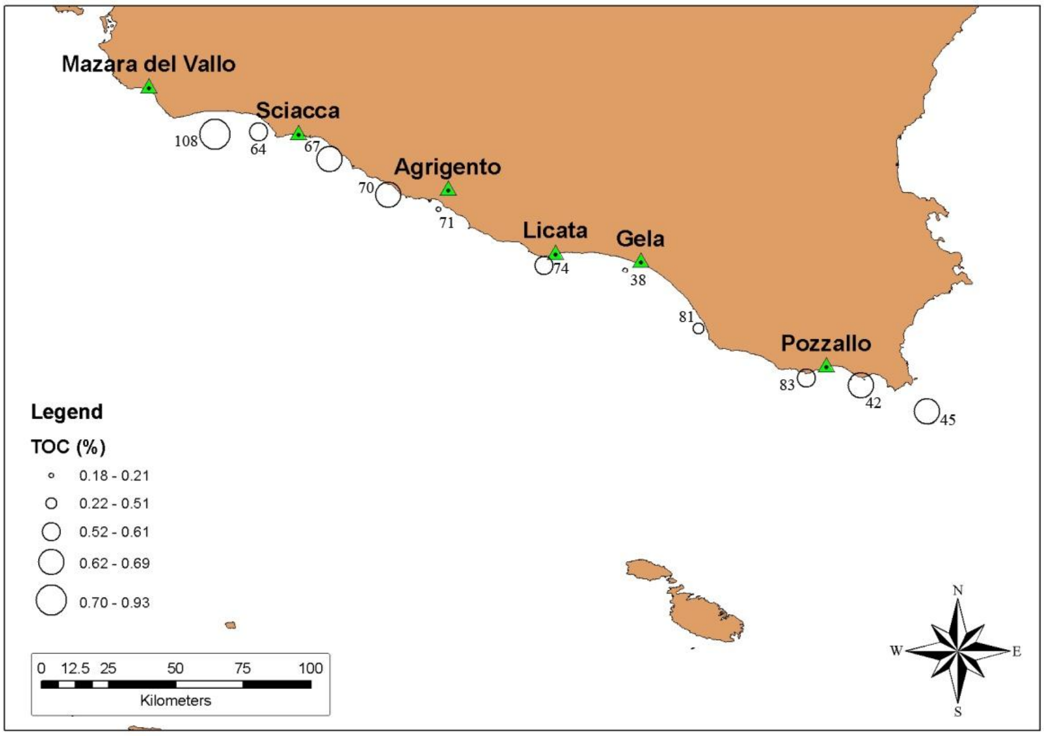


Figure 2.4. TOC distribution (following the Natural Breaks method)

The stations 71 and 38 (Porto Empedocle and Gela, respectively) presented a very high sandy fraction (more than 90% of the total composition), while all other stations showed well distributed grain-size fractions (tab. 2.5). Station 108 and 67, on the west side, showed the higher percentage of mud (silt+clay fractions), followed by stations 81, 83, 74, on the middle-east side, and by the station 64; all presented average values of the three grain-size fractions. A higher percentage of sand, relatively to the other two fractions, was reported for stations 42 and 45, on the eastern side of the sampled area, and for the station 70 (Fig. 2.5).

Table 2.5. Grain-size classification

Stations	Sand%	Silt%	Clay%	Granulometric classification
108	22	48	30	clayey-silt
64	37	35	28	sand-silt-clay
67	18	43	39	clayey-silt
70	50	28	22	silty-sand
71	93	4	3	sand
74	38	37	25	silty-sand
38	93	5	2	sand
81	41	38	21	silty-sand
83	38	45	17	sandy-silt
42	41	46	13	silty-sand
45	50	29	21	silty-sand

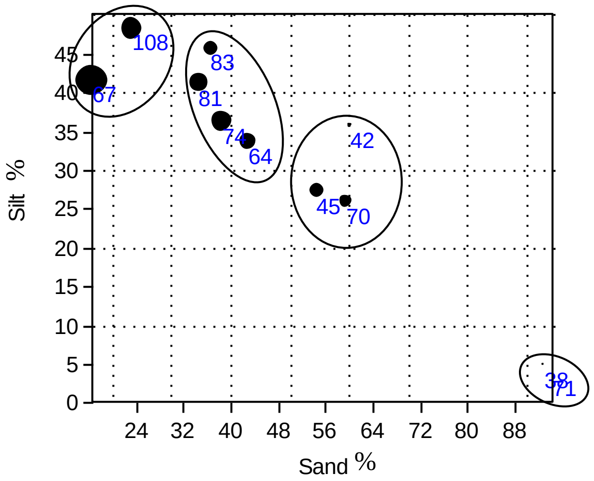


Figure 2.5. Bubble plot of grain-size classes (%). The third axis (clay) is represented as size of disks.

2. 4. 2 Heavy Metals content

Trace elements were investigated to determinate their influence on benthic foraminiferal fauna; resulting data, normalized to the Al value at each station, are shown in figure 2.6.

As, Ni, V, Zn, Cd, Co, and Pb showed homogeneus values for all the stations, excepted for the 71 and 38 (opposite the industries of Porto Empedocle and Gela), which reported the highest concentrations for all of these elements. Vanadium showed higher values also at stations 64 and 45, while Zn presented high concentration also at the station 64.

Unlike other elements, Cu presented its lowest values at the stations 71 and 38, and heterogeneus values for all the other stations, while Cr showed only one pick at the station 71.

Finally, Hg showed similar concentration for almost all stations, with increasing values at the last three stations (values ranging from 0.68 to 2.81 mg/l at stations 67 and 45, respectively).

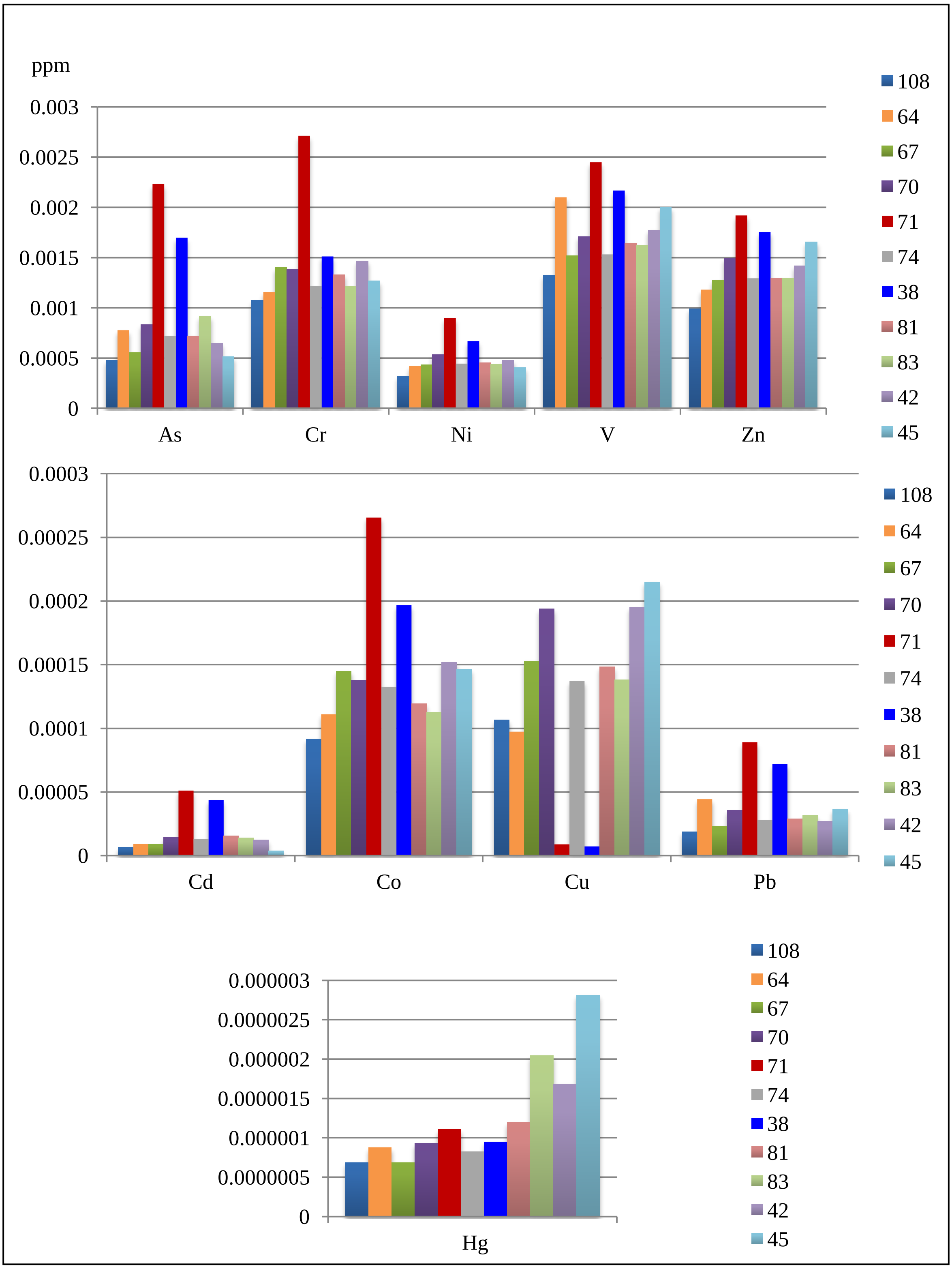


Figure 2.6. Concentration of trace elements (normalized to Al) in the sampled stations.

Data plotted in figure 2.6 became the base of a Q-mode cluster analysis of heavy metals (Fig. 2.7). Resulting dendrogram assembled together stations 71 and 38 (Cluster A) which showed a great similarity distance from all the other stations (Cluster B); this last cluster could be further divided in two sub-cluster, B1 and B2, which separated station 45, situated on the eastern side of sampled area, from the other stations.

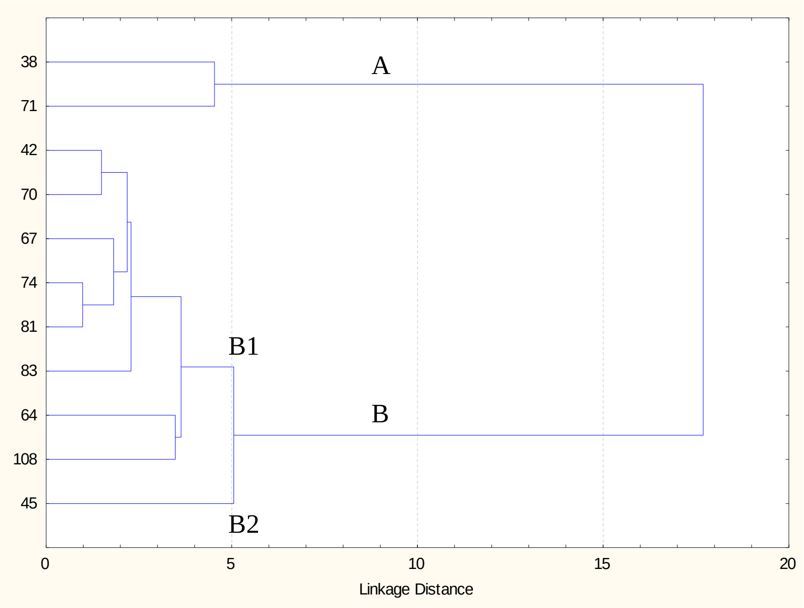


Figure 2.7. Cluster analysis of Al-normalized heavy metals.

Values of Al-normalized heavy metals were compared to the Enrichement Factors (EF) scale proposed by Acevedo-Figueroa *et al.* (2006) (tab. 2.6), showing a severe enrichment by Cd in the stations 71 and 38, which also reported a moderately severe and moderate enrichment respectively by both As and Mn. Moreover Cd values seemed increase, moving from the farthest stations towards stations 71 and 38 (fig 2.8). Cr did not show any noticeable enrichment, except for the moderate value of station 71 (tab. 2.7).

Table 2.6. Enrichment Factors scale (Acevedo-Figueroa *et al.*, 2006).

EF < 1	NO enrichment
EF >1, <3	LOW enrichment
EF >3, <5	MODERATE enrichment
EF >5, <10	MODERATELY SEVERE enrichment
EF >10, <25	SEVERE enrichment
EF > 25, <50	VERY SEVERE enrichment
EF > 50	EXTREMELY enrichment

Table 2.7. Heavy metals Enrichment Factors for the sampled area (bold: severe enrichment; boxed:moderately severe enrichment; underlined: moderate enrichment).

Trace elements\ Station	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn	Hg
108	1.13	2.25	0.71	1.46	0.49	1.24	0.47	0.56	0.04	1.14	0.79	0.70
64	1.83	3.15	0.87	1.57	0.45	1.82	1.07	0.73	0.10	1.81	0.94	0.90
67	1.30	3.16	1.13	1.90	0.71	1.13	0.83	0.76	0.05	1.31	1.01	0.70
70	1.96	4.99	1.07	1.88	0.90	1.26	1.47	0.94	0.08	1.48	1.19	0.95
71	5.23	**17.80**	2.07	3.68	0.04	1.92	5.43	1.57	0.19	2.12	1.53	1.13
74	1.69	4.56	1.04	1.65	0.64	1.57	1.40	0.77	0.06	1.32	1.03	0.85
38	3.98	**15.21**	1.54	2.05	0.03	2.04	3.59	1.17	0.16	1.87	1.40	0.97
81	1.69	5.36	0.93	1.80	0.69	1.39	1.40	0.79	0.06	1.42	1.03	1.23
83	2.15	4.80	0.88	1.65	0.64	1.50	1.35	0.77	0.07	1.40	1.03	2.09
42	1.52	4.27	1.18	1.99	0.91	1.42	1.20	0.84	0.06	1.53	1.13	1.73
45	1.21	1.27	1.14	1.72	1.00	1.81	1.08	0.71	0.08	1.73	1.32	2.88

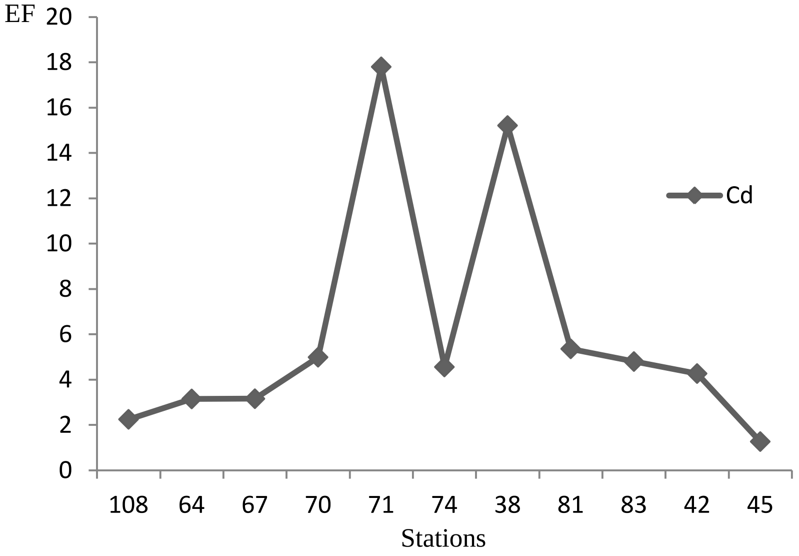


Figure 2.8. Cadmium Enrichment Factor of the sampling area.

2.4.3 FORAMINIFERAL BIODIVERSITY

Total living benthic foraminiferal taxa of the sampled area and their respective abundances were reported in Appendix (II, table 2.8).

Eighty-eight taxa were classified and all well stained forams were counted. When it was not possible to identify individuals at the species level, the classification was limited to their genus name.

Benthic foraminiferal assemblages of the station 108 presented a predominance of *Nonionella turgida* (20%), *Rectuvigerina phlegeri* (18%) and *Florilus boueanum* (16%), typical forms of the shallow-infauna and the epifaunal *Elphidium advenum* (11%), (Fig. 2.9).

The species *R. phlegeri* was dominant in the three stations 64 (33%), 67 (23%) and 70 (18%), which followed the station 108: in the sample 64 *R. phlegeri* was followed by *Textularia agglutinans* (12%), *Adelosina sp*. (9%) and *Bulimina elongata* (7%) (Fig. 2.10), while in the sample 67 by the infaunal species *N. turgida* (20%), *B. elongata* (14%) and *F. boueanum* (12%) (Fig. 2.11), composing about the 70% of the entire assemblage. In the station 70 (Fig. 2.12) low percentages of *R. phlegery* and *F. boueanum* (10%) dominated the total assemblage.

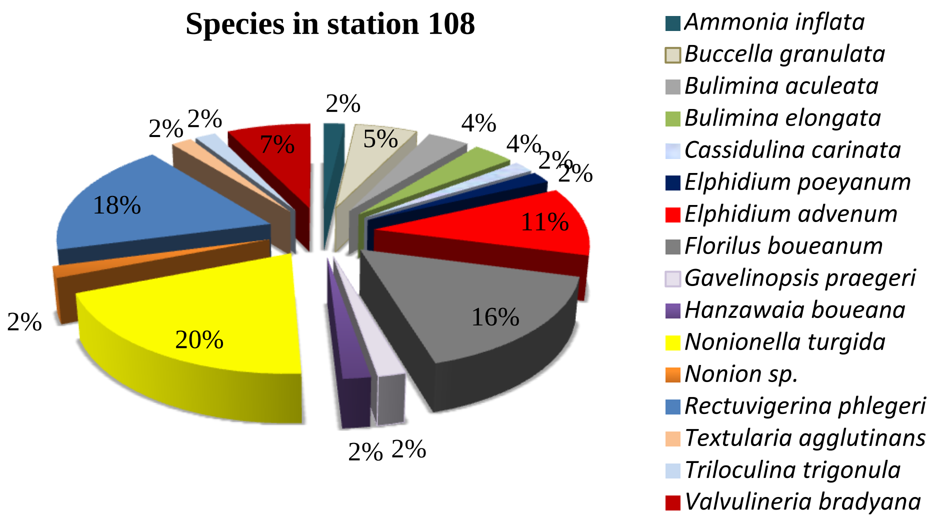


Figure 2.9. Living benthic foraminiferal species composition in the station 108.

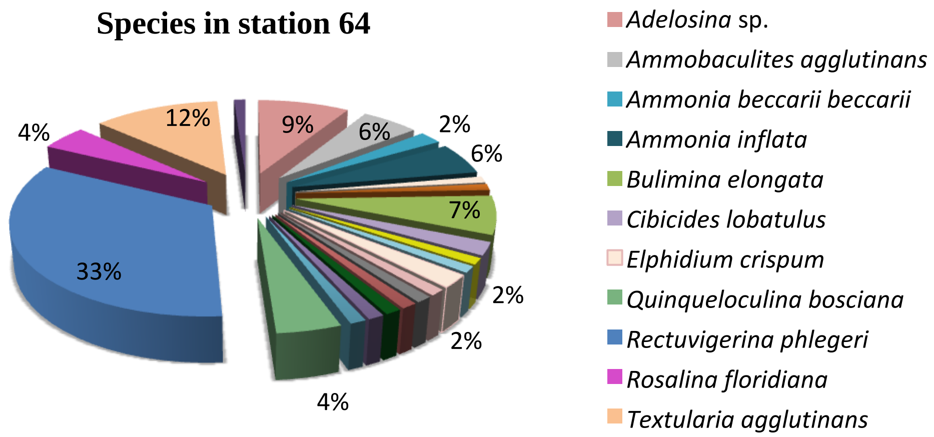


Figure 2.10. Living benthic foraminiferal species composition in the station 64.

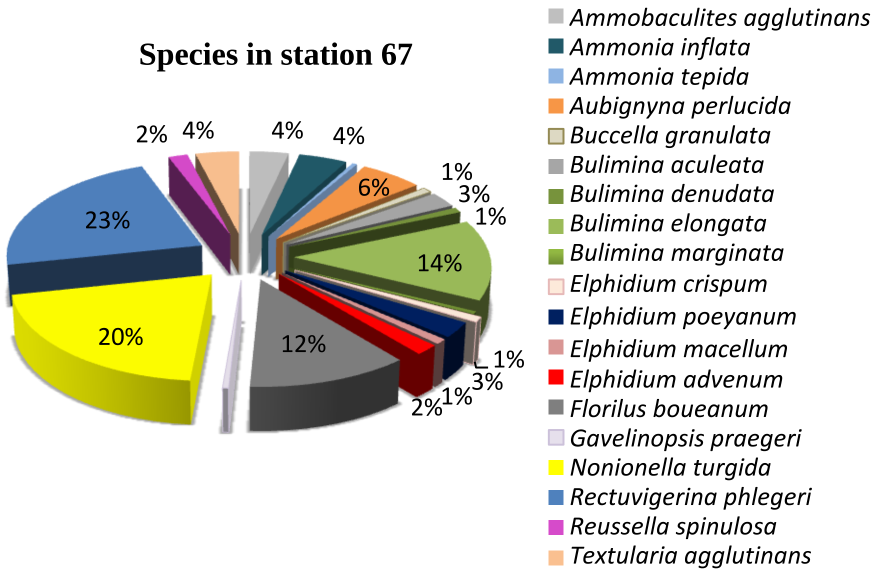


Figure 2.11. Living benthic foraminiferal species composition in the station 67.

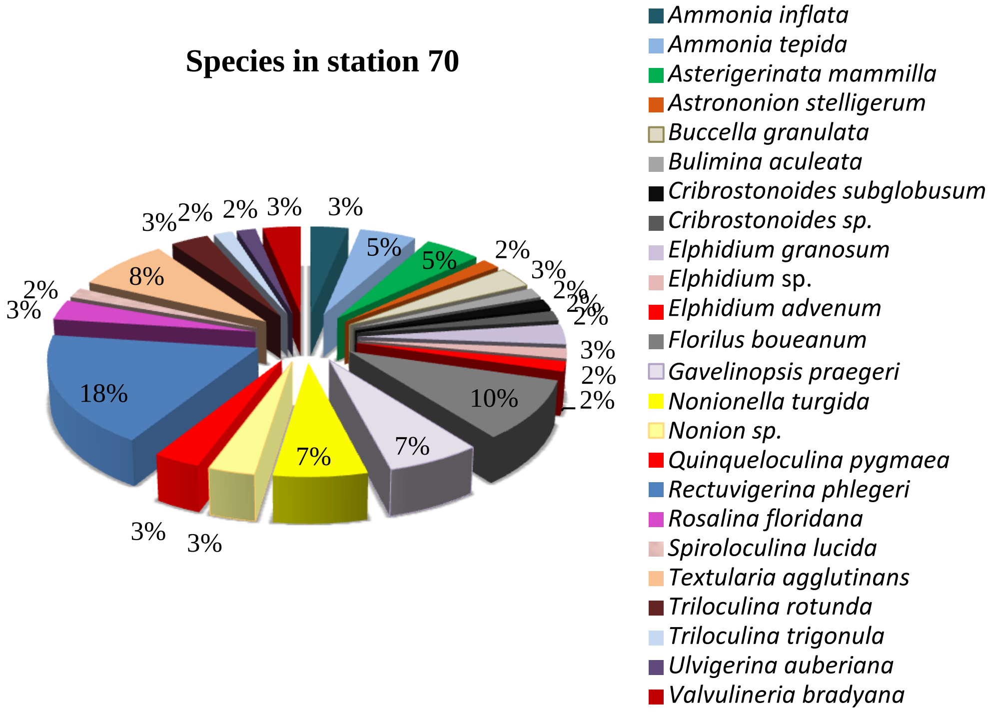


Figure 2.12. Living benthic foraminiferal species composition in the station 70.

The very poor assemblage of the station 71 was most represented by miliolids forms, among which *Triloculina rotunda* (43%) and *Quinquelloculina agglutinans* (15%) were the more abundant (Fig. 2. 13).

In the station 74 the abundance of *R. phlegeri* and *F. boueanum* was very low (two both at 3%), while *N. turgida* (24%) and *B. elongata* (18%) dominated the assemblage, followed by *E. advenum* and *Elphidium poeyanum* (two both at 8%) and *T. agglutinans* (7%) (Fig. 2.14).

The station 38 (Fig. 2.15) was dominated by *Haynesina depressula*, *B. granulata* and the agglutinated species *Eggerelloides scabrum* (34%, 24% and 13% respectively); while the station 81 has presented an assemblage strongly dominated from the species *E. poeyanum* (62%), followed by *Elphidium granosum* (8%) and *Buccella granulata* (6%) (Fig. 2.16).

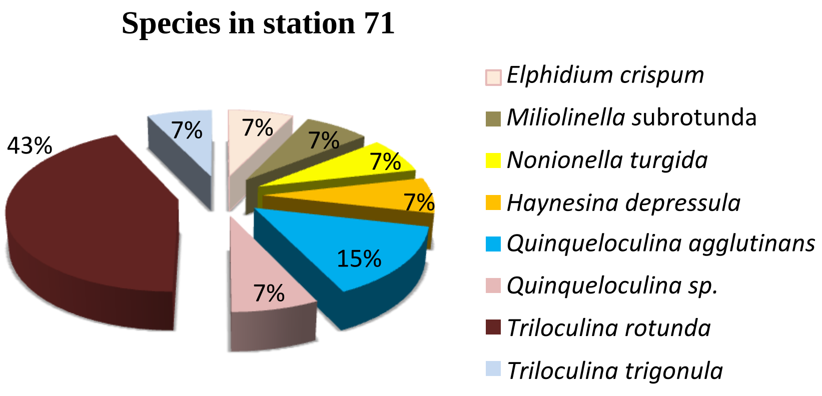


Figure 2.13. Living benthic foraminiferal species composition in station 71.

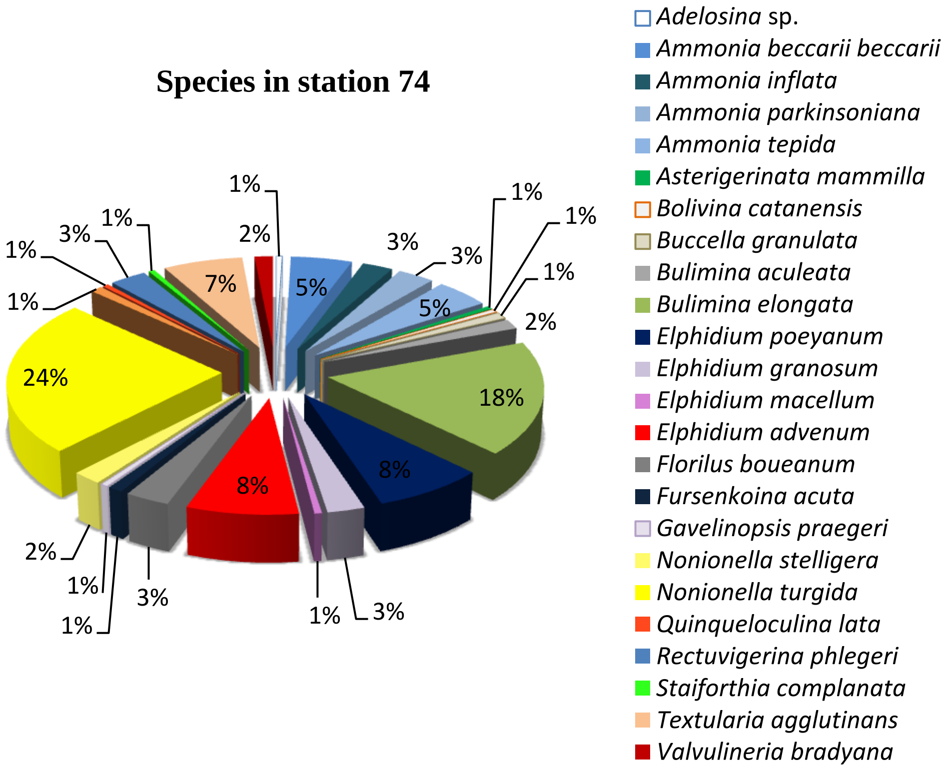


Figure 2.14. Living benthic foraminiferal species composition in the station 74.

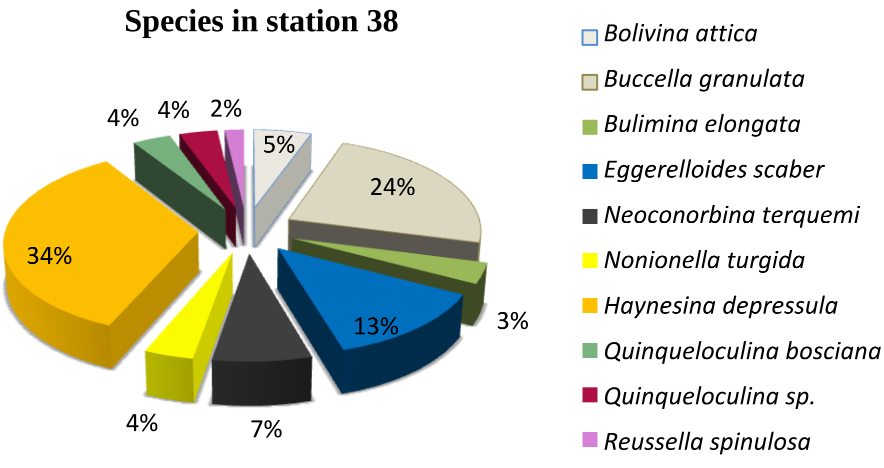


Figure 2.15. Living benthic foraminiferal species composition in the station 38.

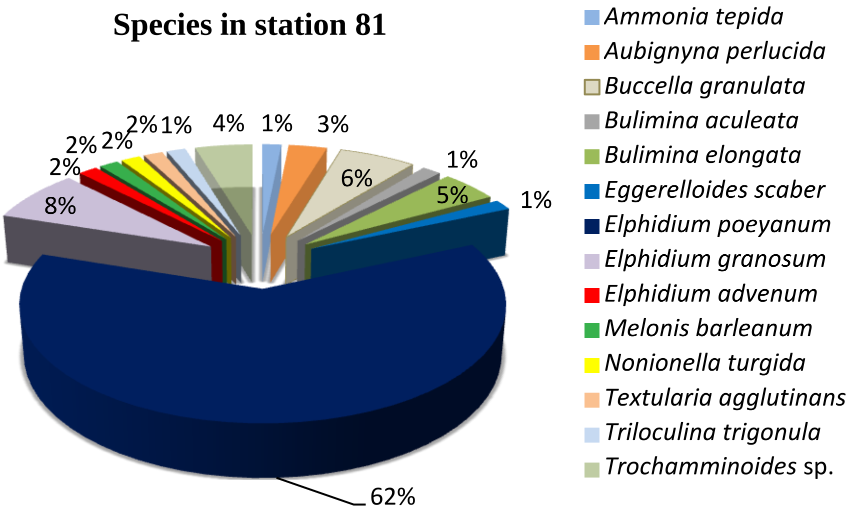


Figure 2.16. Living benthic foraminiferal species composition in station 81.

The assemblage at stations 83 (Fig. 2.17) was principally represented by the species *F. boueanum* (15%), *E. advenum* (12%) and *R. phlegeri* (10%), followed by *B. elongata* (8%), *B. granulata* (7%), *E. poeyanum*, *Ammobaculites agglutinans* and *Bolivina catanensis* (6%) and *Aubignyna perlucida* (5%).

In the station 42 (Fig. 2.18) predominated the *Elphidium* group (24%) togheter with *B. elongata* (17%), and followed by *N. turgida* (8%) and *A. perlucida* (7%), while the station 45 was dominated by the species *R. phlegery* (17%) followed by *F.boueanum* (9%) (Fig. 2.19).

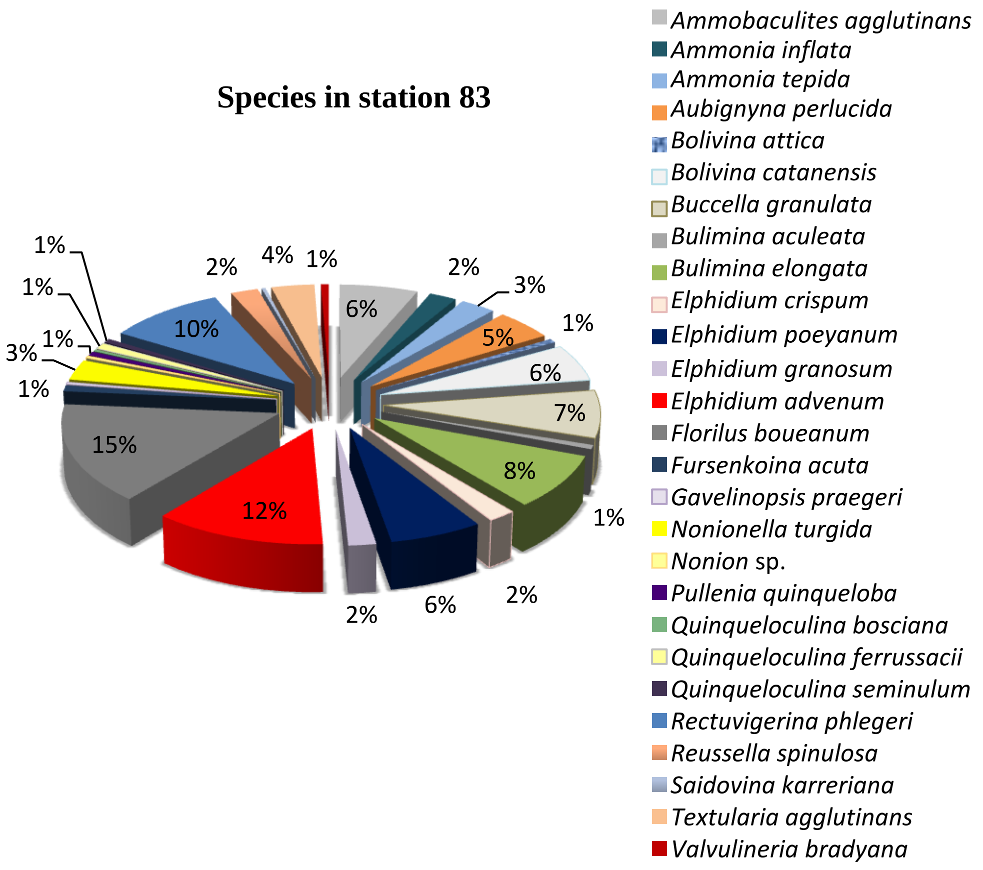


Figure 2.17. Living benthic foraminiferal species composition in the station 83.

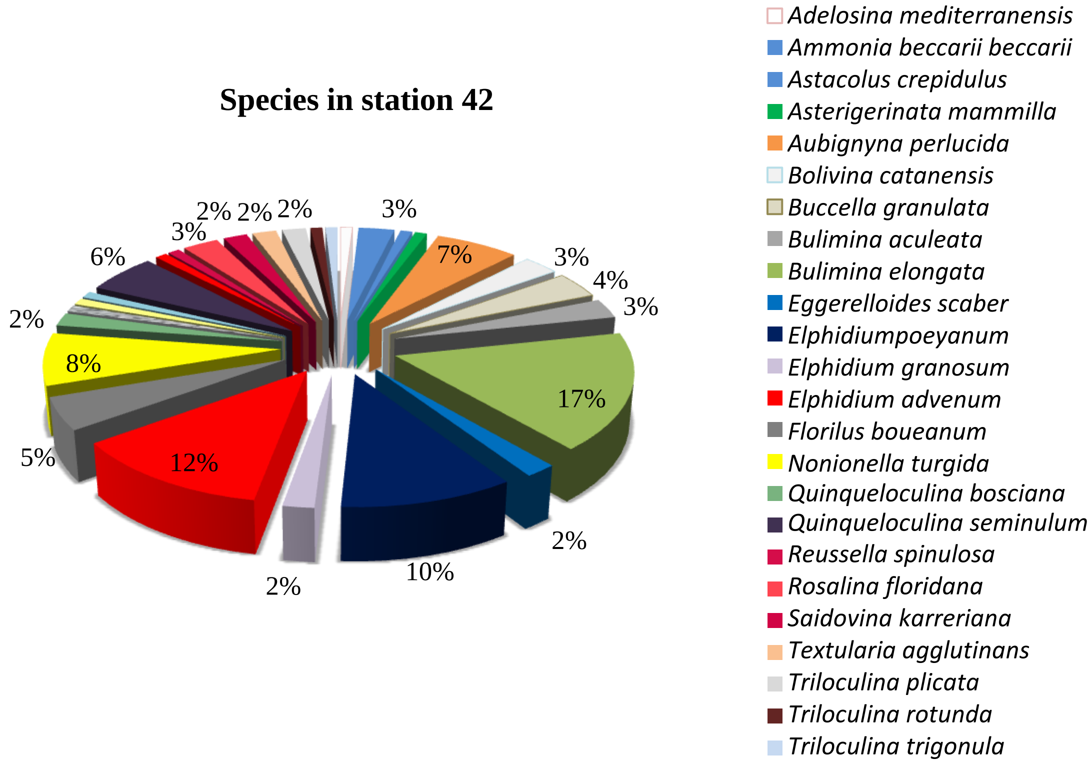


Figure 2.18. Living benthic foraminiferal species composition in the station 42.

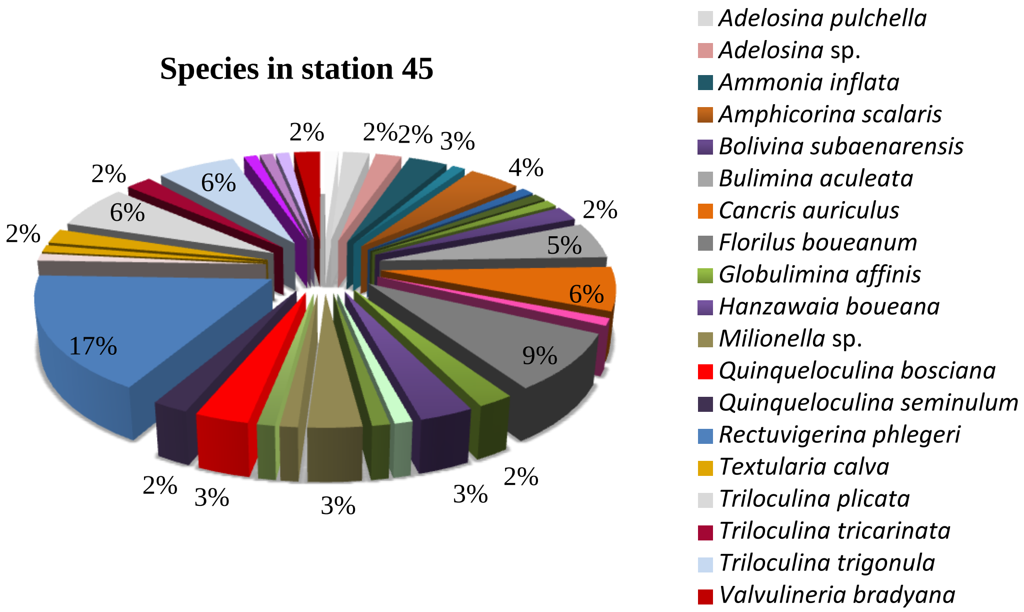


Figure 2.19. Living benthic foraminiferal species composition in the station 45.

Foraminiferal density (TFN) ranged from very low numbers (14 and 35 specimens per volume at the stations 71 and 38, respectively) to higher values, found in the stations 83 (313 specimens), 67 (226 specimens) and 74 (196 specimens) (Fig. 2.20).

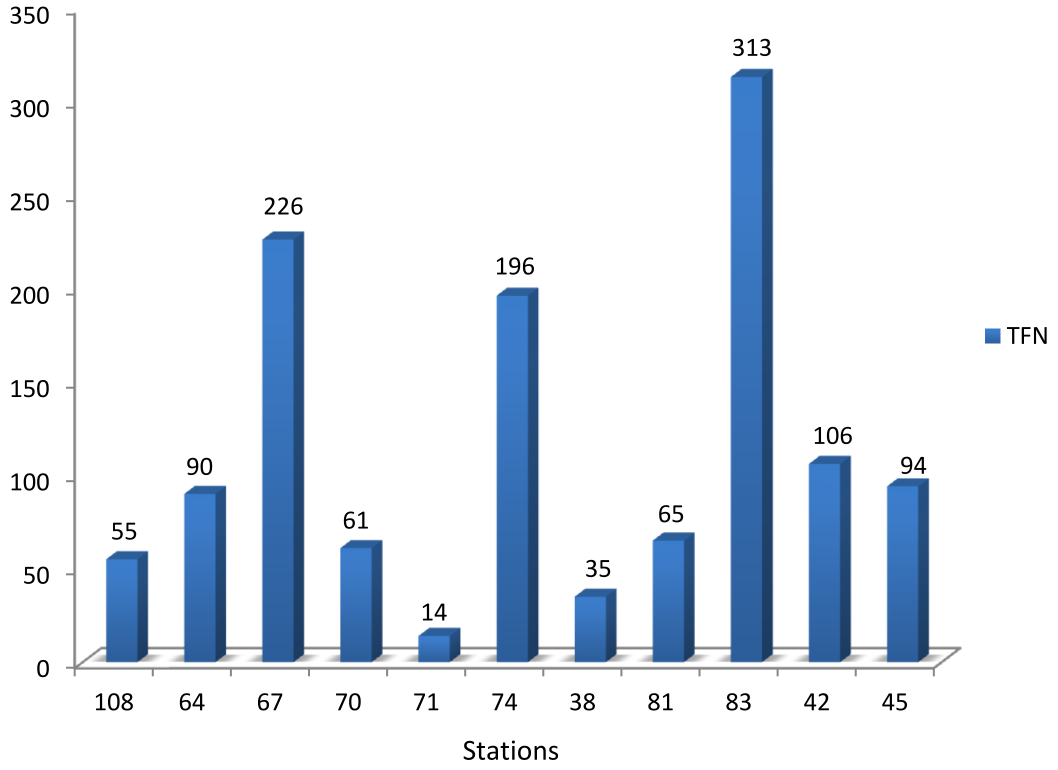


Figure 2.20 – Total Foraminiferal Number per volume (28.26 cm^3) identified in each station.

Biodiversity along the coastal stations was highlighted through the analysis of the species richness and the application of the diversity indices of Shannon-Weaver (H') and Pielou (J), which respectively measure species diversity and equitability (tab. 2.9).

Table 2.9. Diversity indices

	108	**64**	**67**	**70**	**71**	**74**	**38**	**81**	**83**	**42**	**45**
Species richness S	16	22	19	24	8	25	8	14	27	30	34
Shannon H'	2.343	2.42	2.31	2.9	1.77	2.6	1.74	1.57	2.8	2.9	3.15
Pielou J	0.845	0.78	0.78	0.91	0.85	0.8	0.84	0.6	0.85	0.9	0.89

All the samples presented medium or high H' values, with the lowest values at the stations 71, 38 and 81, and the highest ones at the stations 45, 70, 42 and 83 (Fig. 2.21).

Even equitability values were almost all medium-high or high, ranging from 0.78 to 0.9, exception made for the station 81, which presented a medium J value of 0.6 (Fig. 2.22).

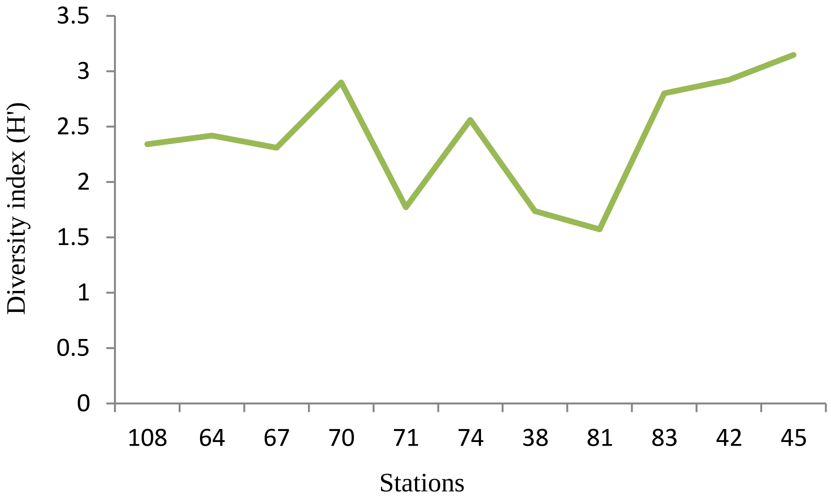


Figure 2.21. Shannon-Weaver index (H'): Species diversity measurement

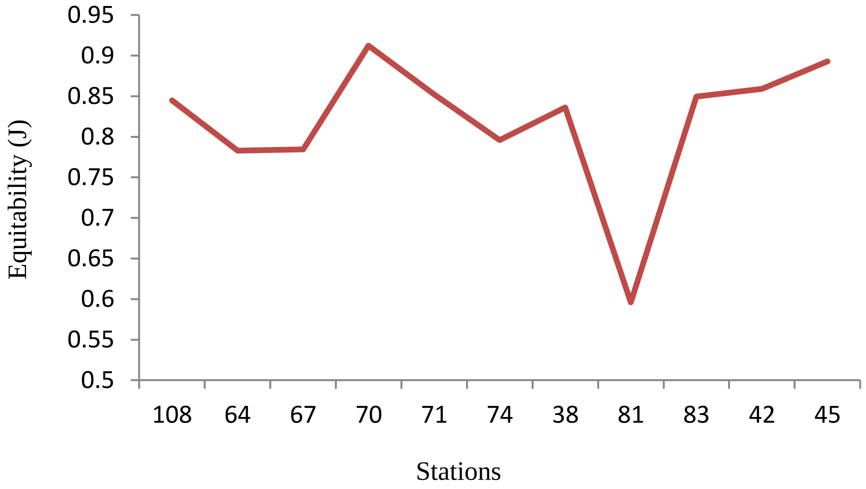


Figure 2.22. Pielou index (J): Equitability measurement

In order to highlight similarities among the coastal stations, related to species absolute abundance, a nMDS analysis was performed on the species density, representing data in a 2D space (Fig. 2.23). Stress value, which is a measure of the "goodness" of the representation, is usually considered high around 23-25% (Clarke and Warwick, 1994). In the nMDS of figure 2.23 stress value was of 10.54%, indicating a low distortion.

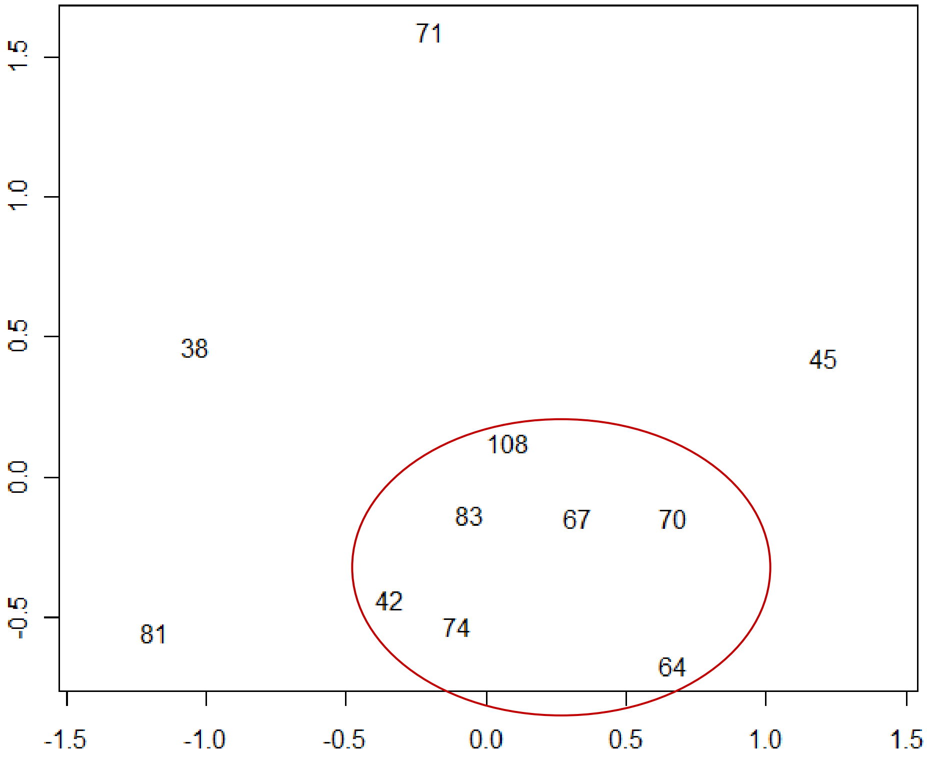


Figure 2.23. Representation of the sampling stations based on community similarities. The red circle included the stations closer together.

Stations 108, 42, 74, 83, 67, 70 and 64 resulted closer together (red circle) than with the stations 45, 81, 38 and 71; this last station showed the greatest distance from all the other ones.

To highlight differences among the sampled stations relatively to their assemblages, it was realized a Q-mode cluster analysis of assemblages. Station 45 resulted clustered together with the same stations grouped within the red circle in figure 2.23: to minimize the influence of this station and highlight the similarities among the other stations, a new cluster analysis was redraw (Fig. 2.24), not including the station 45.

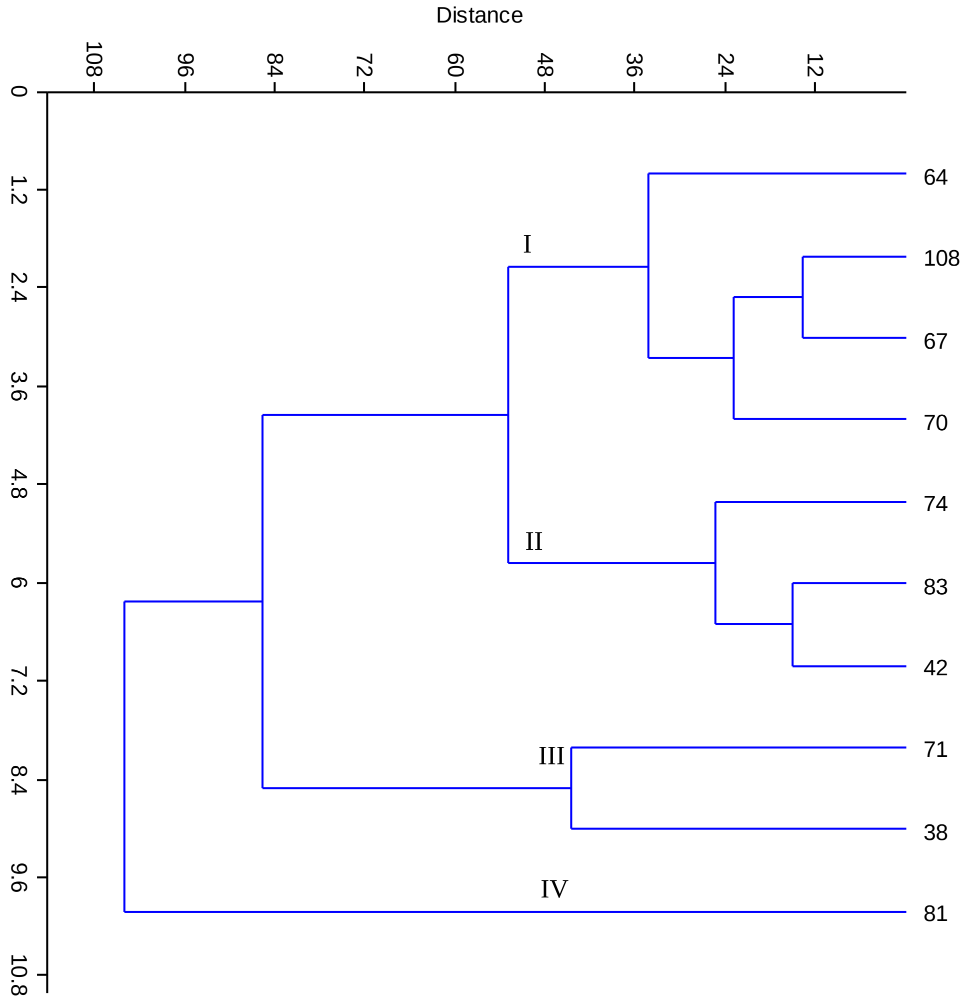


Figure 2.24. Q-mode Cluster analysis of foraminiferal assemblages in the sampled stations (Ward's method, Euclidean distance).

Four group were clustered: Cluster I grouped all the stations located on the west side of the sampled area (108, 64, 67, 70); Cluster II grouped the stations sited at the east side of the sampled area (83 and 42) and the station opposite the town of Licata (74), placed between the two station of Cluster III. Cluster III grouped station 71 and 38, opposite the cities of Porto Empedocle and Gela, respectively: their similarity distance was greater than that among the station within the other clusters. At least Cluster IV was represented uniquely from station 81 (Fig. 2.24).

2.3.5 MALFORMATIONS OF FORAMINIFERAL TESTS

Morphologically abnormal tests were counted and photographed, in order to evaluate possible correlations with heavy metals pollution. Their abundance was of 2 individuals of *F. boueanum* (0.8%) at station 67 and one individual of *C. auriculus* (1%) at station 45 (Fig. 2.25); the morphological abnormalities of all the malformed specimens consisted of reduced size chambers.

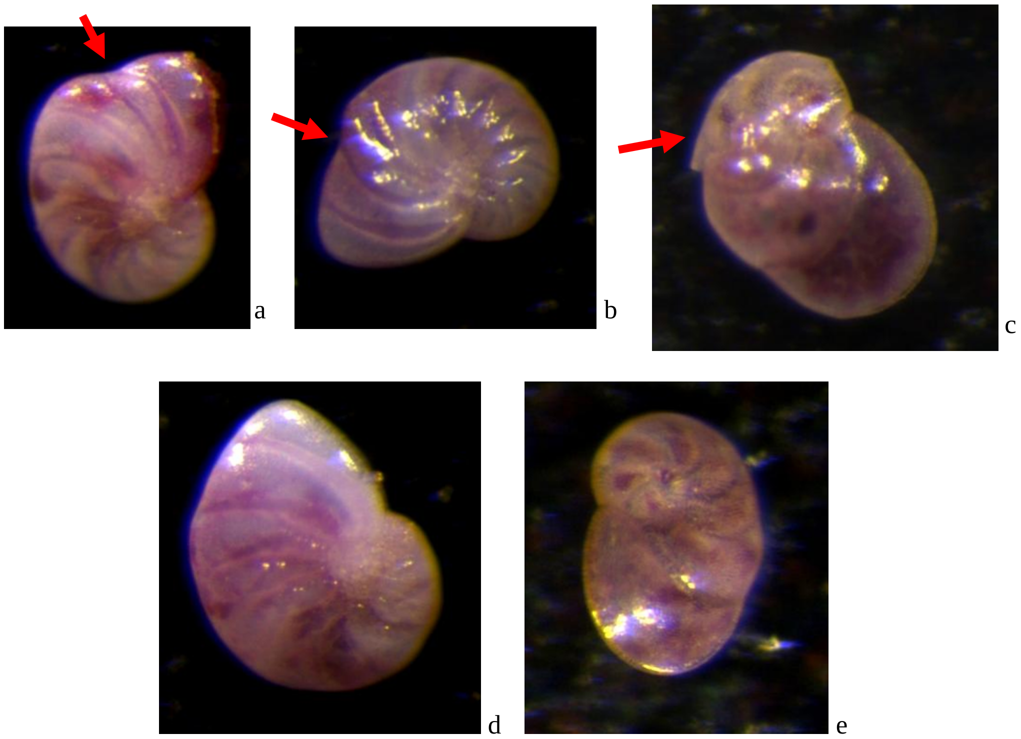


Figure 2.25. Foraminiferal abnormal tests of *Florilus boueanum* (a and b - at the station 67) and of *Cancris auriculus* (c - at station 45), and their corresponding natural forms (d and e, respectively).

2.3.6 STATISTICAL ANALYSES

The statistically significant correlations highlighted from the Correlation Matrix (table 2.10 - Appendix II) are explained below: mud (silt+caly) and sand showed opposite correlation with TOC (positive and negative respectively), and with all the trace elements (negative and positive, respectively), excepted Cu and Hg.

Shannon index (H’) showed a positive correlation with TOC and with Cu, and a negative correlation with Cd; even the species richness (S) was positively correlated with TOC and Cu, and was also positively correlated with Hg, while showed a negative correlation with almost all the other trace elements (As, Cd, Pb, Ba and Mn).

Among the species, the infaunal *Ammonia inflata*, *Bulimina aculeata*, *F. boueanum*, *R. phlegeri* and *T. agglutinans* presented a positive correlation with silt and/or clay fractions and a negative correlation with sand fraction; also *E. poeyanum* and *E. advenum*, respectively infaunal and epifaunal forms, presented a positive correlation with silt or clay fraction. Moreover *B. aculeata*, *F. boueanum* and *R. phlegeri* showed a negative correlation with Cd, Mn, Ni (significantly correlated only with *B. aculeata* and *R. phlegeri*) and Pb and V (significantly correlated only with *B. aculeata* and *F.boueanum*); *B. aculeata* also showed a negative correlation with As.

The epifaunal forams *H. depressula* and miliolids forms such as *Q. agglutinans*, *Quinqueloculina sp.* and *T. rotunda* showed a high positive correlation with As and Cd and different other heavy metals excepted Cu and Hg; *H. depressula*, *Q. agglutinans* and *Quinqueloculina sp.*showed also a negative correlation with Silt and with TOC, while *H. depressula* and *T. rotunda* showed a significant positive correlation with sand.

RDA analysis was conducted in order to evaluate the relationship between abiotic parameters (grain-size, TOC content, heavy metals) and foraminiferal assemblages (Fig. 2.26).

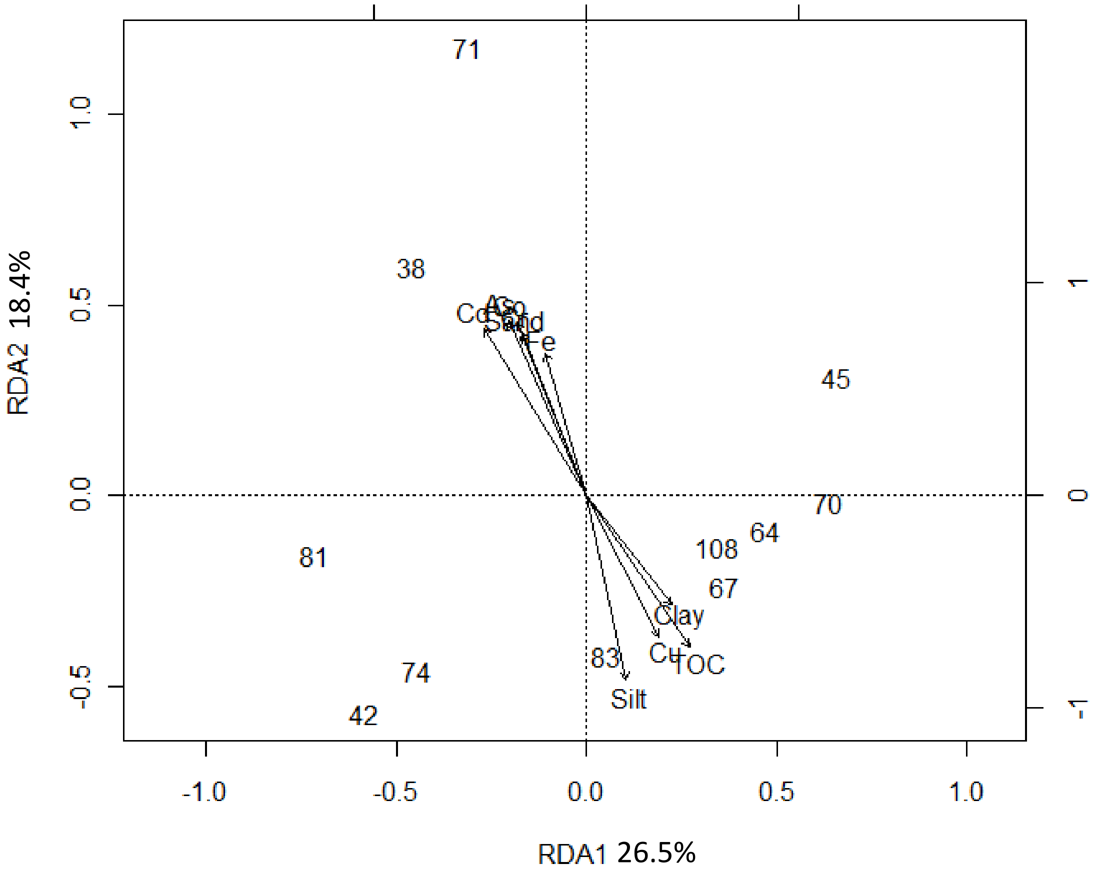


Figure 2.26. RDA biplot of the sampling stations related to foraminiferal assemblages and the grain-size fractions (% silt and clay), TOC (%) and heavy metals.

The resulting biplot represented in the same 2D space the similarity among the stations, relatively to their assemblages, and the projection of explanatory variables, e.g. environmental variables and heavy metals.

In Fig. 2.26, the first two axis explained the 50 % of the total variance.

Almost all the heavy metals, excepted the Cu, and sand were grouped together, positively correlated with the axis 2 (RDA2) and negatively with axis 1 (RDA1); they were also positively correlated with the stations 71 and 38, which showed low similarity with the other stations. Also silt, clay, TOC and Cu were positively correlated together and with the stations 83, 67, 108, 64 and 70.

The other stations did not show any high strong relationship with the abiotic parameters represented by this first two axis.

The result of the BIOENV analysis, that was performed correlating two dissimilarity matrices (on communities and abiotic parameters respectively), highlighted that among all possible combinations of variables the only one parameter “Cd” was responsible for the best correlation value ($R^2 = 0.5669$).

2.5 Discussion

Values and variation of the oceanographic parameters, acquired at the bottom, such as temperature, dissolved oxygen and salinity, did not seem to determine significant changes in benthic foraminiferal distribution; in particular, oxygen values fell within the saturation range, clearly representing not limitant factors for benthic foraminiferal life.

A terrigenous input of organic carbon, for almost all the stations, was highlighted by the anlaysis of $\delta^{13}C$, with the lowest values before and inside the Gulf of Gela; this area is also characterized by the lowest TOC content, which also corresponded to a sandy sediment (Fig. 2.5). This high percentage of sandy fraction could be explained by assuming that the fine fraction was transported away by hydrodynamic movements at the bottom.

The finer component of sediment (silt and clay), which principally characterized the western stations 108 and 67, allowed to a better conservation of the organic matter (TOC), as well as to a greater feeding source in the sediment compared to a higher sandy environment, in which aerobic bacteria intensify their action. According to Van der Zwaan and Jorissen (1991), distribution of benthic forams is strictly connected to this fine fractions (sitl and/or clay), because of its high content of organic matter transported by rivers into the sea, and transported by the current flow (Donnici and Serandrei Barbero, 2002).

Living fauna associated to the sandy sediments of station 71 (Fig. 2.13) was dominated by the genera *Quinqueloculina* spp. and *Triloculina* spp., which are represented by large-dimensioned forms, adapted to feed from the water and at the interface water-substrate, and strictly related to a coarse or vegetal substrate (epifaunal and/or epiphytic; Murray, 2006). According to Yanko *et al.* (1999) and Kfouri *et al.* (2004), these genera are usually found in environments affected by anthropogenic pollution, as well as the shallow-infaunal and epifaunal species *E. scaber* (Alve, 1991; Yanko *et al.*, 1999; Mojtahid *et al.*, 2006), *B. granulata* and *H. depressula* (Yanko *et al.*, 1999), which composed the assemblage of the station 38 (Fig. 2.15), also mostly sandy. Moreover Donnici and Serandrei Barbero (2002) highlighted the linkage between *E. scaber* and depth, and the tendency of this species to tolerate high nutrient input followed by low sediment oxygenation.

Naidu *et al.* (1985), Sharifi *et al.* (1991) and Armynot du Châtelet *et al.* (2004) explained how the total density (TFN) and species diversity (H') tend to decrease in areas at the increasing of the heavy metal concentration: according to these authors, stations 71 and 38 (Cluster III, Fig. 2.24), located in front of the thermoelectric and petrochemical industries respectively, presented the lowest density (TFN) and diversity (H') values (Figg. 2.20 and 2.21) and the highest heavy metals Enrichment Factors for Cd, As, Mn (st 71 and 38) and Cr (st 71) (tab. 2.8). This higher concentration of different heavy metals in the two stations 71 and 38 was also well highlighted by the Q-mode cluster analysis of figure 2.7.

Rectuvigerina phlegeri, followed by *N. turgida* and *F. boueanum* (st 108, 67, 70), and by *T. agglutinans* (st 64, 67, 70) and *B. elongata* (st 64, 67), dominated the assemblages of the western stations (Cluster I, Fig. 2.24); these species, which are almost all typically infaunal, were abundant in sediments with a high or medium-high muddy fraction, rich in organic matter available for the organisms that live within the sediment, in agreement with the clayey-silt composition of their sediment (Fig. 2.5). Excepted *F. boueanum*, these species are considered sensitive to heavy metals pollution, and more adapted to local low-oxygen concentrations; their presence, together with medium-high values of species diversity (H') and homogeneity (J) corresponded to a low enrichment by heavy metals, compared to the natural background of the area (Fig. 2.7, tab. 2.7).

The eastern stations 83 and 42, and the station 74, which were grouped together by the foraminiferal assemblages (Fig. 2.24, Custer II), added the dominance of the *Elphidium* group (*E. peyanum* and *E. advenum*) to the assemblages of the Cluster I; *Elphidium spp*. is a typical opportunistic taxon, which lives in the water-sediment interface (from shallow-infaunal to epifaunal), and could increase in polluted or stressed areas. This cluster included the station located among and after the two more polluted stations, relatively to the shallow-current direction (O-E; Fig 2.2). The presence of the tolerant *Elphidium* group corresponded to a moderate or moderately-severe Cd enrichment, and to similar sand and mud values among these stations (tab. 2.7; Fig. 2.5). Di Bella (1997) highlighted how the species *B. catanensis* is related to an unstressed shallower environment: the abundance of this species at the station 83, together with the highest TFN, showed an unpolluted environment condition (tab. 2.7).

The lowest H' and J values were both found at the station 81 (tab. 2.5), which differed from the other stations (Cluster IV, Fig. 2.24) by the dominance of the shallow infaunal species *E. poeyanum* (61% of total assemblage), and the heterogeneity of species abundance. Jorissen (1988) described *E. poeyanum* in almost all shallow-water assemblages of the Adriatic sea, usually coupled with *E. granosum* and *Ammonia* group. Yanko *et al.* (1999)

included this species among those toleranting organic and heavy metals pollution. Quite often, one or a few taxa of forams will thrive in stressed environments (Schafer, 2000). In this study, the high abundance of the *E. poeyanum* as dominant species at the station 81, together with the predominance of the *Elphidium* group (more than 80%), showed a moderate stress condition, according to Banerji (1992) which found *Elphidium* spp. to be least impacted by increased heavy-metal concentrations.

According to the sandy-silt grain-size, station 45 presented infaunal and epifaunal species, showing higher H' and J indices values, together with a medium TFN. All these features, added to the presence of sensitive species, such as *R. phlegeri*, are associated to low heavy metals enrichment values (tab. 2.7), even if this station presented the highest concentration of Hg (Al-normalized), for which it resulted sub-grouped alone (Cluster B1) in the clustering dendrogram of figure 2.7. The increase in Hg concentration shown by the three eastern stations seemed to follow the flow direction of the superficial current (Fig. 2.2). The lowest Hg values, found in the station 38 and 71, are well linked with the very low TOC content and the absence of the finer grain fraction, with their specific adsorbing effect for trace elements, and in particular mercury.

Singular links between each biotic (species percentage, diversity indices) and abiotic (sediment fractions, TOC and heavy metals) factors were expressed by the correlation matrix (tab. 2.10 – Appendix II). An important result is highlighted from the positive correlation among the most part of the heavy metals and the sandy fraction, in contrast with the natural behavior of these elements, which are generally bound to the finest sediment fractions. This correlation could represent the high input of heavy metals in this environment.

Cu concentrations seemed to be correlated to the fine-grain fraction (silt ad clay) and to the TOC content (tab. 2.10 – Appendix II), as it was highlighted by the RDA biplot (Fig. 2.26); its increase corresponded to an increase of H' and S (species richness), showing how the concentrations reported for this metal did not constitute a limit for the development of foraminiferal communities. Moreover, species richness (S) was positively correlated with Hg, confirming that even the concentrations of this metal did not affect foraminiferal diversity; on the contrary almost all the other elements (As, Cd, Pb, Ba and Mn) seemed to affect species richness (tab. 2.10 – Appendix II).

As it was shown by the Correlation Matrix (tab. 2.10 – Appendix II), species were correlated to sediment fraction corresponding to its infaunal or epifaunal behavior, highliting the important role played by grain-size on species distribution.

Moreover some species, such as *B. aculeata* as well as *R. phlegeri*, that are considered sensitive to heavy metals pollution effects, with the addiction of *F. boueanum*, commonly tolerating pollution (Yanko *et al.*, 1999), show a negative correlation with As, Cd, Mn, Ni, Pb and V.

Although in some cases the absence of forams may be partially attributed to natural factors (e.g. coarse grain-size, low organic matter content and other substrate features), heavy metal pollution also seems to contribute to such phenomenon: the positive correlation between many species and some trace metals, revealed by the RDA, suggested a certain tolerance to heavy metal pollution. *H. depressula* and miliolids forms such as *Q. agglutinans*, *Quinqueloculina sp.* and *T. rotunda,* principally referable to the stations 71 and 38, showed a high tolerance to heavy metal pollution (high positive correlation with As and Cd and other elements), as it was reported in literature; these species were also strongly related to the sandy content of these two stations, which resulted as “selective” environment, for almost all epifaunal assemblages.

In addition, BIOENV analysis has highlighted that among the abiotic parameters which were analyzed, Cd has most influenced foraminiferal distribution and abundance, confirming the presence of a correlation between heavy metals and foraminiferal communities.

At least, malformed tests (Fig. 2.25), which resulted less than or equal to 1% of the total number of individuals observed, were probably due to the natural morphological adaptation to the substrate, according to Boltovskoy *et al.* (1991) and Yanko *et al.* (1998). In fact, deformities are commonly found in up to 1% of total live populations, for a given species in given environmental conditions, representing the range of natural variability (Yanko *et al.*, 1998). Consequently, in this coastal environment and at the observed heavy metals concentrations, test abnormalities were not considered as biomarker of heavy metals pollution.

Chapter 3: Evidence from foraminiferal assemblages in relation to environmental settings in the Sicily Channel

3.1 Introduction

Biological productivity in the ocean is strongly impacted by trace metal distribution. In particular, low concentrations of some first row transition metals are known to be essential for productivity. Geological, physico-chemical (e.g. Morford and Emerson, 1999) and anthropic activities can strongly affect the distribution and concentration of trace metals in the seas, which are proportionally included in shells of many organisms, such as foraminifera.

During foraminiferal shell construction, trace elements which are present in sea water, are adsorbed and precipitate along with the calcium carbonate, trough endo- and exocytosis mechanisms, and then are incorporated into the shell (Erez, 2003). In addition to the biological control, physico-chemical parameters such as pH, temperature, salinity and pressure also influence the times and the modalities of inclusion of minor elements into this precipitation process (Munsel *et al.*, 2010).

Geochemical data, particularly on trace elements, of calcareous foraminiferal tests were applied in the last decades as palaeo-climatic and oceanographic proxies (e.g. Boyle, 1981;Wefer *et al.*, 1999; Lea, 2004), with the aim to fit geochemical signatures recorded in shell calcite with water chemistry, biological processes and habitat preferences of forams (Hester and Boyle, 1982; Boyle, 1988; Delaney *et al.*, 1985; Boyle and Keigwin, 1985, 1987; Delaney and Boyle, 1986; Lea and Boyle, 1990; Bertram *et al.*, 1995; Hastings *et al.*, 1996; Rosenthal *et al.*, 1997; Van Geen and Luoma, 1998; Lea *et al.*, 1999; Rühlemann *et al.*, 1999; Marchitto *et al.*, 2000; Rickaby *et al.*, 2000; Maréchal-Abram *et al.*, 2004; Rumolo *et al.*, 2009; Bryan and Marchitto, 2010; Munsel *et al.*, 2010). Numerous studies conducted in open seas and oceanic environments showed how Mg content of biogenic calcites may be driven by temperature (Rosenthal *et al.*, 1997; Tachikawa and Elderfield, 2002), as well as Cd concentration in benthic foraminiferal tests is related with Cd water content and consequently with dissolved phosphate in the deep seawater, due to the high correlation of dissolved Cd distribution with that of phosphate. Both are then associated with the degradation of labile organic matter. Moreover dissolved Cd distribution, reflecting the flow-related mixing of different deepwater masses, is used to reconstruct deepwater circulation (Katz *et al.*, 2010).

The aim of this chapter was to evaluate evidence from foraminiferal assemblages in relation to environmental settings of the Sicily Channel and to apply foraminiferal tests of the species *Uvigerina mediterranea* as oceanographic proxy of the bottom-water and/or possible biomarker of heavy metal pollution. The genus *Uvigerina* was frequently used for the same purpose by numerous authors, such as Marchitto *et al.* (2000), Rosenthal *et al.* (1997), Katz *et al.* (2010). Among the species belonging to this genus, *Uvigerina mediterranea* was selected for its wide distribution and best shells preservation in the samples of the studing area, and for its large size.

3.2 Study Area

Seventeen stations were sampled along 4 coastal-offshore transect located close to the southern Sicily coast in the Sicily Channel, as displayed in figure 3.1 and table 3.1. Three of the four transects, the Sciacca-Pantelleria (T1), Pozzallo-Malta (T3) and Capo Passero ones (T4), are located along two offshore branches of the Continental Shelf; this conferred them a peculiar relation between depth and distance from the coasts, as it is shown in the Fig. 3.1.

The Sciacca-Pantelleria transect is about 50 miles long and included 5 sampled stations, here named in order of increasing distance from the coast: 164 – 272 – 440 – 611 – 776. Depth profile slowly increased until the middle of the transect (from -104 to -272 m), decreased in the station 611 (- 117m), and then falls down sharply in the continental slope (st 776, - 752m). As the Sciacca-Pantelleria ones, the transects of Pozzallo-Malta, constituted by 4 stations named 137 – 299 – 410 – 581, and Capo Passero-offshore, constituted by 3 stations named 89 – 143 – 199, showed a slow increase in depth values, with a range going from -89 to -147m for the western transect and from -97 to -137m for the eastern one, covering a distance from the coast of 40 and 22 miles, respectively.

The Gela-offshore transect (T2) showed a completely different bathymetrical profile. It included 5 stations: the first two stations, named 77 and 180, are located in the Continental Shelf and in the Continental Slope, at -51m and -588m respectively, while the further stations named 342 and 683 in the Bathial Plane (-769m and -1060m); the station 513 represent a sediment slope, with a depth of -530m. Data relative to the depth and position of each station are synthesized in the table 3.1.

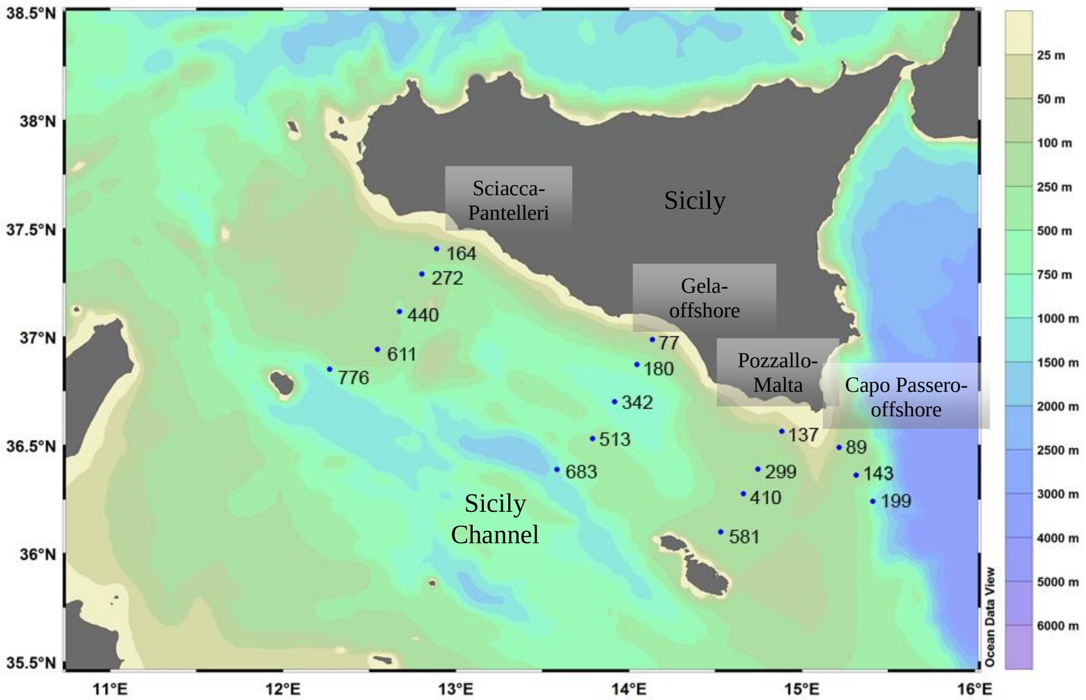


Figure 3.1. Sampling stations located in four transect in the Sicily Channel

Table 3.1. Coordinates, depth, distance from the coast of the four transects.

	Station	Longitude [east]	Latitude [north]	Depth [m]	Distance from the coast (nautical miles)
T1	164	12.889	37.406	-104	10.2
	272	12.803	37.29	-226	18.4
	440	12.673	37.117	-272	30.1
	611	12.546	36.943	-117	42.1
	776	12.27	36.85	-752	55.8
T2	77	14.136	36.987	-51	8.0
	180	14.047	36.873	-588	16.2
	342	13.917	36.7	-769	28.1
	513	13.79	36.53	-530	40.4
	683	13.583	36.387	-1060	51.9
T3	137	14.884	36.564	-86	9.2
	299	14.746	36.389	-139	20.7
	410	14.662	36.275	-142	29.0
	581	14.53	36.1	-147	41.1
T4	89	15.216	36.49	-97	12.4
	143	15.314	36.362	-148	21.1
	199	15.41	36.24	-137	30.0

3.2 Materials and Methods

3.2.1 SAMPLING METHODS AND GRAIN-SIZE ANALYSIS

Sampling methodology, based on the use of box corer and the analysis performed on grain-size composition of the sampling sediment followed the same protocols illustrated in the Chapter 2.

3.2.2 ANALYSIS OF TOTAL BENTHIC FORAMINIFERAL ASSEMBLAGES

For the analysis of Benthic Foraminiferal Assemblages, the first cm of each station, corresponding to a constant volume of 28.26 cm^3, was washed using a 63 micron mesh, in order to remove the finest sediment fraction (clay and colloids), and then dried at 50°C for 48 h (Alve, 1991). To be sure to exclude juveniles forms, that could more easily have been transported due to their species weight (Alve, 1991), samples were dry sieved again with a 125 micron mesh and only the greater fraction was utilized for the biological study.

Samples were quartered with a microsplitter and, from each subsample, there were picked up at least 300 well preserved benthic foraminifera, used for statistical analysis (Alve, 1991).

Individual density, species richness and diversity of benthic forams were analyzed using the Shannon-Weaver (2) (Shannon and Weaver, 1949) index and the Pielou index (3) (Pielou, 1966).

In order to highlight faunal diversity and distribution, density (TFN), species richness (S), Shannon-Weaver (H’) and Pielou (J) indices were calculated on the total number of benthic forams from the first centimeter of each small core by the software *Past*, as previously explained in the Chapter 2.

3.2.3 STATISTICAL ANALYSES

All statistical analyses were realized through the use of the software *Past*, *Statistica 8.0* and *R*-2*.14.1*.

As was previously done for living benthic forams (Chapter 2), also for the dead fauna only the species exceeding 5% of the assemblage in at least one sample were used to perform statistical analyses.

Q-mode cluster analysis was performed on living benthic foraminifera, applying the Ward's method and the euclidean distance (Fontanier *et al.*, 2008), in order to highlight the similarities among the stations in relation to species assemblages; groupings resulted from this analysis became the basis of others R-mode cluster analyses (Ward's method, Euclidean distance) performed to highlight which species dominated each group.

Benthic foraminiferal thanatocenosis were examined using Redundancy Analysis (RDA), as it was explained in Chapter 2.

The Mantel test (Mantel, 1967) was applied to examine the correlation between two triangular matrices: a dissimilarity matrix calculated on the base of environmental parameters (euclidean distance on standardized environmental variables – silt and clay fractions, TOC, distance from the coast and bathimetry) and a dissimilarity matrix calculated among stations in terms of thanatocenosis (Bray-Curtis distance on forams abundances).

At last box plots were made on trace element content in foraminiferal tests, to compare those data to the reference ones; in the cases in which the concentration of the trace element was lower than detection limit (<dl) it was statistically assumed the half value of detection limit for the metal.

3.2.4 ANALYSIS OF TRACE ELEMENTS IN *UVIGERINA MEDITERRANEA* TESTS

The *Uvigerina metiterranea* (Hofker, 1932; Fig. 3.2) is a shallow infaunal species very abundant in Mediterranean sea, from circalittoral zone (-50÷ -70m deep) down to the Bathial Plane (about -1000 m) (Parker, 1958; Parisi, 1981; Sgarrella and Moncharmont Zei, 1993).

Sediment samples were washed using a 63 micron mesh and dried at 40°C (Rumolo *et al.* 2009). The big dimensions of *U. mediterranea* specimens allow to dry sieved samples using a 125 micron mesh (Munsel *et al.,* 2010), to exclude the greatest part of juvenile forms. Indeed, a study conducted by Maréchal-Abram *et al.* (2004) on *Ammonia beccarii* cultures, showed as, in any cases, juvenile forms (constituted by the proloculus and at least 4 chambers) presented a different cadmium partition coefficient (D_{Cd}) from adult ones.

At least 30 well preserved specimens of *U. mediterranea* were picked from the 0-2 cm core surface (Rumolo *et al.*, 2009) from all the stations excluding the 77 because of the target species absence.

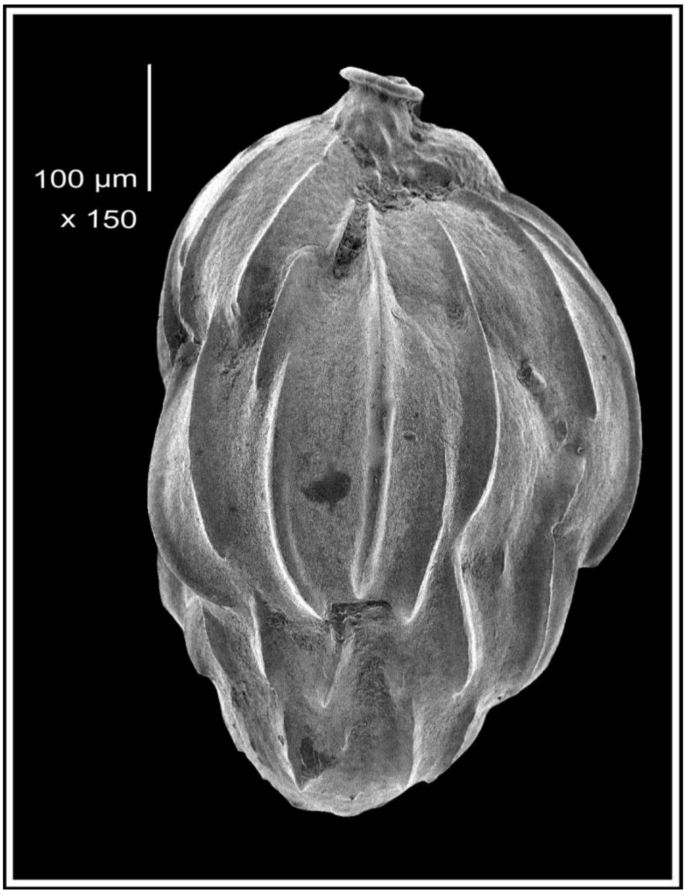


Figure 3.2. *Uvigerina mediterranea* specimen (570 x 364 microns) of the Sicily Channel (SEM picture)

Tests preparation felt the Rumolo *et al.* (2009) protocol which modified the Lea and Boyle (1993) procedure. Specimens were washed with 18MΩ (milli-Q) water and then lightly crushed in order to allow the best removal of possible post-mortem oxides. Test scraps were disposed into 1.5 ml tubes, ultrasonically cleaned in milli-Q water for three times.

Samples were briefly ultrasonically cleaned in 18MΩ water (three times) and in methanol (two times). Oxide coatings were reduced in a solution consisting of anhydrous-hydrazine, citric acid and ammonium hydroxide, while organic matter was oxidized in a solution of hydrogen-peroxide and sodium-hydroxide. Secondary barite was dissolved in alkaline diethylenetriamine-pentaacetic acid (DTPA) and then removed by rinsing with ammonium hydroxide. The remaining sample was transferred to a new centrifuge tube; any potential absorbed metal was leached with 0.001 N HNO3 and finally, the shells were dissolved with 12 mL of 1 M HNO3. In order to minimize contamination risks, laminar air flow clean bench was used alone with high purity grade reagents and laboratory acid-washed materials.

Chemical analyses were performed by ICP-AES (Inductively Coupled Plasma – Atomic Emission Spectroscopy) and ICP-MS (Inductively Coupled Plasma – Mass

Spectroscopy) at the geochemistry laboratory of IAMC-CNR Institute of Naples (Italy). Particularly, simultaneous analyses of Mg, Mn, Sr, and Cd concentrations were carried out using a Varian ICP-MS, whereas Ca was determined by a Varian Vista MPX ICP-AES. Analyses were carried out by external calibration using standards in the same matrix of forams samples, prepared for the dilution of ICP-MS High- Purity Standard Solutions. Instrumental stability and matrix effects were constantly verified by measuring a number of internal standards (Rh, Re for ICP-MS; Sc, Y for ICP-AES). Based on repeated analyses of standards over several runs, on different days, the error in the ICP analyses for Me/Ca was estimated to be between ±3÷7% (2σ; n=20). Lacking species standard reference material for trace metals in carbonates of foraminifera, the TM 25-2 (certified reference waters) was used to verify accuracy (estimated between 98 and 102% for all the analytes) of instrumental measurements. Calculated accuracy ranged from 98 to 102% for all the measured analytes. Reproducibility obtained by preparation and analyses of replicate samples was 12% for all measured element/calcium ratios, confirming the robustness of the results in terms of analytic methods and cleaning procedures (Rumolo *et al.*, 2009).

Manganese/calcium ratio was performed in order to screen against contamination from diagenetic coatings or detrital material by applying the limit of 100 µmol mol^{-1}, in accordance with Barker *et al.* (2003) and Boye (1983).

To assess the applicability of the Cd/Ca ratio in benthic foraminiferal tests as indirect measuring tool of dissolved Cd concentration at bottom water, it was applied the relation (4) for the Partition Coefficient of trace elements ($D_{TE;}$ Boyle, 1981), which was modified taking into account the increase of Cd concentration in porewater than that in bottom water (5):

$$D_{TE} = [TE/Ca]_{forams} / [TE/Ca]_{bottomwater} \qquad (4)$$

$$Cd_{bottomwater} = [Cd]_{forams}/[Ca]_{forams} * [Ca]_{porewater} * (1/D_{Cd} * \boldsymbol{\alpha}) \qquad (5)$$

were **α**, ranging from 1.6 to 2.6, represents the increase of Cd concentration from bottom water to porewater (Klinkhammer *et al.*, 1982; McCorkle and Klinkhammer, 1991).

Average values measured for bottom water Cd in the Sicily Channel by Placenti (2010), relative to seawater (LIW and AIS), were used as reference, together with relative TE/Ca ratio in benthic forams tests from unpolluted areas and the Cd Partition coefficient ($D_{Cd\ forams/water}$; Lea, 1999) (tab.3.2).

Table 3.2. Trace element abundances relative to benthic forams calcite. *Reference data are from Lea (1999) and Havach *et al.* (2001), average data for seawater dissolved Cd are from ***Placenti (2011, in the Sicily Channel) and ****UNEP (1990, in Mediterranean sea).

Elements	Ions in calcite	Benthic forams from natural environments (mol_{TE}/mol_{Ca}) *	Partition Coefficient (D_{Cd}) **	[Cd] at the LIW domain ($nmol_{Cd}/mol_{Ca}$) ***	[Cd] at the AIS domain ($nmol_{Cd}/mol_{Ca}$) ***	[Cd] in Mediterranean sea water (nmol/l) ****
Calcium	Ca^{+2}	1	-	-	-	-
Magnesium	Mg^{+2}	$0,5 - 10 \times 10^{-3}$	-	-	-	-
Stronzium	Sr^{+2}	$0,9 - 1,6 \times 10^{-3}$	-	-	-	-
Manganese	Mn^{+2}	$1 - 500 \times 10^{-6}$	-	-	-	-
Cadmium	Cd^{+2}	$0,02 - 0,25 \times 10^{-6}$	2±1	0.84	0.17	0.009–0.06

Moreover it was applied the empirically derived formula of Rosenthal *et al.* (1997) (6) to the Mg/Ca values of *Uvigerina mediterranea* tests to reconstruct bottom water temperature.

$$T°C = 22.7 \log (Mg/Ca) - 3.05 \qquad (6)$$

3.3 Results

3.3.1 GRAIN-SIZE ANALYSES

Grain-size and depth profiles for each transect were represented in figure 3.3 and 3.4 respectively. Both T1 and T2 presented sandy fraction in only one station: st. 611 at the T1, in which sand prevailed on silt and clay, and st. 513 at the T2 where the three fractions were proportionally distributed; the general sediment grain-size of these two transects could be classified as silty-clay. T3 was characterized by a silty-clay composition, presented by the first and the last stations (137 and 581, respectively) and a sand-silt-clay composition for the central stations (299 and 410) which presented similar values for all the three grain fractions. Finally T3 was characterized by the complete absence of sand fraction, and from a predominant silty-clay composition in the two farthest stations (143 and 199).

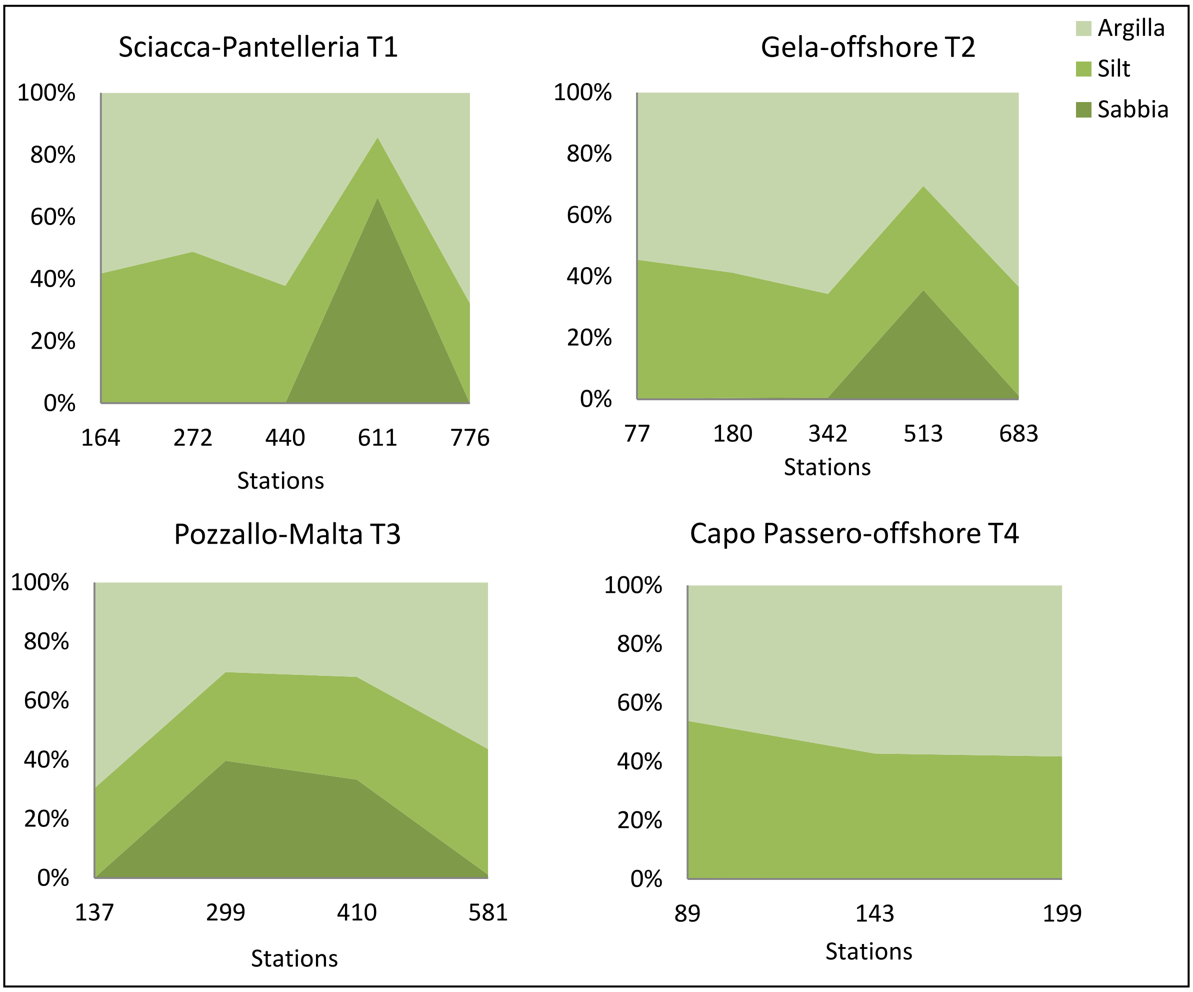


Figure 3.3. Grain-size profiles along the four transects

T1 and T2 presented a slope in correspondence of the 4th stations (611 and 513); T2 was constituted by almost all deep stations, while the deepest station of T1 was represented by the station 776 (at about -752 m). T3 and T4 presented values which ranged between about -89 and -148 m (st 137 and 143, respectively) (Fig. 3.4).

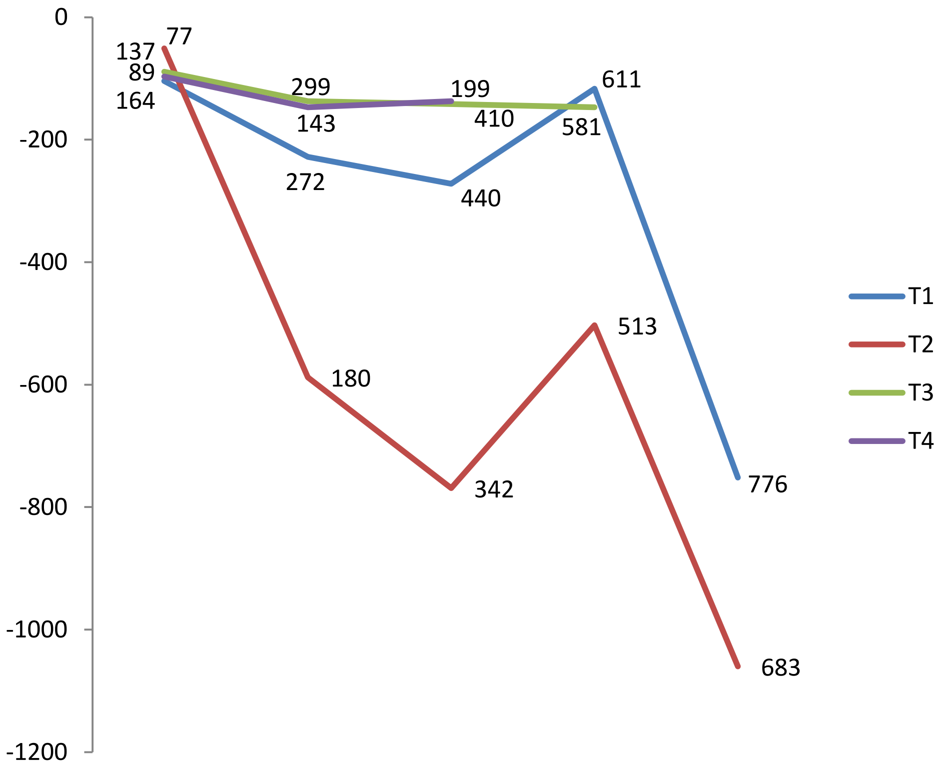


Figure 3.4. Depth profiles along the four transects

3.3.2 ANALYSIS OF TOTAL BENTHIC FORAMINIFERAL ASSEMBLAGES

141 Species belonging to 84 genera of dead benthic forams were found (tab. 3.3 – Appendix III).

Diversity indices (Shannon H', Pielou J and species richness S) were displayed in table 3.4 (Appendix III). The species richness (S) ranged from 25 to 51 individuals per 28.26 cm^3 of sediment, while the Total Foraminiferal Number showed a wide range of values, with the lowest individual number in the stations 342, 199 and 272 (with 208, 308 and 636 individuals, respectively) and the highest ones in the stations 611, 410 and 513 (ranging from 57780 to 19712 individuals), followed by the stations 299 (17152 individuals) and 581 (10944 individuals) (Fig. 3.5).

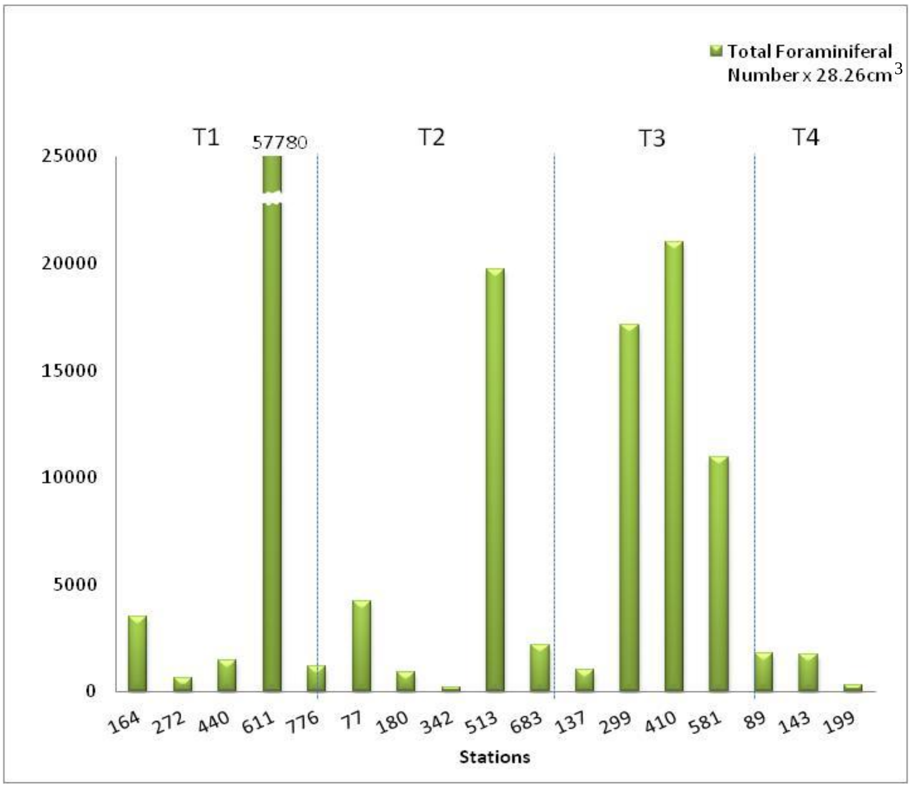


Figure 3.5. Total benthic foraminiferal densities (TFN per 28,26 cm^3 of sediment) of the top-core.

Species diversity, highlighted by the Shannon-Weaver index (*H'*), showed middle-high and high values for all the stations (from 2.5 for the stations 342 and 199, to 3.34 for the station 611; Fig. 3.6), and the Pielou index (*J*) ranged from 0.77 to 0.89 (stations 342 and 137-513, respectively) denoted an homogeneous specimens repartition among the species (Fig. 3.7).

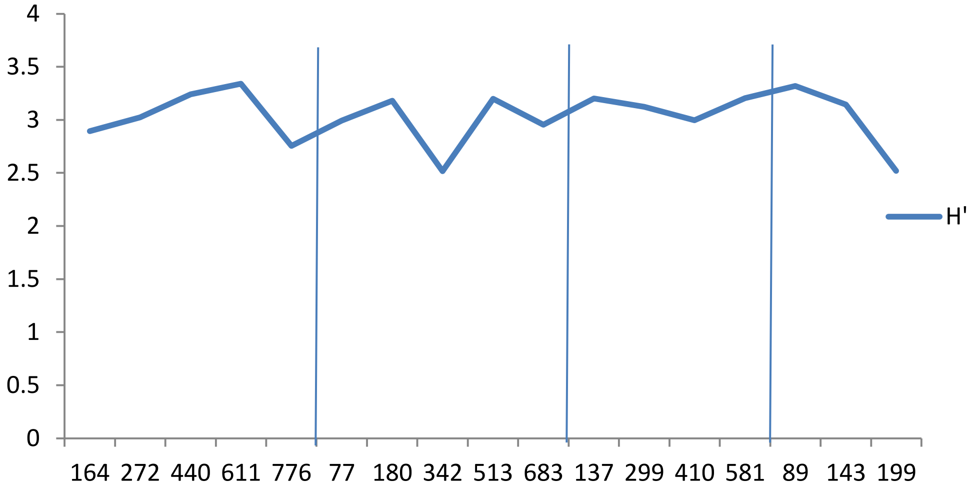


Figure 3.6. Shannon-Weaver index (H'): Species diversity measurement

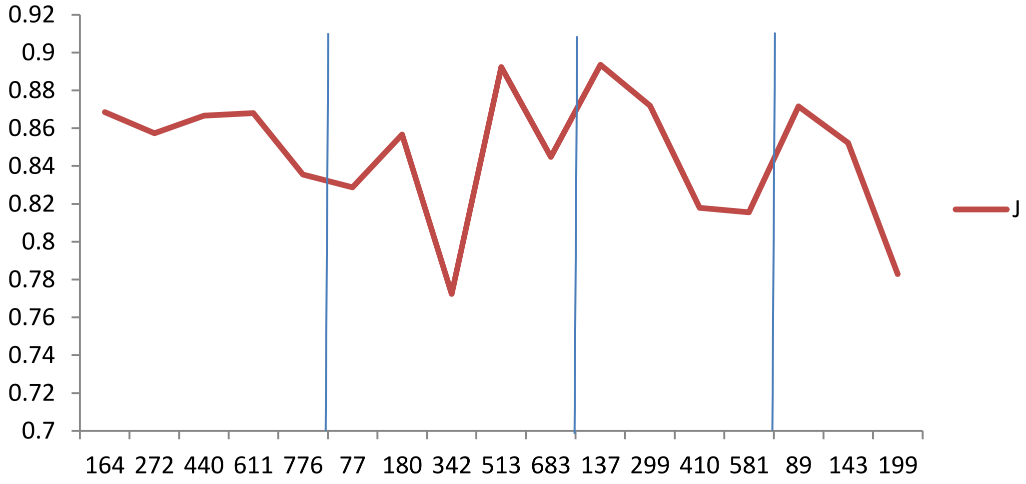


Figure 3.7. Pielou index (J'): Homogeneity measurement

3.3.3 STATISTICAL ANALYSES

Cluster analysis, performed per stations grouped by species frequency and abundance, displayed the distinction of three clusters (Fig. 3.8). Results were plotted in the bathymetric map of the sampling area (Fig. 3.9): Cluster I grouped together all the first stations of the four transtects (st. 164, 77, 137, 89), and the following two stations of T1 (st. 272, 440) and one station of T4 (st. 143); Cluster II, presented a short distance (high similarity) from the cluster I, and has interested almost all the stations of T3 (st. 299, 410, 581), and the fourth stations of T1(st. 611) and T2 (st. 513). Finally, Cluster III brought together the farthest stations of T1(st. 776), T2 (st. 683) and T4 (st. 199), and second and third stations (st. 342, 513) of T3.

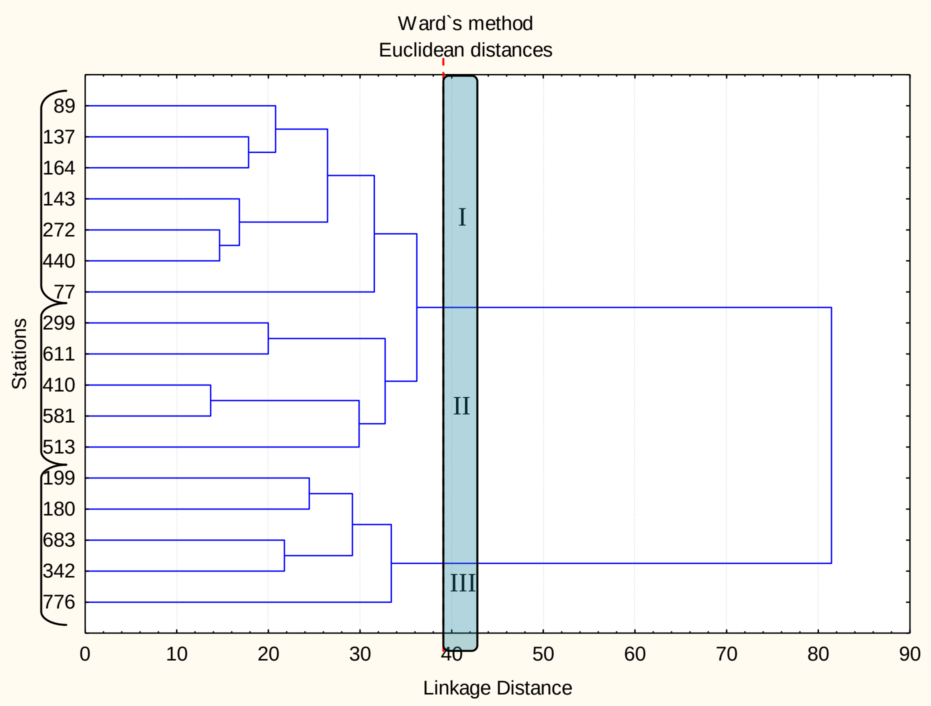


Figure 3.8. Q-mode Cluster analysis of foraminiferal assemblages in the sampled stations (Ward's method, Euclidean distance).

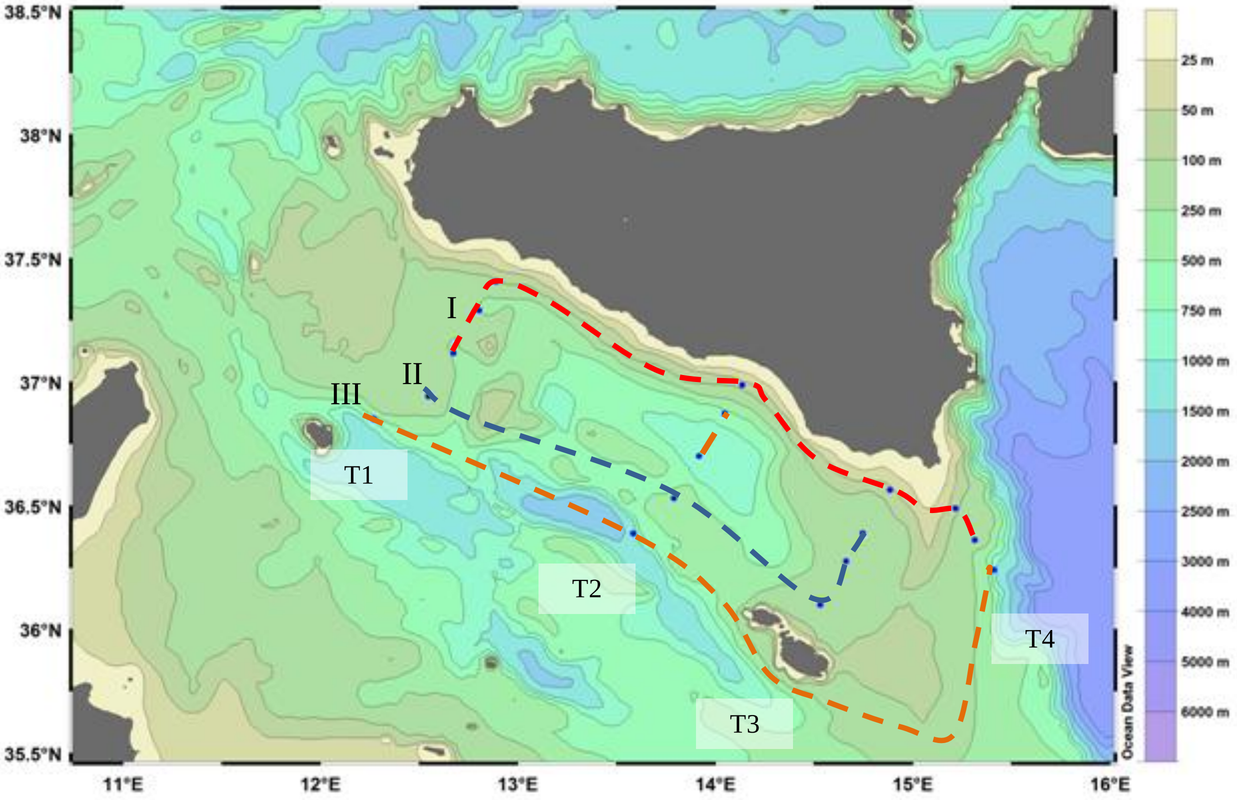


Figure 3.9. Bathymetric correlation with benthic foraminiferal assemblages (cluster I: red; cluster II blue; cluster III orange) .

By performing a R-mode cluster analysis on forams abundance for each of the three clusters highlighted from figure 3.8, it was showed that Cluster I was dominated by *Bulimina aculeata* (20%), *Cassidulina carinata* (16%) and *Uvigerina peregrina* (12%) (Fig. 3.10), Cluster II was dominated by *B. aculeata* (18%), *Textularia agglutinans* (18%) and *Bulimina marginata* (15%) (Fig. 3.11), and Cluster III was strongly dominated by *Uvigerina mediterranea* with a percentage of 31%. (Fig. 3.12).

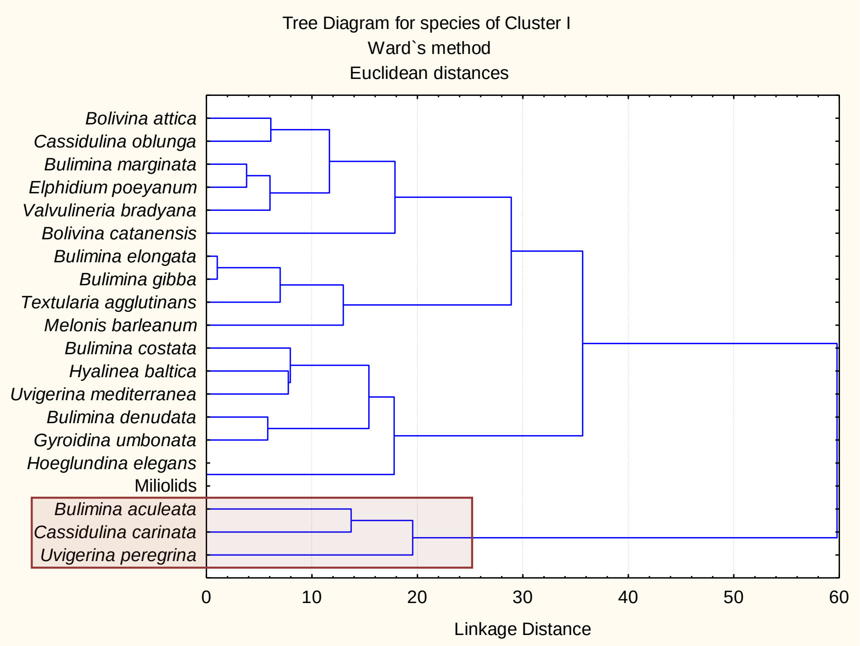


Figure 3.10. R-mode Cluster analysis of foraminiferal assemblages in the stations belonging to the Cluster I of figure 3.8 (Ward's method, Euclidean distance).

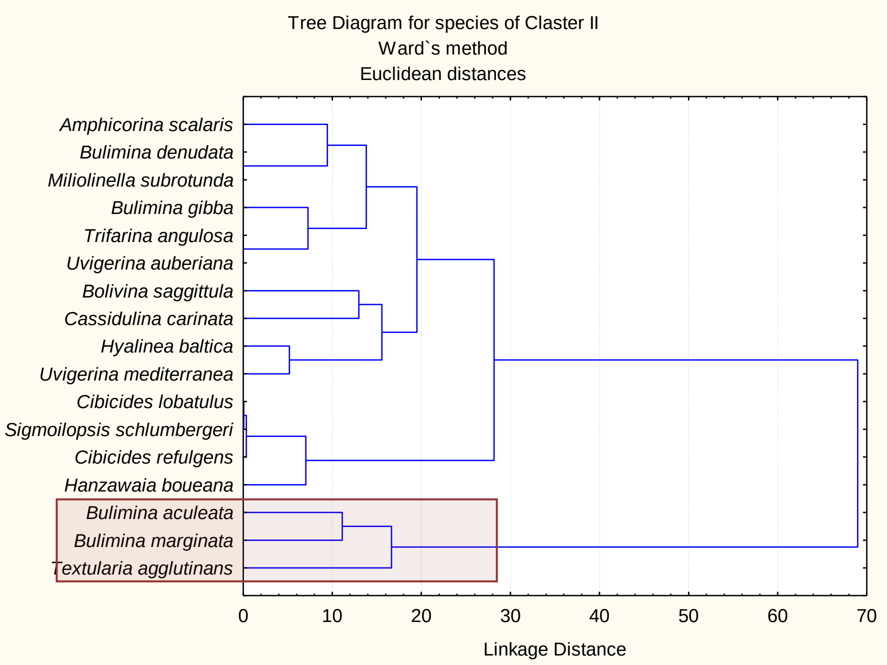


Figure 3.11. R-mode Cluster analysis of foraminiferal assemblages in the stations belonging to the Cluster II of figure 3.8 (Ward's method, Euclidean distance).

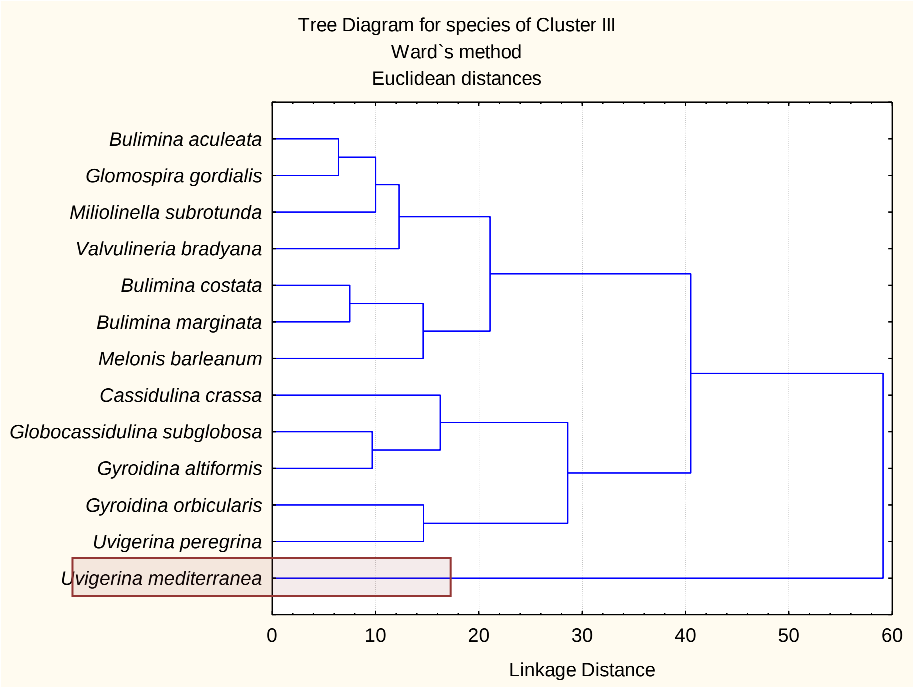


Figure 3.12. R-mode Cluster analysis of foraminiferal assemblages in the stations belonging to the Cluster III of figure 3.8 (Ward's method, Euclidean distance).

In figure 3.13 species richness (S) values of the three clusters were reported: Cluster I showed the highest value, followed by Cluster II and Cluster III.

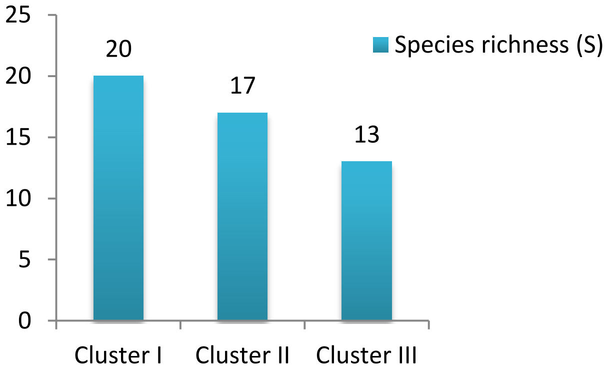


Figure 3.13 Species richness (S) of the three clusters highlighted in figure 3.8.

In the Redundancy Analysis (RDA) the space of the N dependent variables (species more abundant than 5%) is replaced by the space of N factors. The first M axes are constrained to the M= 4 independent (explanatory) environmental variables. In the biplot of figure 3.14 stations are projected in the space of the two most representative factors (axes RDA1 and RDA2) that explained the 30% of the total variance (Total Inertia: 0.6876; Constrained Inertia: 0.2703; RDA1: 0.14548 RDA2: 0.06690). Overall, the environmental variables explain almost 45% of the variance.

Variance was principally explained by the factor1, which in this case is mainly related to the depth. Three groups were highlighted, corresponding to the three clusters of the cluster analysis (Fig. 3.8): orange stations, representing the Cluster III, were positively correlated with depth, with distance from the coast and with clay fraction, while red stations, which represent Cluster I, were positively related to silt fraction, then showed a low negative correlation with the depth and a negative correlation with the distance from the coast. Finally blue stations, which represent Cluster II, were influenced by sand fraction, and partially by depth.

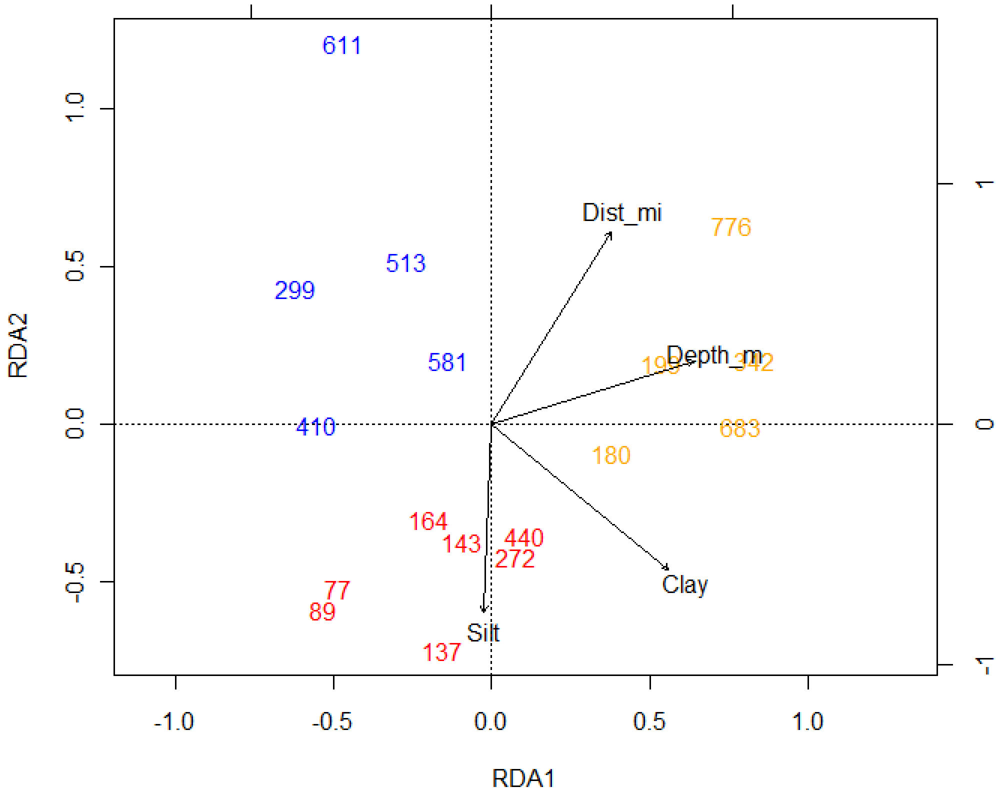


Figure 3.14. RDA biplot of the sampling stations related to the grain-size fractions (% silt and clay), bathymetry (m), distance from the coast (m) and foraminiferal assemblages (percentage of species more abundant than 5%).

The Mantel test was performed in order to evaluate the correlation between environmental parameters (bathymetry, distance from the coast, silt and clay fractions and TOC) and benthic foraminiferal thanatocenosis. It had shown a medium value of correlation (R^2= 0.5061; significance = 0.001), highlighting the influence of the given environmental parameters on foraminiferal assemblages.

3.3.4 ANALYSIS OF TRACE ELEMENTS IN *UVIGERINA MEDITERRANEA* TESTS

Trace element analyses in the *U. mediterranea* shells were conditioned by the calcium content of the samples, correlated to the number of well preserved individuals picked. For this reason not all the stations gave a useful result. All the results were schematized in table 3.5.

Table 3.5. Trace element's content in *U. mediterranea* (Hofker, 1932) tests.

	Samples	Ca ppb	Mn/Ca µmol/mol	Mg/Ca mmol/mol	Cd/Ca µmol/mol	Sr/Ca mmol/mol	Depth m
	164	10672	24.7	1.86	<dl	1.43	-104
	272	802	-	0.49	-	1.4	-226
	440	20368	20.5	2.58	0.93	1.73	-272
T1	776	33645	23.6	2.29	0.25	1.69	-752
	180	11794	15.8	2.75	<dl	1.39	-588
	342	23324	3.8	1.98	0.03	1.33	-769
	513	24284	20.6	2.43	<dl	1.31	-530
T2	683	18740	7.7	2.35	0.99	1.29	-1060
	137	1605	-	1.23	-	1.43	-89
	299	22297	14.2	2.37	0.04	1.35	-139
	410	31029	18.4	2.32	<dl	1.33	-142
T3	581	28213	4.4	1.82	<dl	1.36	-147
	89	1926	<dl	1.35	-	1.43	-97
	143	20984	26.1	1.82	<dl	1.33	-148
T4	199	1378	-	1.03	0.32	1.43	-137
Detection limits (µmol/mol)		-	0.00236	-	0.002423		

In some cases it was not possible to quantify the amount of trace element in the foraminiferal tests; this was probably due to three different factors: the low concentration of the elements, the limited available amount of carbonate and the adopted strong cleaning procedures.

Mn/Ca values ranged between 3.8 and 26.1 µm/l with almost all homogeneous values, with the lower values in T2 and T3, while Cd/Ca values showed a wide range, between 0.03 and 0.99 µm/l, with numerous stations not detectable (<dl); Mg/Ca and Sr/Ca showed generally homogeneus values, with the exception of the st 272, with the lowest Mg/Ca value (0.49 µm/l) (tab. 3.5).

Analyzed trace elements relative to the biogenic calcite were compared to their references (table 3.2). Each trace element/Ca ratio was elaborated in a box plot, divider per transect and a blue line was driven to mark the upper limit of the reference values (Fig. 3.15).

Mg/Ca and Mn/Ca values were well below the reference limits (0,5÷10 mmol/mol and 1÷500 µmol/mol respectively, tab. 3.2) then it was not driven any line for them; on the contrary Sr/Ca and Cd/Ca showed values above the blu line.

While Sr/Ca retained above the reference values (0,9÷1,6 mmol/mol, tab. 3.2) the median of each transect, showing exceeding values in only one transect (T1), three of the four transects of the Cd/Ca box plot exceeded the blue line (0,02÷0,25 µmol/mol, tab. 3.2) (Fig. 3.5).

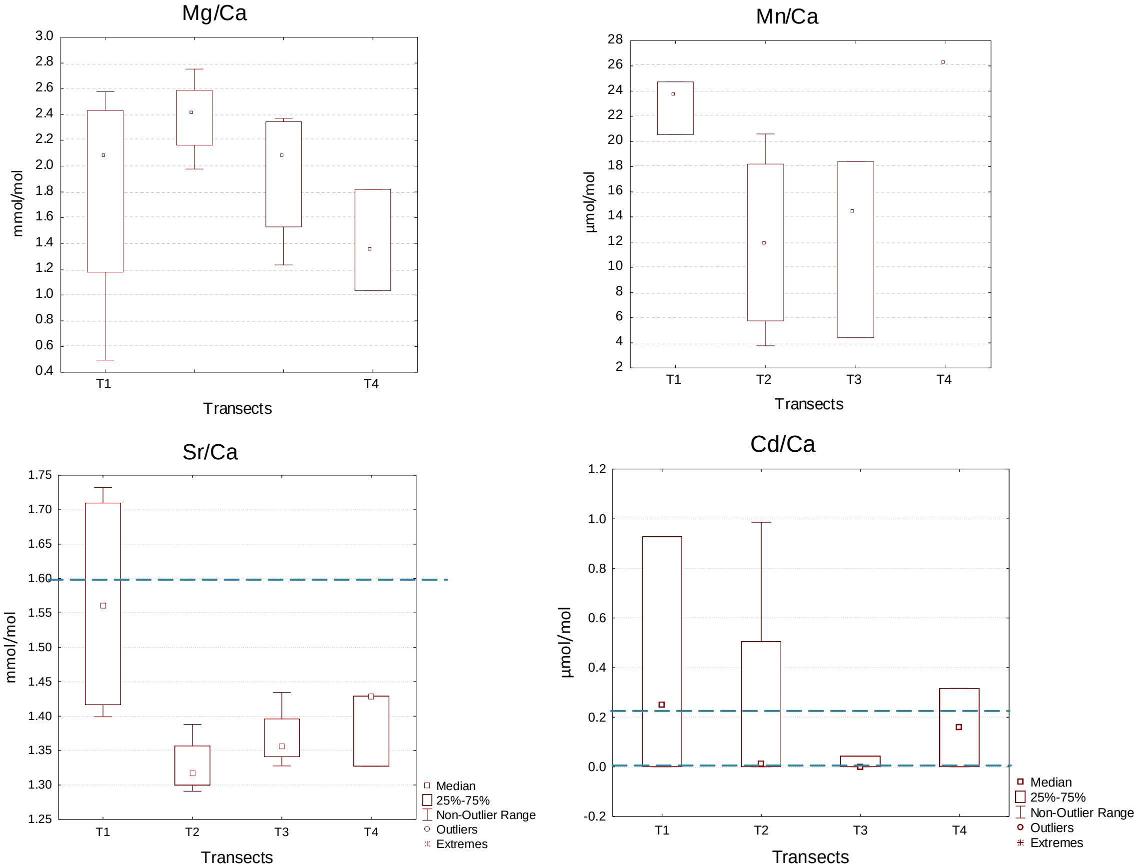


Figure 3.15. Box plot of relative Mg/Ca, Mn/Ca, Sr/Ca and Cd/Ca values within the four transects. The blue lines represented the range of reference values of unpolluted benthic foraminiferal tests.

To obtain indirect Cd bottom water values as much as possible compliant to the direct average values given by Placenti (2010) and UNEP (1990) (tab. 3.2), it was necessary to apply the highest values of the **α** coefficient (5). Estimed Cd concentration in bottom water ranged between 0.048 nmol/l to 1.89 nmol/l, with an average value of 0.96 nmol/l (tab.3.6).

Table 3.6. Estimed values of Cd concentration in bottom water, by applying (5) with **α** = 2.6. f: foraminifera; bw: bottom water.

Samples	measured **Cd/Ca f** µmol/mol	estimed **Cd/Ca bw** µmol/mol	estimed **Cd bw** nmol/l
440	0.93	0.178529	1.78529
776	0.25	0.048176	0.481764
342	0.03	0.004828	0.0482822
683	0.99	0.189614	1.89614
199	0.32	0.060999	0.609994

The application of empirically derived formula for the temperature (6) (Rosenthal *et al.*, 1997) has highlighted the set of values of the table 3.7.

Table 3.7. Estimed Temperature values (°C); CF= correction factor

	Samples	Mg/Ca [mmol/mol]	T (estimed) [°C]	T (measured) [°C]	depth [m]	CF 6%	CF 25%	T estimed CF [°C]
	164	1.86	19.92	14.38	-104	1.195181	4.97992	14.94
	272	0.49	19.34	14.28	-226	1.160626	4.835942	14.51
	440	2.58	20.06	14.17	-272	1.203677	5.015322	15.05
T1	776	2.29	20.01	13.97	-752	1.200551	5.002297	15.01
	180	2.75	20.09	13.96	-588	1.205394	5.022476	15.07
	342	1.98	19.95	13.98	-769	1.196767	4.986529	14.96
	513	2.43	20.03	14.26	-530	1.202088	5.008701	15.03
T2	683	2.35	20.02	13.90	-1060	1.201257	5.005239	15.02
	137	1.23	19.74	14.98	-89	1.184473	4.935304	14.81
	299	2.37	20.02	14.58	-139	1.201499	5.006246	15.02
	410	2.32	20.02	14.72	-142	1.200921	5.003839	15.01
T3	581	1.82	19.91	14.84	-147	1.194641	4.977672	14.93
	89	1.35	19.78	14.81	-97	1.186731	4.944712	14.83
	143	1.82	19.91	14.42	-148	1.194601	4.977503	14.93
T4	199	1.03	19.66	14.57	-137	1.179864	4.916101	14.75

Derived temperature showed an uniform range of values, but they were not conform to the measured ones. Applying the correction factor of -6% (Lear *et al.*, 2002) values resulted higher at the same. Only applying a correction factor of -25% temperature values became comparable to that measured (tab. 3.7).

3.4 Discussion

Sediment's grain-size along the transects showed a similar pattern for T1 and T2, in which there was a sand accumulation zone at almost constant distance from the coast (42 and 40 nautical miles far from the coast), probably due to hydrological phenomena, and in correspondence of two sites of lower bathymetry.

The presence of sandy fraction in the two central stations of T3 could be influenced by the presence of the Maltese island, while the transect T4, which was only 30 nautical miles away from the coast, completely missed the sandy fraction.

Once again, the bathymetric profile of the four transects showed a correspondence between T1 and T2, even if T1 is shallower than T2. Despite their different grain-size profile, T3 and T4 were characterized by similar depth profiles: grain-size difference could be due to the proximity of T3 to the Maltese coast, together with the influence of shallow (AIS) and intermediate (LIW) currents.

Samples which presented a sandy fraction also presented the highest density (TFN – Fig. 3.5); among them, the sample 611 showed the highest TFN (57780 individuals in 28,26 cm^3 of sediment). This sample was characterized by a high component of coarse sediment and the presence of numerous diagenized tests, often reporting smoothed edges, which usually indicates a transport by the current.

To prevent the possible inclusion of transported specimens within the thanatocenosis, all specimens who showed the beginning of mineralization or a broken or smoothed test have not been taken into account.

The lower density (TFN) of benthic forams was found in the samples 342 (T2), placed at a very high depth compared to nearby stations, and 199 (T4), placed at the same distance from the coast but at a lower depth (-120m) than the sample 342; a possible explanation to this low specimens density for the sample 199 could be done assuming that the meeting of two currents, the AIS from the Sicily Channel and the Ionian current from the Ionian Sea, created a continuative stress condition for benthic forams communities. Thanatocenosis associated to the stations 342 and 199 reported lower values of diversity indices (H ') and homogeneity (J), further supporting a higher stress condition.

The applied diversity indices (Shannon H 'and Pielou J) generally showed high values for all stations, indicating a general unstressed environment.

According with Aller and Cochran (1976) and Benninger *et al.* (1979), foraminiferal distribution is inversely related to the depth. Another important factor which influenced foraminiferal distribution was represented by the distance from the coast: the concurrent influence of these two factors in foraminiferal distribution was highlighted from figure 3.9, in which the three biofacies grouped by the Q-mode cluster analysis of species (Fig. 3.8) were graphically reported. Cluster I grouped together the first stations of the four transect, placed closer to the coast, and some other stations of T1 and T4; their assemblage, with the highest species richness (Fig. 3.13), was dominated by the species *Bulimina aculeata*, *Cassidulina carinata* and *Uvigerina peregrina*, which are cosmopolitan, shallow infaunal, deposit feeders and opportunistic taxa (Corliss and Fois, 1990; Hayward, 2002; Murray, 2006; Violanti *et al.*, 2011; Goldstein and Corliss, 1994) indicative of intermediate organic carbon fluxes and high seasonality due to phyto-detritus input from seasonal blooms (Duchemin *et al.*, 2008).

Cluster II represented an intermediate assemblage, between the shallower Cluster I and the deeper Cluster III, as it was highlighted from the species richness (S) (Fig. 3.13); *B. aculeata* was presented as dominant species also in this cluster, followed by *Bulimina marginata* and the agglutinated species *Textularia agglutinans*. Despite the muddy affinity highlighted from Murray (2006) for *B. marginata*, this cluster gathered together the stations which presented a sandy component and the station 581 of the T3 transect. At last *Textularia agglutinans* is typical of silt to silty-sand substrate and highly dynamic seafloor environments (Sabbatini *et al.*, 2010).

Cluster III included the farthest stations of the four transects, with the low species richness (S) and the lower diversity indices (Figg. 3.13, 3.6 and 3.7). The species *Uvigerina mediterranea* showed a high dominance (about 31%) on the entire assemblage; this species is usually found in well oxygenated sediments, rich in organic matter, in which it showed to be a superior competitor and highly resistant to predator disturbance (de Stigter *et al.*, 1998). The *U. mediterranea* large dimensions and its ecological range could suggest a high hydrodynamic environment, rich in nutrient, characterizing the farthest stations.

In addition to the depth and distance from the coast, sediment grain-size strongly influenced foraminiferal distribution (Murray, 2006).

This conclusion could be explained by the RDA biplot of figure 3.14 in which the stations were distributed according to the influence of the environmental variables on foraminiferal assemblages: the stations in yellow (relative to the Cluster III), were principally influenced by the depth, and secondarily from the percentage of mud in the sediment, stations in red were principally influenced from the silt content and from the lower distance from the coast, and finally the stations in blue were principally influenced by the sandy content, and secondarily by the sampling depth (Fig. 3.14). Moreover, medium value of correlation between abiotic and biotic dissimilarity matrices shown by Mantel test, highlighted the importance of the analyzed environmental parameters on foraminiferal distribution and abundance.

This characterization of benthic foraminiferal thanatocenosis highlighted a natural environment condition, principally conditioned by the oceanographic features.

On this general basis there were analyzed the trace elements incorporated in the *U. mediterranea* tests, in order to assess forams ability to reflect the bottom water concentrations also in a semi-enclosed basin, such as the Mediterranean Sea.

Manganese/calcium values resulted well below the value of 100 µmol/mol, which represents the thresholds for likely trace metal contamination (Barker *et al.*, 2003; Boyle, 1983; Bryan and Marchitto 2010), confirming a good cleaning of the samples.

Manganese/calcium and magnesium/calcium ratios in foraminiferal tests showed the absence of any enrichment, by comparing them with the values reported from Lea (1999) for unpolluted foraminiferal tests. Also Sr/Ca in forams showed general lower values, with a very low exceeding of only two samples belonging to the T1 (Fig. 3.15 and tab. 3.2).

Cadmium/calcium in forams showed higher values than that of reference, due to an enrichment of this element in the sediment, of which is not possible suppose any origin at the moment (Fig. 3.15).

By comparing mean Cd values from the Sicily Channel sediments (Tranchida *et al.*, 2010) and the *World Average Shale* (0.235 and 0.11 mg Kg^{-1}, respectively), Sicily Channel sediments resulted doubly concentrated in Cd than those of the world oceans; this consideration allowed to consider the porewater as an important source of dissolved Cd for benthic infaunal forams of the Sicily Channel, such as *U. mediterranea*. Generally, Cd/Ca from infaunal species shows higher value than that from epifaunal species (Tachikawa and Elderfield, 2002) due to the increasing of dissolved Cd concentration from bottom water to porewater (Klinkhammer *et al.*, 1982; McCorkle and Klinkhammer, 1991). By applying this correction factor (**α**) to the cadmium Partition Coefficient (D_{Cd}) the average values of Cd concentration obtained in bottom water were consistent with that reported from Placenti (2011) at the LIW domain (tab. 3.2).

Studies conducted on surface sediment of oceanic environment and on laboratory culturing have demonstrated a strong dependence of benthic shell Mg/Ca on growth temperature (Nürnberg *et al.*, 1996; Lea, 1999).

Rosenthal *et al.* (1997) highlighted that the genus *Uvigerina* showed a “puzzling” chemical composition respect to all the other species, usually utilized in this kind of studies. The authors explained this difference as the reflection of biological processes on calcification and chemical assumption in foraminiferal tests. Moreover Lear *et al.* (2002) showed as *Uvigerina* spp. tests exhibited a lower sensitivity of the 6% per °C to the temperature.

In this study the application of the relationship between Temperature and Mg in foraminiferal tests (6) highlighted how *U. mediterranea* tests were lower sensitive towards temperature regards than 25% per °C (tab. 3.7). This particularly high $[Mg/Ca]_{forams}$ ratio was in accordance with Ferguson *et al.*, (2008) who have suggested to attribute an important role to salinity in Mg-inclusion within foraminiferal test, because of the higher salinity values that Mediterranean Sea shows than the oceans ones.

Conclusions

Benthic forams are often used as bioindicators of environmental stress and pollution, due to their sensitivity to environmental variables. This study aims to detect benthic foraminiferal assemblages in the Sicily Channel and to verify the possibility to apply them as bio-indicators for marine bottoms.

The first result of this study was the creation of the preliminary *Atlas of Benthic Foraminifera in the Siclily Channel*, as useful taxonomical instrument for further studies on benthic foraminiferal communities in the Sicily Channel, included that focused on the bioindication.

Species more abundant than 5% were described, and a map of distribution within the study area was made for each of these species, accompained by their own SEM photos.

A total of 8 Orders, 30 Superfamilies, 55 Families, 92 Genera and 189 Species of forams were found in the Sicily Channel.

Rotalidae was the most abundant Family in all the sampling area; along the coastal stations, *Rectuvigerina phlegery, Nonionella turgida* and *Bulimina elongata* presented a wide distribution among the living species, while *Bulimina aculeata, Bulimina marginata* and *Cassidulina carinata* are the most abundant species among the offshore thanatocenosis in the Sicily Channel.

It will be necessary to improve this Atlas with further sampling, also adding more ecological as well as ecotoxicological informations relatively to each species.

It was also investigated the applicability of a morphometric method which - compared to a simple morphological description – could classify and identify benthic forams in a more objective way: to achieve this objective three species belonging to the genus *Bolivina* were chosen as simple morphological models, because of their abundance in the samples, the flat morphology and the bilateral symmetry of their tests. This analysis showed that the morphometric parameters better classifying the three species were principally the Length/Width ratio, Perimeter/Width, Perimeter/Length ratio and the Bottom angle.

The selected morphometric parameters were performed only on “bolivinids morphology” - test biserial, elongate, ovoid to triangular in outline, somewhat compressed (Loeblich and Tappan, 1988) - and the use of morphometry as a classification instrument required the synergic application of more morphometric parameters to give reliable results. This implied that morphometric analysis could not operate a irrefutable classification of the species, but could only represent a supporting tool for the morphological classification.

It was tested the possibility to use benthic forams as bio-indicators, according to the literature already present, asking how and whether different concentrations of heavy metals in the top sediment could affect their assemblages.

The study of living coastal assemblages of benthic forams has shown the strong influence of the grain-size and TOC factors on their distribution. In fact in presence of muddy sediment, rich in organic matter, shallow-infaunal to infaunal species dominate the assemblage, while on the contrary epifaunal species tend to increase with the increase of sandy fraction. Values and variation of oceanographic parameters such as temperature, dissolved oxygen and salinity did not seem however to determine significant changes in benthic foraminiferal distribution. In addition, at stations enriched in heavy metals, such as As, Cd, Cr, and in surrounding areas, there was a noticeable variation in the assemblages, with a strong decrease or even disappearance of sensitive species - such as *R. phlegeri* - and an increase of tolerant species - such as *Elphidium poeyanum,* miliolids forms and *Haynesina depressula*.

Living benthic forams seemed thus to respond to environmental stress as well as heavy metals pollution; however, the correlation between heavy metals and the silt and clay fractions of sediment made it difficult to determine whether sediment characteristics or pollution effects had the strongest influence on the forams assemblages.

The environmental complexity often makes it difficult to find a clear relationships between biotic and abiotic compartments; in this case some relationship seem to be evident (e.g. Cd influence on living benthic forams), but it may be useful to develop this topic making comparative studies on both laboratory cultures and sampling in the field, to bring more clear evidences.

The benthic forams thanatocenosis of the open sea within the Sicily Channel showed a natural environment generally unpolluted, in which the species were distributed principally in response to the bathymetry. Including heavy metals in the tests of the shallow-infaunal species *Uvigerina mediterranea*, selected because of its frequent use in this type of analysis and of its abundance in the Sicily Channel, it has been shown that Cd values were considerably higher than the reference value for the tests, as well as its Partition Coefficient ($D_{Cd(forams/water)}$). This was probably due to high concentration of Cd in pore water.

Finally the estimation of bottom temperature through the Mg analysis in *U. mediterranea* tests showed higher temperature range than the measured one, highlighting that temperature was not the only parameter influencing the Mg inclusion in foraminiferal tests in the Sicily Channel. This result should confirm Ferguson's hypothesis about the implication of both salinity and temperature effects, on the inclusion of this element in foraminiferal tests: in fact Sicily Channel is characterized by high salinity values, particularly in the deepest areas, where the deeper Levantine Intermediate Water (LIW), colder and saltier takes the place of the shallow AIS current (warmer and less salty, coming from the Atlantic Ocean).

The analysis relative to the inclusion of trace elements in tests of forams from the Sicly Channel appear to be too approssimative at the moment, to be applied as instrument providing any punctual data, excepted average values.

However it could be interesting to deeply investigate the effects of salinity on the Mg inclusion in foraminiferal tests, and the importance of pore water on the geochemistry of benthic foraminiferal shells in the Sicily Channel.

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APPENDIX I

1.2 Morphometric analysis of the shell in the genus Bolivina from the Gulf of Gela (Sicily Channel): a valid classification instrument?

1.2.1 INTRODUCTION

The paleontological application of benthic foraminifera, since their discovery, has determined the succession of classifications, starting from the once of Alcide d'Orbigny (1826), until that proposed by Loeblick and Tappan (1992), all based on morphological features of the shells. The use of morphometric techniques applied to the shells of forams found wide use in science, especially in the field of Paleoecology, Paleoceanography (Coccioni *et al.,* 2005), Paleobiology (Wade *et al.,* 2007), Palaeobiogeography (Parker *et al.,* 1999) and Paleobathymetry (Spencer, 1996).

The morphometry is the study of geometrical variations of the organisms morphology. It consists of a metric analysis, aimed at the quantification of the shell's shape. In the case of foraminifera, it concerns the variations in size and shape of the shell, through which there can be determinated interspecies identifying characteristics. There are several methods for extracting data using image analysis: these methods include the measurement of lengths and angles, and the analysis of the structure. The use of morphometric techniques allows to add a quantitative element to the description, conferring more rigorous comparison that is no longer based only on a subjective interpretation of the individuals morphology but also on the numerical comparison of the form's measurement thus allowing a description as objective as possible. Moreover, the use of morphological classifications often involves several difficulties in the assignment of a specimen to a species, highlighting how the taxonomic classification of forams is a complex task. For this reason, over the past decade, many studies have supported the morphological classification with the morphometric analysis of the shell and/or the genetic DNA sequencing, giving more certainty to the forams classification.

The objective of this study was to explore the reliability of the morphometric analysis, as technique for the taxonomic classification (up to the species level), by examining the benthic forams genus *Bolivina* (d'Orbigny, 1843), very common in the Sicily Channel.

1.2.2 STUDY AREA

Sampling has been carried out in the Gulf of Gela, along the northern coast of the Sicily Channel, geographically limited from Punta Braccetto to the east, and Licata to the west (Fig. 1.2.1). The Gulf takes its name from the town that faces on it, and represent the largest bay of Sicily, with a coastline of about 70 km. The bottom reaches a depth of -250m at about 20 miles from the coast and is characterized by a sandy-silt grain-size, where the sand component is completely replaced by silt and clay at a depth of about -50 meters (tab. 1.2.1) (Musco *et al.*, 2009).

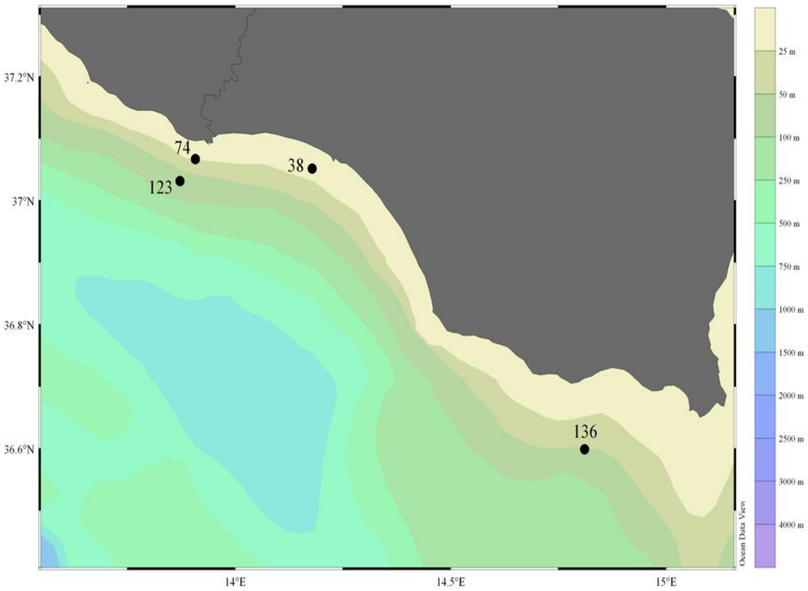


Figure 1.2.1. Sampling sites located in the Gulf of Gela

Table 1.2.1. Result of granulometric analysis in the investigated stations.

Station	Section	% Clay	% Silt	% Sand	Weight (g) d>500µm	Weight (g) d<500µm	Total Weight (g)	% Fraction d>500µm	Granulometric classification
38	0-5	16,73	49,14	34,13					sandy-silt
74	0-5	14,48	36,00	49,02	1,96	110,08	112,04	1,7	silty-sand
123	0-5	34,40	65,60						clayey-silt
136	0-5	34,65	65,35						clayey-silt

Coastal areas are also characterized by the abundance of macrophyte organisms (*eg. Posidonia oceanica)* and algal mats.

1.2.3 MATERIALS AND METHODS

Sediment samples were collected during the summer 2006 by box-corer in four stations located in the Gulf of Gela (Sicily Channel, Italy), where *Bolivina* genus was well represented.

Table 1.2..2. Location and bathymetry of sample stations

Station	Latitude	Longitude	Depth (m)
38	37° 02’ 79"	14° 10’ 75"	-10,2
74	37° 04' 00"	13° 54' 45"	-23,7
123	37° 01' 86"	13° 52' 50"	-52,8
136	36° 35' 87"	14° 48' 76"	-84,3

The first 2 cm of sediment, taken from a small PVC tube of 25 cm x 63 mm Ø, were used to identify and pick the specimens of *Bolivina*.

Samples were washed through a 63 micrometers mesh and then dried at 50 °C. Dry sediment was sieved again with a 125 µm mesh, to be sure that only adult forms will be counted.

Loeblick and Tappan (1992) classification and the publication of Parker *et al.* (1999) were used to morphologically referred the individuals to three species of the *Bolivina* genus, chosen for their marked differences: *B. alata, B.dilatata* and *B. catanensis*.

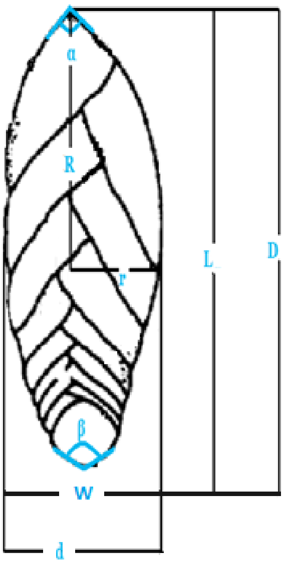
All specimens were photographed in their frontal projection, using an optical microscope (Leica MZ16, highest optical magnification of 11,5X) and then measured through the software *Image-Pro Plus 6.0* (Image Cybernetics, Roper Industries, USA, image analysis and processing). Selected morphometric parameters are listed in the table 1.2.3 and described in the Fig. 1.2.2. They were selected according to Parker *et al.* (1999) and from measures provided by the software *Image-Pro Plus* 6.0 and grouped into three classes: linear values, angular values, and their ratios.

Table 1.2.3 and Figure 1.2.2. Morphometric parameters

L	size lenght
W	size width
P	perimeter
R	larger radius
r	minor radius
D	larger diameter
d	minor diameter

A	aspect (**L/W**)
P/Lu	perimeter/lenght
P/La	perimeter/width
R/r	radius ratio
D/d	diameter ratio
α/β	angular ratio

α	apical angle
β	first chamber side angle

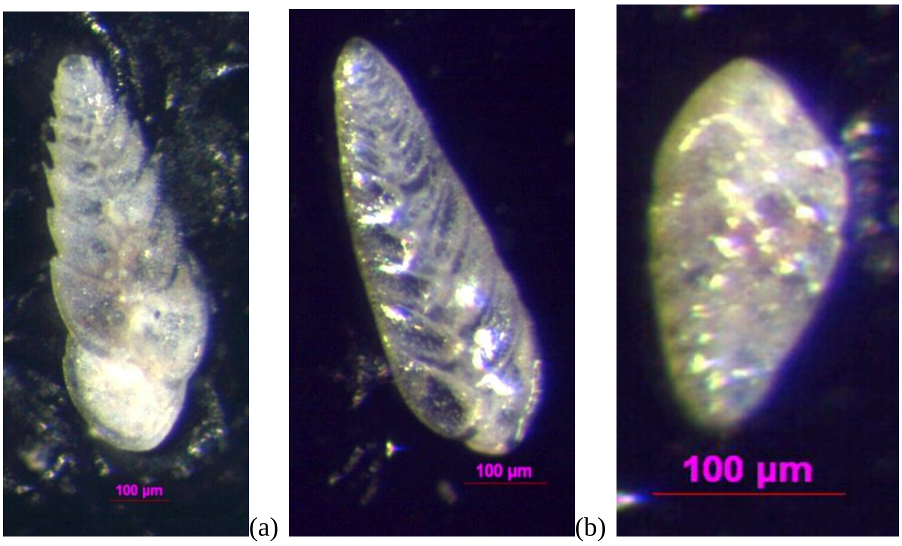


Differences in morphometric characters were tested through the statistical analysis performed with the software *Statistica 8*.0 on a standardized dataset. For each parameter the Kruskal-Wallis (1952) nonparametric test was used to detect the significance of differences between species, and even the Discriminant Analysis for each group of parameters (ratios - angular sizes - linear values), in order to identify the parameters that better discriminate the species.

As the Discriminant analysis was completed, for each group it was built a matrix structure, which created a number of Roots (linear combination of variables according to groups) equal to the number of groups -1. On these "roots" it was drawn up a Scatterplot, created in order to show which set of parameters reported a greater separation between the species.

1.2.4 RESULTS AND DISCUSSION

140 specimens were separated and referred to the 3 distinct species *B. alata*, *B. catanensis* and *B. dilatata* (Fig. 1.2.3).



(a) (b) (c)

Figure 1.2.3. Specimens of the four species: (a) *Bolivina alata*, (b) *B. catanensis*, and (c) *B. dilatata*

The box plots constructed for the Aspect (L/W), the diameter ratio (D/d), the radius ratios (R/r) and the perimeter/width ratio (P/W) showed a similar trend, comparing the three species in the four graphs. The species *B. catanensis* was found to have higher values and a wider range than the species *B. alata*, which appears to have higher values and a wider range than the species *B. dilatata*. In addition, the range of each species were quite distinct from each other, except between *B. catanensis* and *B. alata* for the parameter (P/W) (Figg. 1.2.4, 1.2.5, 1.2.6 and 1.2.7).

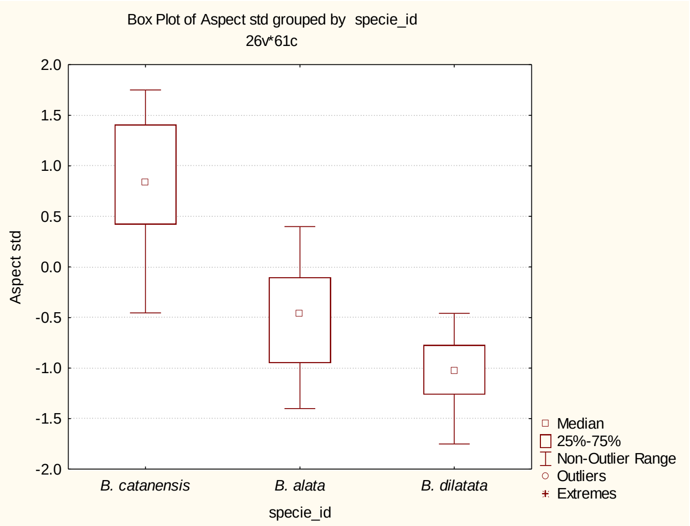


Figure 1.2.4. Aspect (L/W)

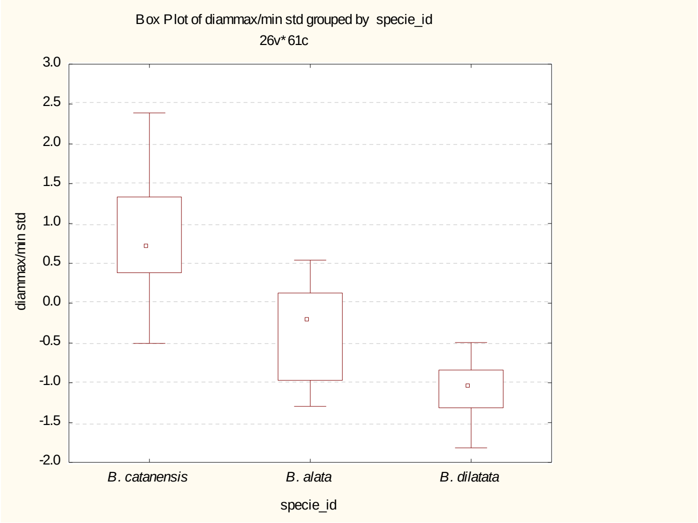


Figure 1.2.5. Diameter ratio (D/d)

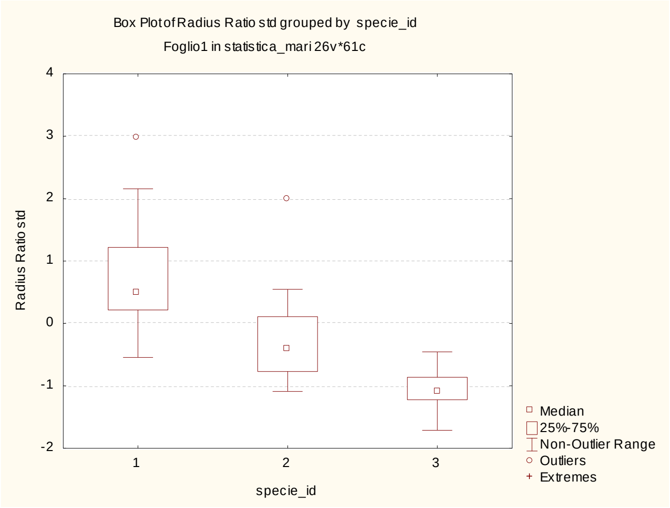


Figure 1.2.6. Radius ratio (R/r)

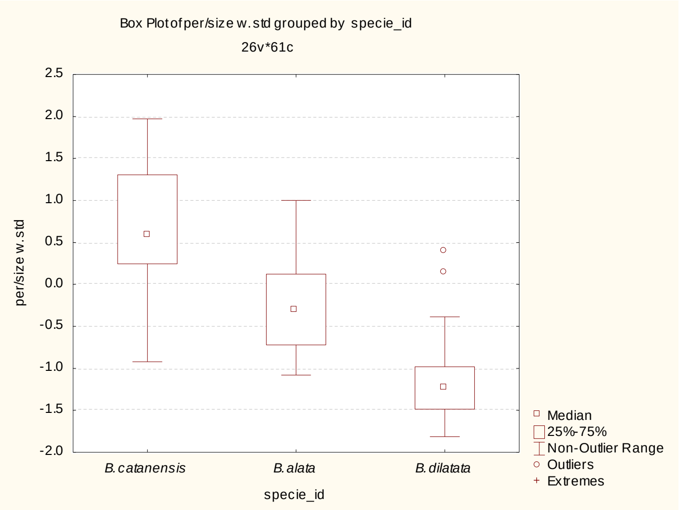


Figure 1.2.7. Perimeter/Width (P/W)

In the box plots of the Perimeter (P), the species *B. dilatata* appears to have the narrower range of values than the other two species, followed by *B. alata*, which presented the highest values, and at last *B. catanensis*, with the lowest values. The dimensional range of individuals of the species *B. dilatata* and *B. alata* both fall within that of the species *B. catanensis*, indicating a difficult recognition between these species by this parameter (Fig. 1.2.8).

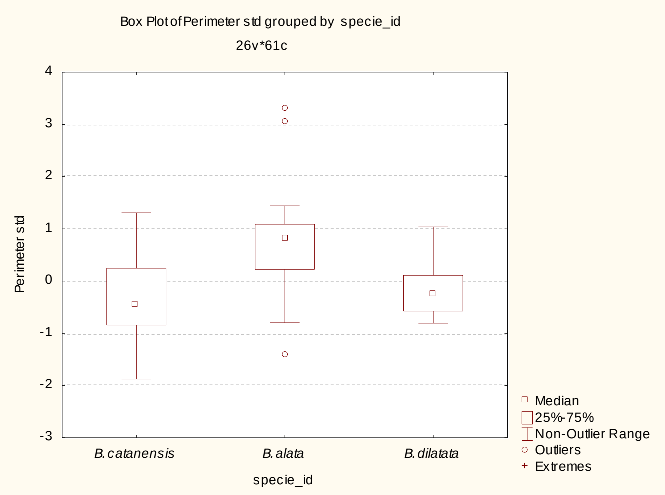


Figure 1.2.8. Perimeter (P)

Unlike the perimeter (P), for the Width (W) only the range of the species *B. dilatata* falls largely within the range of *B. alata*, while the ranges of both differ considerably from that of *B. catanensis*. As regards the extent of range, however, it was found an increase in the dispersion of values from *B. dilatata* to *B. catanensis*, as was previously noted for the Perimeter (Fig. 1.2.9).

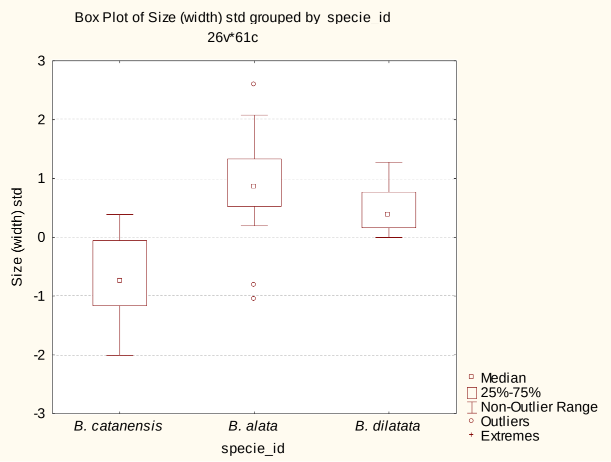


Figure 1.2.9. Width (W)

In the box plots for the Perimeter/Length ratio (P/L) the wider range was that of *B. alata*, which included within it the all values of the species *B. dilatata*, and only in part those of *B. catanensis*. Regard to this parameter, *B. catanensis* presented the smaller and better differentiated range among the three species (Fig. 1.2.10).

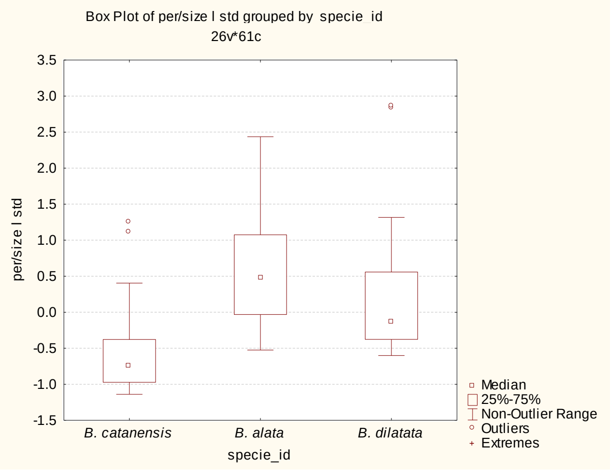


Figure 1.2.10. Perimeter/Lenght (P/L)

The box plots for the two angles (bottom angle β and upper angle α) have different ranges for each species: in the first box plot the range wideness decreases from *B. alata* to the *B. catanensis*, while in the second box plot it decreases from *B. catanensis* to *B. alata*. In both graphs, *B. alata* presents the lowest values, followed by *B. catanensis* and finally by *B. dilatata*. It is important to note that, for the upper angle (α), the ranges of species *B. alata* and *B. dilatata* were mostly overlapped, and both included within the range of *B. catanensis*, making this parameter not functional in distinguishing between species. A similar consideration may be partially made up for the bottom angle (β), in relation to which the ranges of the species *B. catanensis* and *B. dilatata* fall within that of *B. catanensis* (Fig. 1.2.11 and 1.2.12).

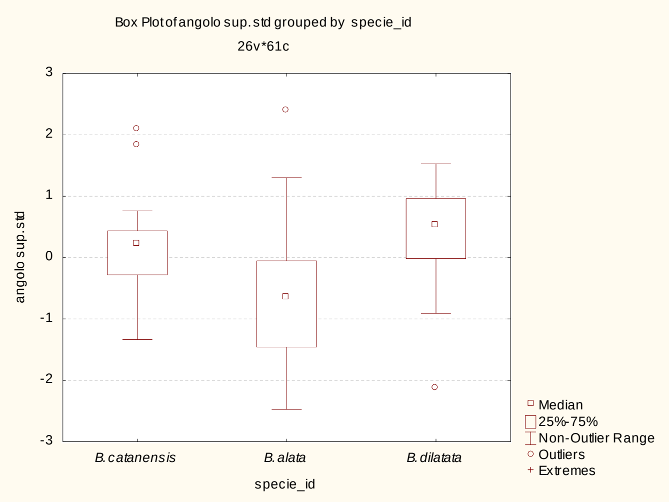


Figure 1.2.11. Bottom angle (β)

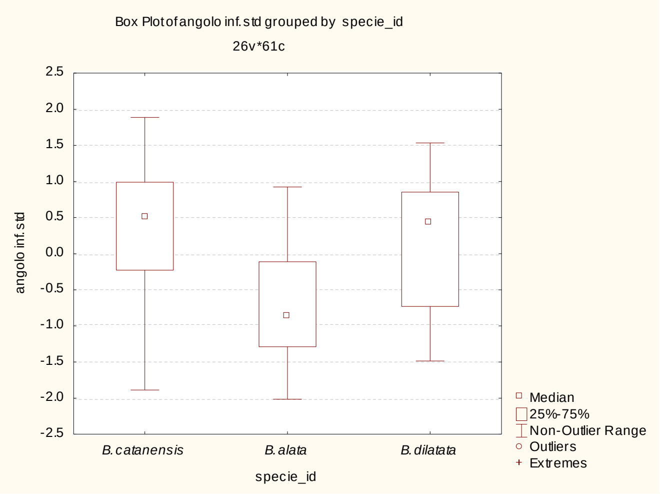


Figure 1.2.12. Upper angle (α)

The values and ranges of the three species, in relation to the angles ratio (α/β) and Length (L) appeared, once again, to be overlapped, although maintaining a difference in the wideness of the range, going from the lower dispersion of the values within *B. dilatata* to the greater dispersion of the values of *B. catanensis* (Figg. 1.2.13 and 1.2.14).

These measures do not seem useful as parameters discriminating the three species.

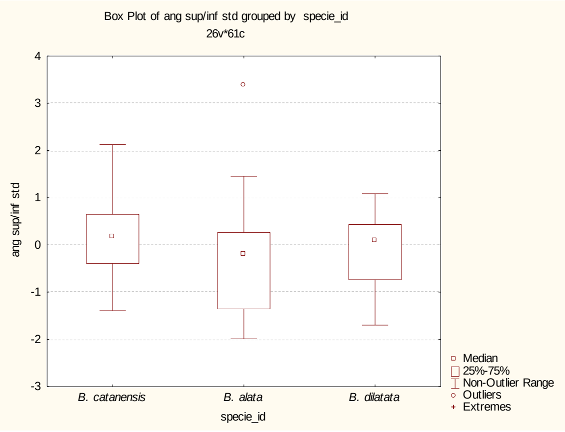


Figure 1.2.13. Angles ratio (α/β)

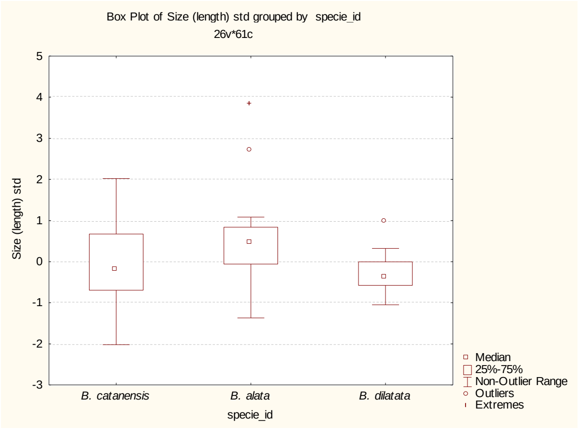


Figure 1.2.14. Lenght (L)

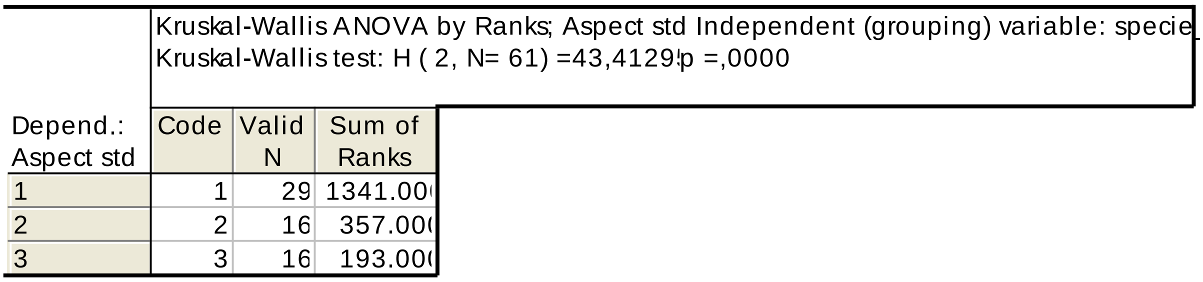
From the total Box plots analysis it seemed to emerge that the most distinctive values for the three species were: the Aspect (A), the Diameter ratio (D/d), the Radius ratio (R/r) and finally the Perimeter/Width ratio (P/W), these follow the width (W) and the Perimeter/Length ratio (P/L).

This Box plots analysis has largely been confirmed by the nonparametric Kruskal-Wallis test applied to each parameter relatively to the three species.

The p-values analysis highlighted that the parameters for which the species were significantly different among them were: Aspect (A), the Perimeter/Width ratio (P/W), the Diameter ratio (D/d), the Radius ratio (R/r), the Width (W), the Perimeter/Length ratio (P/L), the Bottom angle (β), the Perimeter (P) and the Upper angle (α) (tables from 1.2.4 to 1.2.12).

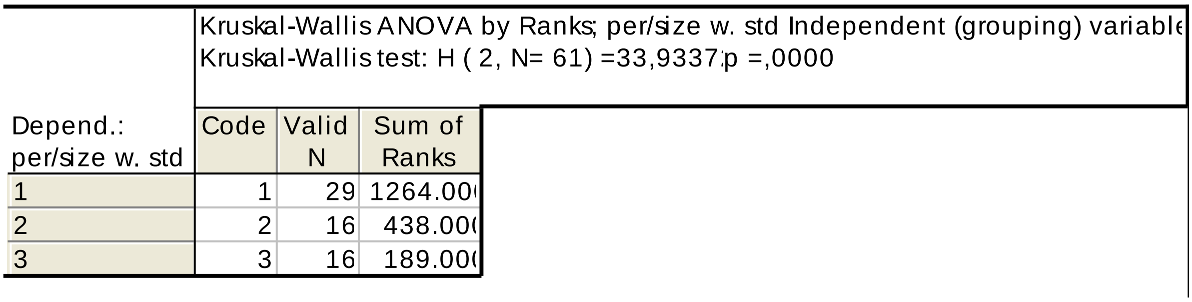
Although from the box plots analysis these last three measures (β, P and α) were found not usable to differentiate each other the three species, they had p-values slightly higher than those of the other parameters listed above, but still well below the threshold value ($p < 0.05$).

Table 1.2.4. Non parametric test of Kruskal-Wallis – Aspect (A)


Kruskal-Wallis ANOVA by Ranks; Aspect std Independent (grouping) variable: specie
Kruskal-Wallis test: H (2, N= 61) =43,4129 p =,0000

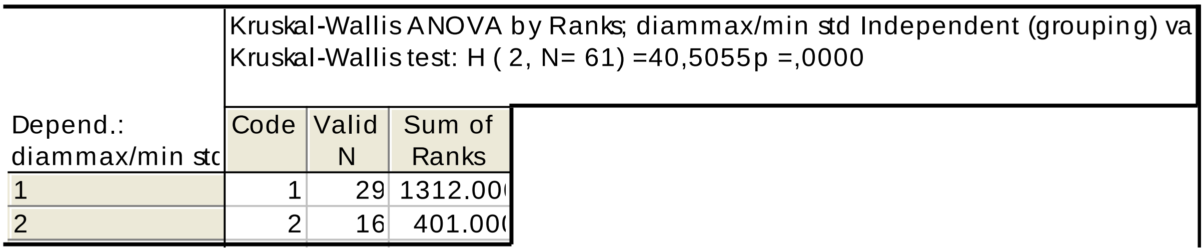
Depend.: Aspect std	Code	Valid N	Sum of Ranks
1	1	29	1341.00
2	2	16	357.00
3	3	16	193.00

Table 1.2.5. Non parametric test of Kruskal-Wallis – Perimeter/Length (P/L)


Kruskal-Wallis ANOVA by Ranks; per/size w. std Independent (grouping) variable
Kruskal-Wallis test: H (2, N= 61) =33,9337 p =,0000

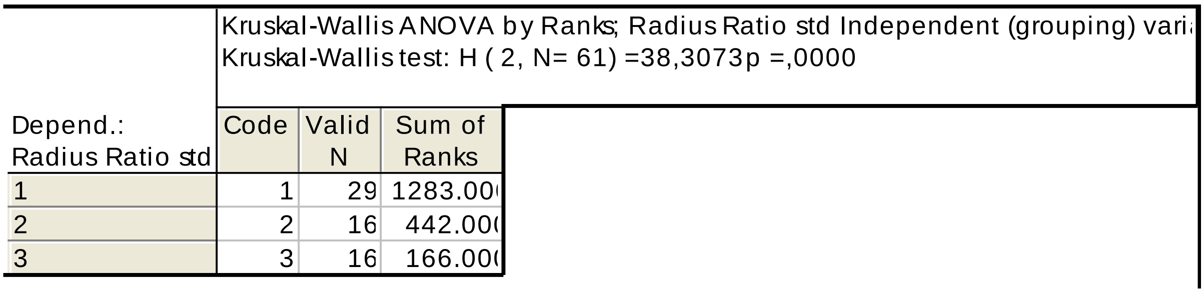
Depend.: per/size w. std	Code	Valid N	Sum of Ranks
1	1	29	1264.00
2	2	16	438.00
3	3	16	189.00

Table 1.2.6. Non parametric test of Kruskal-Wallis – Diameter ratio (D/d)


Kruskal-Wallis ANOVA by Ranks; diammax/min std Independent (grouping) va
Kruskal-Wallis test: H (2, N= 61) =40,5055 p =,0000

Depend.: diammax/min std	Code	Valid N	Sum of Ranks
1	1	29	1312.00
2	2	16	401.00

Table 1.2.7. Non parametric test of Kruskal-Wallis – Radius ratio (R/r)


Kruskal-Wallis ANOVA by Ranks; Radius Ratio std Independent (grouping) vari
Kruskal-Wallis test: H (2, N= 61) =38,3073 p =,0000

Depend.: Radius Ratio std	Code	Valid N	Sum of Ranks
1	1	29	1283.00
2	2	16	442.00
3	3	16	166.00

Table 1.2.8. Non parametric test of Kruskal-Wallis – Width (La)

	Kruskal-Wallis ANOVA by Ranks; Size (width) std Independent (grouping) variab Kruskal-Wallis test: H (2, N= 61) =33,6345 p =,0000		
Depend.: Size (width) std	Code	Valid N	Sum of Ranks
1	1	29	504.000
2	2	16	746.000
3	3	16	641.000

Table 1.2.9. Non parametric test of Kruskal-Wallis – Perimeter/Length ratio (P/Lu)

	Kruskal-Wallis ANOVA by Ranks; per/size l std Independent (grouping) variable: s Kruskal-Wallis test: H (2, N= 61) =23,4328 p =,0000		
Depend.: per/size l std	Code	Valid N	Sum of Ranks
1	1	29	570.000
2	2	16	707.000
3	3	16	614.000

Table 1.2.10. Non parametric test of Kruskal-Wallis – Bottom Angle (β)

	Kruskal-Wallis ANOVA by Ranks; angolo inf. std Independent (grouping) variabl Kruskal-Wallis test: H (2, N= 61) =10,8819 p =,0043		
Depend.: angolo inf. st	Code	Valid N	Sum of Ranks
1	1	29	1060.00
2	2	16	298.00
3	3	16	533.00

Table 1.2.11. Non parametric test of Kruskal-Wallis – Perimeter (P)

	Kruskal-Wallis ANOVA by Ranks; Perimeter std Independent (grouping) variable: Kruskal-Wallis test: H (2, N= 61) =12,5588 p =,0019		
Depend.: Perimeter std	Code	Valid N	Sum of Ranks
1	1	29	723.000
2	2	16	708.000
3	3	16	460.000

Table 1.2.12. Non parametric test of Kruskal-Wallis – Upper Angle (α)

Kruskal-Wallis ANOVA by Ranks; angolo sup. std Independent (grouping) variab
Kruskal-Wallis test: H (2, N= 61) =10,4756 p =,0053

Depend.: angolo sup. std	Code	Valid N	Sum of Ranks
1	1	29	942.000
2	2	16	315.000
3	3	16	634.000

Again according to the analysis of box plots, the Kruskal-Wallis test highlighted how the parameters the Angles ratio (α/β) and Length (L) showed no significant difference among the species (tab.1.2.13 and 1.2.14).

Table 1.2.13. Non parametric test of Kruskal-Wallis – Angle ratio (α/β)

Kruskal-Wallis ANOVA by Ranks; ang sup/inf std Independent (grouping) variabl
Kruskal-Wallis test: H (2, N= 61) =3,39976 p =0,1827

Depend.: ang sup/inf std	Code	Valid N	Sum of Ranks
1	1	29	1009.00
2	2	16	394.00
3	3	16	488.00

Table 1.2.14. Non parametric test of Kruskal-Wallis – Lenght (L)

Kruskal-Wallis ANOVA by Ranks; Size (length) std Independent (grouping) vari
Kruskal-Wallis test: H (2, N= 61) =5,53164 p =,0629

Depend.: Size (length) std	Code	Valid N	Sum of Ranks
1	1	29	854.000
2	2	16	632.000
3	3	16	405.000

The processing of box plots and non-parametric Kruskal-Wallis test for each parameter, only informed on parameter qualities as a distinctive element among species, but could not compared its qualities to the other parameters.

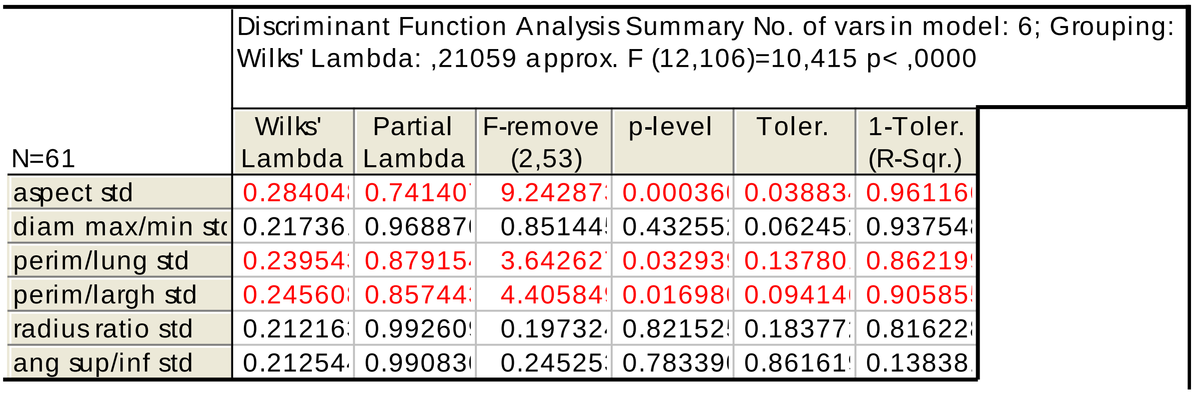
To obtain this information it was necessary to perform the Discriminant analysis of the parameters. Discriminant analysis performed on the three different group of parameters (linear values, angular values and ratios) showed that the parameters which better discriminated the three species for each group, were:

1) Aspect (A), Perimeter/Width ratio (P/W), Perimeter/Length ratio (P/L) (tab. 1.2.15);

2) Bottom Angle (β) (tab. 1.2.16);

3) Width (W) and Length (L) (tab. 1.2.17).

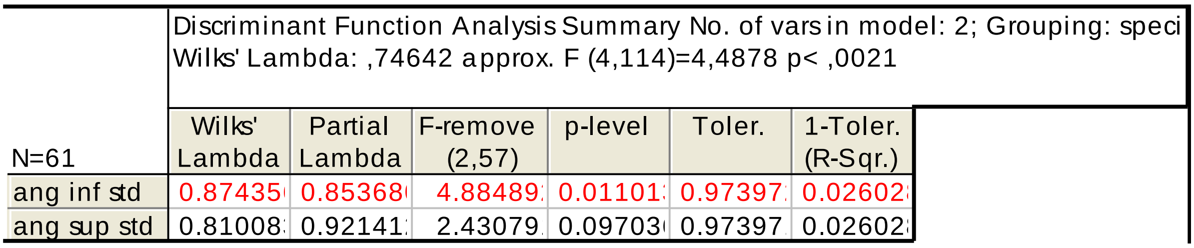
Table 1.2.15. Discriminant analysis “Ratios”



Discriminant Function Analysis Summary No. of vars in model: 6; Grouping:
Wilks' Lambda: ,21059 approx. F (12,106)=10,415 p< ,0000

N=61	Wilks' Lambda	Partial Lambda	F-remove (2,53)	p-level	Toler.	1-Toler. (R-Sqr.)
aspect std	0.28404	0.74140	9.24287	0.00036	0.03883	0.96116
diam max/min st	0.21736	0.96887	0.85144	0.43255	0.06245	0.93754
perim/lung std	0.23954	0.87915	3.64262	0.03293	0.13780	0.86219
perim/largh std	0.24560	0.85744	4.40584	0.01698	0.09414	0.90585
radius ratio std	0.21216	0.99260	0.19732	0.82152	0.18377	0.81622
ang sup/inf std	0.21254	0.99083	0.24525	0.78339	0.86161	0.13838

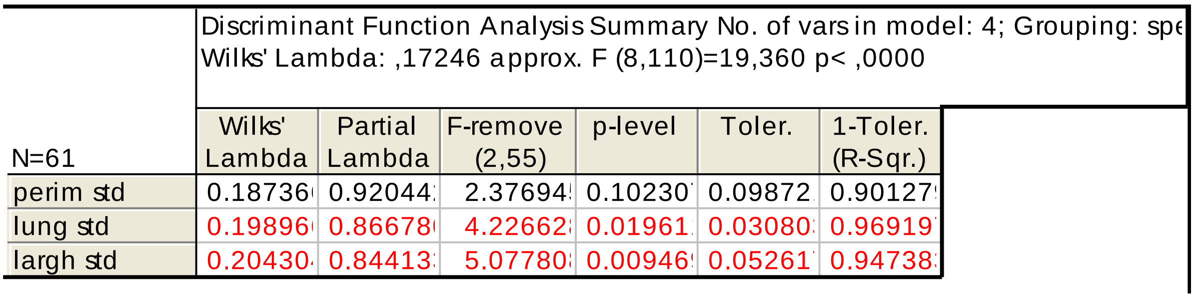
Table 1.2.16. Discriminant analysis “Angolar values”



Discriminant Function Analysis Summary No. of vars in model: 2; Grouping: speci
Wilks' Lambda: ,74642 approx. F (4,114)=4,4878 p< ,0021

N=61	Wilks' Lambda	Partial Lambda	F-remove (2,57)	p-level	Toler.	1-Toler. (R-Sqr.)
ang inf std	0.87435	0.85368	4.88489	0.01101	0.97397	0.02602
ang sup std	0.81008	0.92141	2.43079	0.09703	0.97397	0.02602

Table 1.2.17. Discriminant analysis “Linear values”



Discriminant Function Analysis Summary No. of vars in model: 4; Grouping: spe
Wilks' Lambda: ,17246 approx. F (8,110)=19,360 p< ,0000

N=61	Wilks' Lambda	Partial Lambda	F-remove (2,55)	p-level	Toler.	1-Toler. (R-Sqr.)
perim std	0.18736	0.92044	2.37694	0.10230	0.09872	0.90127
lung std	0.19896	0.86678	4.22662	0.01961	0.03080	0.96919
largh std	0.20430	0.84413	5.07780	0.00946	0.05261	0.94738

Based on the parameters selected and highlighted from the discriminant analysis has been built an Structure Matrix, from whose Roots were obtained respectively three Scatterplots (scatter diagrams).

From the Scatterplot constructed on the group "Ratios", *B. alata* and *B. dilatata* showed different behavior than *B. catanensis* relatively to the two Roots: *B. catanensis* had two both a slightly negative and slightly positive correlation with Root2 and more positive with Root1; both the *B. alata* and *B. dilatata* had a negative correlation with the Root1, *B. alata* had a prevalent positive correlation with the Root2, while *B. dilatata* has a prevalent negative correlation with the Root2. For these parameters there seemed to be a good distinction between the *B. catanensis* and the other two species, and a lighter difference between the other two species in regard to their way to correlate with the two Roots (Fig. 1.2.15).

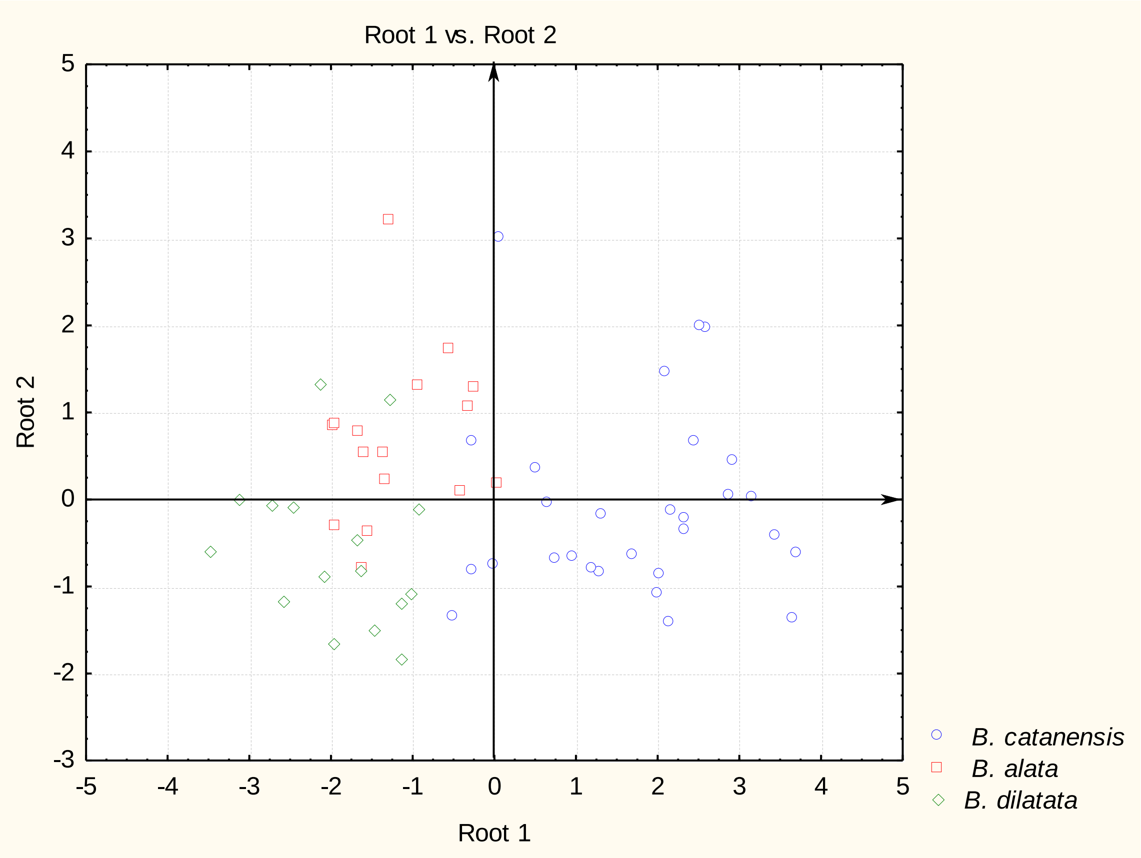


Figure 1.2.15. Scatter diagram – “Ratios”

In the Scatterplots relative to the two angles (α and β) the three species showed an almost similar behaviour: they all had a negative and positive fairly mild correlation with to both the Roots, which made it difficult to use these two parameters as distinctive elements of one or another species (Fig. 1.2.16).

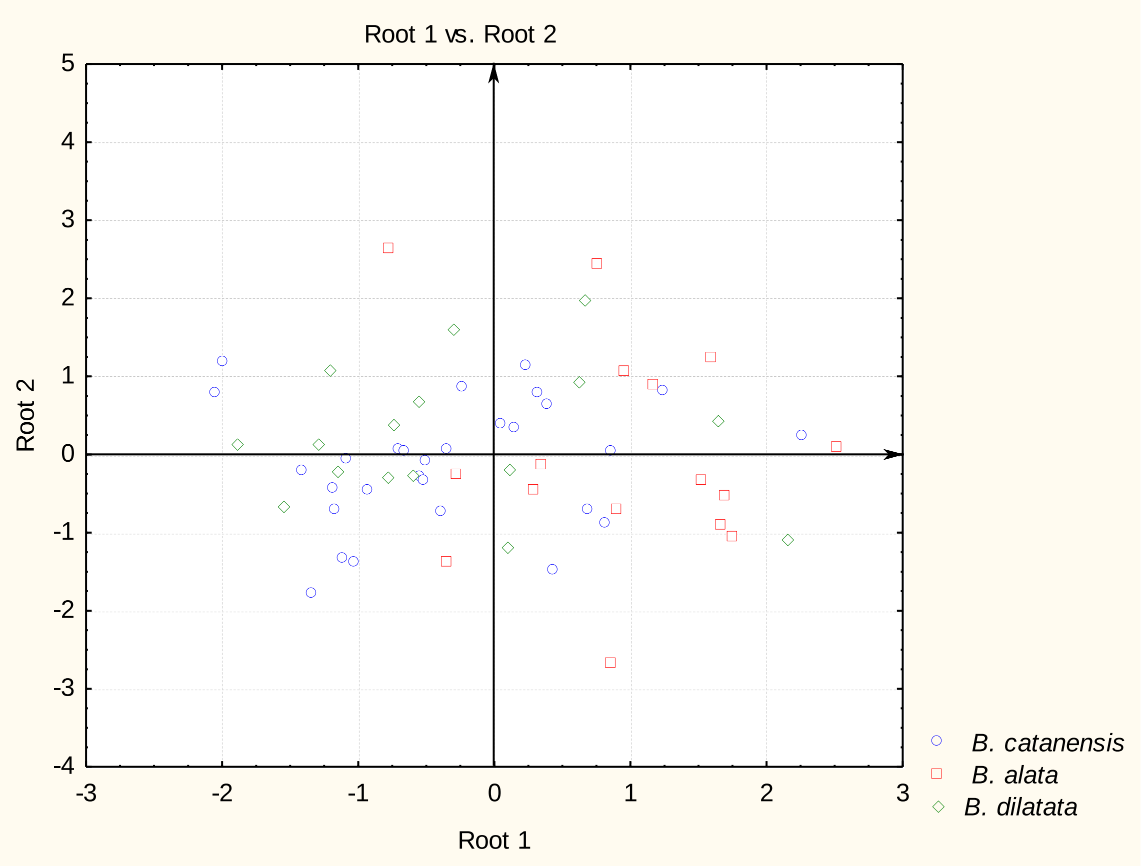


Figure 1.2.16. Scatter diagram – “Angles”

Scatterplot of the "Linear values" (Fig. 1.2.17) showed that the behavior of the three species is quite different relatively to the two Roots: *B. catanensis* showed a negative correlation with the Root1, *B. alata* showed a mainly positive correlation with the Root1 and mainly negative with the Root2, while *B. dilatata* had a significantly positive correlation with the Root1 and more positive with the Root2. Even for these parameters, such as for those belonging to the "Ratios" group, there seemed to be a good distinction between the species, regarding the way they are related to the two Root, even if the clouds of data distribution (specimens of each species), depending to the two Roots, were more dispersed than in figure 1.2.15 (grouping “Ratios”).

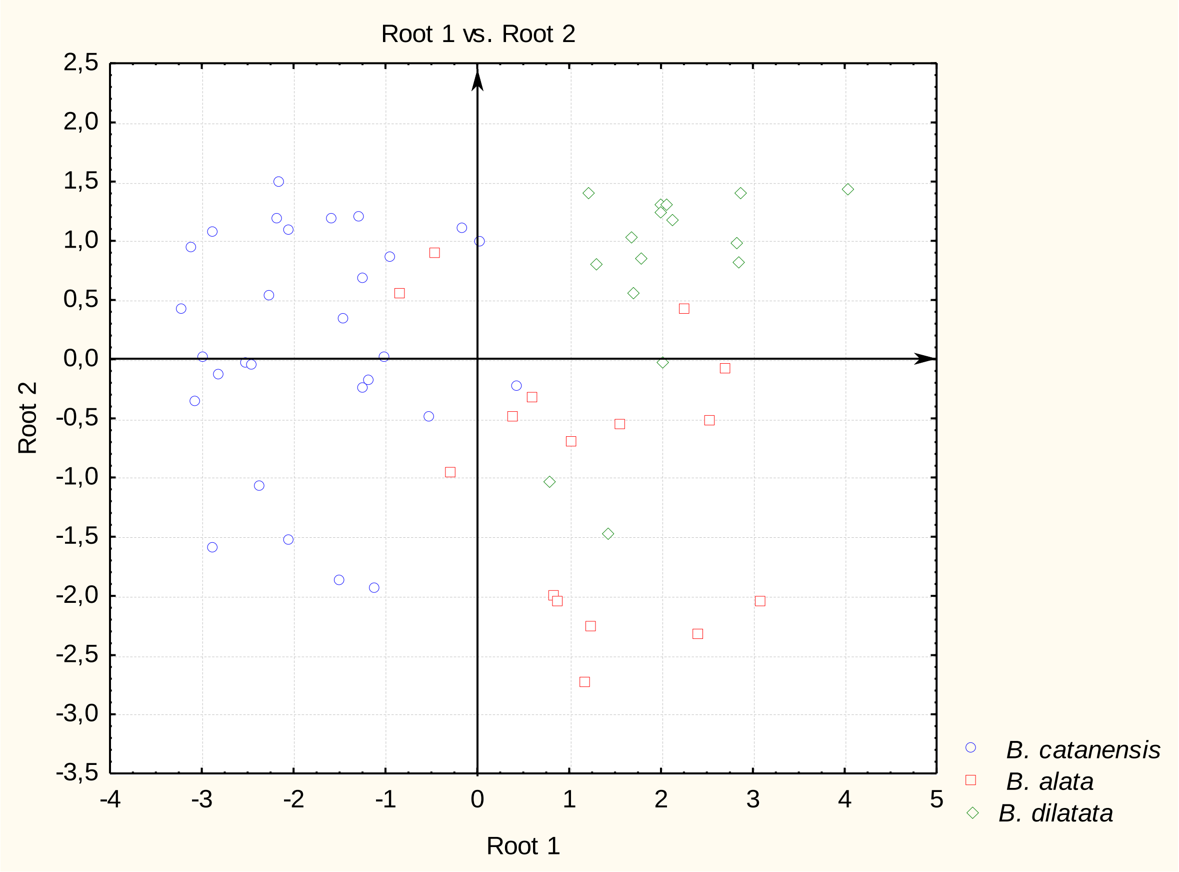


Figure 1.2.17. Scatter diagram – “Linear values”

1.2.5 CONCLUSIONS

The comparison between the different tests (Kruskal-Wallis, Discriminant Analysis) and graphs (box plots and Scatterplots) showed that the morphometric characters that better classify the three species were principally found within the grouping "Ratios", and in particular were: the Aspect (**L/W**), the Perimeter/Width ratio (**P/W**) and the Perimeter/Length ratio (**P/L**), followed by the size Width (**W**), the Radius ratio (**R/r**) and the Diameter ratio (D/d), and, at last, the Bottom angle (β).

On the contrary, the Upper angle (α), the Angles ratio (α/β), the Length (L) and the Perimeter (P), could not be considered as discriminating the three species of the genus *Bolivina*.

The morphometric analysis has revealed to be not perfectly precise if used as the only one instrument for the classification of the studied species of *Bolivina*, but very useful if coupled with morphological and/or genetic analysis (*e.g.* observation of ornamentation, etc ...).

The investigation of new or better morphometric parameters, applicable to different morphologies of foraminifera, should be oriented towards the analysis of shell proportions rather than linear or angular values, which showed to be more inadequate to this scope.

APPENDIX II

Table 2.8. Live benthic Forams from the southern Sicily coasts (continuing in the next page).

Taxa	108	64	67	70	71	74	38	81	83	42	45
Adelosina italica	0	0	0	0	0	0	0	0	0	0	1
Adelosina mediterranensis	0	0	0	0	0	0	0	0	0	1	0
Adelosina pulchella	0	0	0	0	0	0	0	0	0	0	2
Adelosina sp.	0	8	0	0	0	1	0	0	0	0	2
Ammobaculites agglutinans	0	5	8	0	0	0	0	0	20	0	0
Ammonia beccarii beccarii	0	2	0	0	0	10	0	0	0	3	0
Ammonia inflata	1	5	10	2	0	5	0	0	7	0	3
Ammonia parkinsoniana	0	0	0	0	0	6	0	0	0	0	0
Ammonia tepida	0	0	1	3	0	9	0	1	9	0	0
Ammoscalaria sp.	0	0	0	0	0	0	0	0	0	0	1
Amphicorina scalaris	0	1	0	0	0	0	0	0	0	0	4
Astacolus crepidulus	0	1	0	0	0	0	0	0	0	1	0
Asterigerinata mammilla	0	0	0	3	0	1	0	0	0	1	0
Astrononion stelligerum	0	0	0	1	0	0	0	0	0	0	0
Aubignyna perlucida	0	0	13	0	0	0	0	2	15	7	0
Bigenerina nodosaria	0	0	0	0	0	0	0	0	0	0	1
Biloculinella cylindrica	0	0	0	0	0	0	0	0	0	0	1
Biloculinella labiata	0	0	0	0	0	0	0	0	0	0	1
Bolivina attica	0	0	0	0	0	0	1	0	2	0	0
Bolivina catanensis	0	0	0	0	0	1	0	0	18	1	0
Bolivina subaenarensis	0	0	0	0	0	0	0	0	0	0	2
Buccella granulata	3	0	2	2	0	2	8	4	23	4	0
Bulimina aculeata	2	0	6	1	0	3	0	1	2	3	5
Bulimina denudata	0	0	2	0	0	0	0	0	0	0	0
Bulimina elongata	2	6	31	0	0	35	2	3	26	18	0
Bulimina marginata	0	0	1	0	0	0	0	0	0	0	0
Cancris auriculus	0	0	0	0	0	0	0	0	0	0	6
Cassidulina carinata	1	0	0	0	0	0	0	0	0	1	0
Cibicides lobatulus	0	2	0	0	0	0	0	0	0	0	0
Cribrostonoides subglobusum	0	0	0	1	0	0	0	0	0	0	0
Cribrostonoides sp.	0	0	0	1	0	0	0	0	0	0	0
Discammina sp.	0	1	0	0	0	0	0	0	0	0	0
Eggerelloides scaber	0	1	0	0	0	0	5	1	0	2	0
Elphidium crispum	0	2	2	0	1	0	0	0	6	0	0
Elphidium poeyanum	1	1	6	0	0	15	0	40	20	11	0
Elphidium granosum	0	0	0	2	0	5	0	5	6	2	0
Elphidium macellum	0	0	2	0	0	1	0	0	0	0	1
Elphidium sp.	0	0	0	1	0	0	0	0	0	0	0
Elphidium advenum	6	0	4	1	0	15	0	1	37	13	0
Florilus boueanum	9	1	27	6	0	6	0	0	48	5	8
Fursenkoina acuta	0	0	0	0	0	2	0	0	3	0	0
Gavelinopsis praegeri	1	0	1	4	0	1	0	0	1	1	0
Globobulimina affinis	0	0	0	0	0	0	0	0	0	0	2

Glomospira gordialis	0	1	0	0	0	0	0	0	0	0	0
Hanzawaia boueana	1	0	0	0	0	0	0	0	0	0	3
Haynesina depressula	0	0	0	0	1	2	13	0	0	0	0
Lagena laevis	0	1	0	0	0	0	0	0	0	0	0
Melonis barleanum	0	0	0	0	0	0	0	1	0	0	0
Miliolinella semicostata	0	0	0	0	0	0	0	0	0	0	1
Miliolinella subrotunda	0	0	0	0	1	0	0	0	0	0	1
Miliolinella sp.	0	0	0	0	0	0	0	0	0	0	3
Neoconorbina terquemi	0	0	0	0	0	0	2	0	0	0	1
Nonionella stelligera	0	0	0	0	0	4	0	0	0	0	0
Nonionella turgida	11	0	46	4	1	48	2	1	10	8	0
Nonionella sp.	1	0	0	0	0	0	0	0	0	0	0
Nonion sp.	0	0	0	2	0	0	0	0	1	0	0
Nouria polymorphinoides	0	1	0	0	0	0	0	0	0	0	0
Pseudoeponides falsobeccarii	0	0	0	0	0	0	0	0	0	0	1
Pullenia quinqueloba	0	0	0	0	0	0	0	0	2	0	0
Pyrulina sp.	0	1	0	0	0	0	0	0	0	0	0
Quinqueloculina agglutinans	0	0	0	0	2	0	0	0	0	0	0
Quinqueloculina bosciana	0	4	0	0	0	0	2	0	1	2	3
Quinqueloculina ferussacii	0	0	0	0	0	0	0	0	3	0	0
Quinqueloculina lamarkiana	0	0	0	0	0	0	0	0	0	1	0
Quinqueloculina lata	0	0	0	0	0	1	0	0	0	1	0
Quinqueloculina pygmaea	0	0	0	2	0	0	0	0	0	0	0
Quinqueloculina polygona	0	0	0	0	0	0	0	0	0	1	0
Quinqueloculina seminulum	0	0	0	0	0	0	0	0	2	6	2
Quinqueloculina sp.	0	0	0	0	1	0	0	0	0	0	0
Rectuvigerina phlegeri	10	30	51	11	0	6	0	0	30	1	16
Reussella spinulosa	0	0	4	0	0	0	0	0	7	1	0
Rosalina bradyi	0	4	0	2	0	0	0	0	0	3	0
Saidovina karreriana	0	0	0	0	0	0	0	0	1	2	0
Spiroloculina excavata	0	0	0	0	0	0	0	0	0	0	1
Spiroloculina lucida	0	0	0	1	0	0	0	0	0	0	0
Stainforthia complanata	0	0	0	0	0	1	0	0	0	0	0
Textularia agglutinans	1	11	9	5	0	13	0	1	11	2	3
Triloculina plicata	0	0	0	0	0	0	0	0	0	2	6
Triloculina rotunda	0	0	0	2	6	0	0	0	0	1	0
Triloculina tricarinata	0	0	0	0	0	0	0	0	0	0	2
Triloculina trigonula	1	0	0	1	1	0	0	1	0	1	6
Trochamminoides sp.	0	0	0	0	0	0	0	3	0	0	0
Uvigerina auberiana	0	0	0	1	0	0	0	0	0	0	0
Uvigerina costata	0	1	0	0	0	0	0	0	0	0	0
Uvigerina mediterranea	0	0	0	0	0	0	0	0	0	0	1
Uvigerina peregrina	0	0	0	0	0	0	0	0	0	0	1
Uvigerina sp.	0	0	0	0	0	0	0	0	0	0	1
Valvulineria bradyana	4	0	0	2	0	3	0	0	2	0	2
Total live individuals	55	90	226	61	14	196	35	65	313	106	94

Table 2.10. Correlation matrix of the granulometry, trace elements, species abundance and diversity indices (it continued in the following two pages).

	H'	**J**	**TFN**	**S**	Sand	Silt	Clay	TOC	As	Cd	Co	Cr	Cu	Fe	Mn	Ba	Ni	Pb	V	Zn	Hg
H'	1.00																				
J	0.64	1.00																			
TFN	0.40	-0.01	1.00																		
S	0.93	0.35	0.48	1.00																	
Sand	-0.24	0.37	-0.57	-0.36	1.00																
Silt	0.35	-0.31	0.58	0.47	-0.94	1.00															
Clay	0.08	-0.38	0.47	0.17	-0.92	0.73	1.00														
TOC	0.61	0.12	0.24	0.60	-0.76	0.81	0.58	1.00													
As	-0.57	0.14	-0.39	-0.68	0.84	-0.86	-0.69	-0.90	1.00												
Cd	-0.65	0.06	-0.43	-0.75	0.83	-0.85	-0.68	-0.90	0.98	1.00											
Co	-0.39	0.23	-0.41	-0.49	0.83	-0.89	-0.65	-0.81	0.88	0.88	1.00										
Cr	-0.43	0.14	-0.39	-0.51	0.70	-0.73	-0.56	-0.71	0.85	0.82	0.93	1.00									
Cu	0.75	0.08	0.35	0.85	-0.53	0.61	0.37	0.70	-0.82	-0.83	-0.58	-0.54	1.00								
Fe	-0.25	0.15	-0.36	-0.24	0.75	-0.75	-0.63	-0.70	0.66	0.61	0.58	0.41	-0.59	1.00							
Mn	-0.55	0.12	-0.44	-0.65	0.85	-0.88	-0.69	-0.90	0.99	0.97	0.94	0.90	-0.76	0.66	1.00						
Ba	-0.53	0.13	-0.42	-0.64	0.76	-0.80	-0.59	-0.80	0.95	0.91	0.92	0.95	-0.75	0.57	0.97	1.00					
Ni	-0.49	0.16	-0.43	-0.59	0.86	-0.88	-0.70	-0.87	0.96	0.95	0.95	0.93	-0.66	0.56	0.98	0.95	1.00				
Pb	-0.49	0.18	-0.49	-0.60	0.89	-0.93	-0.70	-0.88	0.96	0.92	0.88	0.81	-0.78	0.80	0.95	0.91	0.92	1.00			
V	-0.27	0.19	-0.50	-0.31	0.85	-0.87	-0.69	-0.76	0.77	0.71	0.78	0.69	-0.54	0.86	0.79	0.74	0.78	0.91	1.00		
Zn	-0.18	0.33	-0.40	-0.25	0.89	-0.91	-0.74	-0.79	0.77	0.76	0.90	0.76	-0.36	0.66	0.83	0.75	0.85	0.82	0.81	1.00	
Hg	0.54	0.28	0.20	0.64	0.12	0.02	-0.28	0.03	-0.15	-0.22	0.00	-0.06	0.46	0.25	-0.10	-0.14	-0.12	-0.05	0.19	0.30	1.00
Adelosina sp.	0.25	-0.02	-0.03	0.34	-0.11	0.04	0.18	0.15	-0.23	-0.34	-0.25	-0.29	0.08	0.41	-0.24	-0.22	-0.28	-0.01	0.28	-0.18	0.12
Ammobaculites agglutinans	0.17	-0.05	0.78	0.19	-0.45	0.42	0.42	0.09	-0.17	-0.26	-0.31	-0.24	0.05	-0.18	-0.27	-0.25	-0.26	-0.21	-0.17	-0.36	0.06
Ammonia beccarii	0.25	-0.05	0.21	0.36	-0.11	0.17	0.03	0.17	-0.22	-0.21	-0.16	-0.21	0.15	0.06	-0.20	-0.19	-0.19	-0.22	-0.13	-0.25	-0.16
Ammonia inflata	0.49	0.13	0.77	0.49	-0.62	0.49	0.69	0.38	-0.48	-0.57	-0.47	-0.46	0.36	-0.29	-0.52	-0.47	-0.51	-0.45	-0.38	-0.44	0.04
Ammonia tepida	0.26	-0.04	0.72	0.30	-0.34	0.37	0.26	0.07	-0.19	-0.21	-0.32	-0.28	0.27	-0.32	-0.22	-0.26	-0.20	-0.34	-0.48	-0.25	-0.01

	H'	**J**	**TFN**	**S**	Sand	Silt	Clay	TOC	As	Cd	Co	Cr	Cu	Fe	Mn	Ba	Ni	Pb	V	Zn	Hg
Asterigerinata mammilla	0.46	0.36	-0.05	0.36	0.09	-0.01	-0.18	0.24	-0.17	-0.15	-0.08	-0.09	0.45	-0.35	-0.15	-0.19	0.00	-0.22	-0.22	0.02	-0.14
Aubignyna perlucida	0.16	-0.17	0.73	0.26	-0.42	0.50	0.27	0.15	-0.27	-0.25	-0.21	-0.14	0.33	-0.50	-0.30	-0.29	-0.24	-0.41	-0.38	-0.27	0.20
Bolivina catanensis	0.40	0.16	0.73	0.44	-0.15	0.37	-0.14	0.08	-0.10	-0.15	-0.23	-0.18	0.21	-0.12	-0.16	-0.18	-0.17	-0.24	-0.24	-0.17	0.42
Bolivina subaenarensis	0.46	0.29	-0.07	0.52	0.05	-0.09	-0.01	0.13	-0.24	-0.30	0.00	-0.12	0.42	0.28	-0.15	-0.16	-0.20	-0.05	0.19	0.29	0.78
Buccella granulata	-0.04	-0.10	0.49	-0.03	-0.15	0.31	-0.06	0.00	-0.07	0.01	-0.28	-0.33	0.00	-0.27	-0.15	-0.26	-0.18	-0.26	-0.44	-0.23	0.03
Bulimina aculeata	0.59	0.11	0.57	0.66	-0.62	0.60	0.55	0.62	-0.71	-0.69	-0.40	-0.42	0.75	-0.59	-0.64	-0.58	-0.61	-0.74	-0.64	-0.34	0.36
Bulimina elongata	0.14	-0.26	0.80	0.27	-0.54	0.57	0.43	0.24	-0.38	-0.34	-0.38	-0.39	0.18	-0.36	-0.42	-0.40	-0.41	-0.50	-0.51	-0.53	-0.15
Cancris auriculus	0.46	0.29	-0.07	0.52	0.05	-0.09	-0.01	0.13	-0.24	-0.30	0.00	-0.12	0.42	0.28	-0.15	-0.16	-0.20	-0.05	0.19	0.29	0.78
Eggerelloides scaber	-0.37	-0.20	-0.36	-0.31	0.46	-0.37	-0.49	-0.38	0.26	0.36	0.18	-0.03	-0.35	0.43	0.22	0.05	0.20	0.31	0.35	0.22	-0.09
Elphidium crispum	0.06	0.01	0.67	0.06	-0.24	0.22	0.23	-0.11	0.10	-0.02	-0.07	0.04	-0.14	-0.01	0.00	0.05	0.00	0.04	0.05	-0.17	0.09
Elphidium poyeanu	-0.06	-0.64	0.60	0.20	-0.55	0.65	0.35	0.17	-0.39	-0.34	-0.43	-0.32	0.33	-0.45	-0.39	-0.39	-0.39	-0.55	-0.56	-0.49	0.03
Elphidium granosum	0.14	-0.33	0.48	0.31	-0.26	0.42	0.02	0.07	-0.24	-0.21	-0.35	-0.26	0.38	-0.33	-0.24	-0.30	-0.21	-0.40	-0.44	-0.25	0.14
Elphidium advenum	0.39	0.05	0.76	0.41	-0.50	0.66	0.24	0.43	-0.40	-0.38	-0.44	-0.36	0.34	-0.53	-0.43	-0.39	-0.43	-0.59	-0.69	-0.52	0.06
Florilus boueanum	0.69	0.37	0.81	0.62	-0.63	0.64	0.51	0.61	-0.58	-0.62	-0.50	-0.46	0.56	-0.59	-0.61	-0.54	-0.57	-0.65	-0.64	-0.45	0.26
Fursenkoina acuta	0.27	0.04	0.78	0.32	-0.25	0.33	0.11	0.00	-0.08	-0.13	-0.25	-0.24	0.07	-0.04	-0.13	-0.15	-0.18	-0.21	-0.32	-0.22	0.18
Gavelinopsis praegeri	0.38	0.34	0.30	0.19	-0.34	0.30	0.33	0.41	-0.29	-0.30	-0.34	-0.27	0.34	-0.63	-0.33	-0.31	-0.23	-0.40	-0.56	-0.31	-0.30
Miliolinella sp.	0.25	0.33	-0.24	0.26	0.32	-0.37	-0.21	-0.16	0.14	0.06	0.38	0.33	0.13	0.45	0.25	0.29	0.20	0.31	0.48	0.56	0.69
Neoconorbina terquemi	-0.11	0.22	-0.29	-0.15	0.52	-0.57	-0.39	-0.41	0.28	0.34	0.31	-0.01	-0.28	0.62	0.28	0.12	0.20	0.41	0.43	0.53	0.30
Nonionella turgida	0.16	0.04	0.62	0.11	-0.50	0.46	0.47	0.34	-0.31	-0.24	-0.24	-0.24	0.18	-0.62	-0.32	-0.27	-0.29	-0.50	-0.71	-0.43	-0.37
Nonionella sp.	-0.04	0.10	-0.21	-0.18	-0.35	0.38	0.27	0.56	-0.27	-0.24	-0.38	-0.26	-0.10	-0.34	-0.29	-0.18	-0.38	-0.32	-0.47	-0.52	-0.28
Nonion depressulum	-0.46	0.06	-0.25	-0.53	0.62	-0.67	-0.46	-0.66	0.61	0.69	0.50	0.23	-0.68	0.61	0.58	0.43	0.50	0.60	0.40	0.49	-0.25
Quinqueloculina agglutinans	-0.40	0.13	-0.36	-0.49	0.57	-0.61	-0.45	-0.60	0.80	0.73	0.82	0.95	-0.57	0.40	0.84	0.94	0.83	0.76	0.64	0.62	-0.07
Quinqueloculina bosciana	0.33	0.24	-0.04	0.39	0.25	-0.16	-0.32	-0.03	-0.06	-0.12	-0.06	-0.24	0.05	0.57	-0.10	-0.19	-0.13	0.14	0.45	0.14	0.51
Quinqueloculina seminulum	0.62	0.34	0.29	0.69	0.05	0.20	-0.33	0.24	-0.26	-0.28	-0.08	-0.11	0.51	-0.02	-0.23	-0.25	-0.20	-0.24	-0.02	0.07	0.75
Quinqueloculina sp.	-0.40	0.13	-0.36	-0.49	0.57	-0.61	-0.45	-0.60	0.80	0.73	0.82	0.95	-0.57	0.40	0.84	0.94	0.83	0.76	0.64	0.62	-0.07
Rectuvigerina phlegeri	0.61	0.26	0.62	0.55	-0.66	0.56	0.68	0.59	-0.59	-0.69	-0.58	-0.54	0.45	-0.39	-0.65	-0.57	-0.62	-0.54	-0.42	-0.53	0.09
Textularia agglutinans	0.47	-0.03	0.76	0.52	-0.62	0.59	0.58	0.42	-0.52	-0.58	-0.57	-0.51	0.42	-0.40	-0.57	-0.54	-0.51	-0.55	-0.47	-0.58	-0.13

	H'	**J**	**TFN**	**S**	Sand	Silt	Clay	TOC	As	Cd	Co	Cr	Cu	Fe	Mn	Ba	Ni	Pb	V	Zn	Hg
Triloculina plicata	0.59	0.35	-0.08	0.66	0.12	-0.03	-0.20	0.23	-0.31	-0.33	0.02	-0.10	0.55	0.18	-0.21	-0.22	-0.20	-0.14	0.16	0.27	0.82
Triloculina rotunda	-0.10	0.36	-0.43	-0.26	0.62	-0.58	-0.58	-0.40	0.64	0.59	0.72	0.86	-0.25	0.15	0.69	0.75	0.78	0.59	0.52	0.61	-0.08
Triloculina trigonula	0.34	0.25	-0.41	0.36	0.15	-0.10	-0.18	0.20	-0.17	-0.20	0.08	0.10	0.44	0.07	-0.06	-0.02	-0.06	-0.04	0.15	0.31	0.65
Trochamminoides sp.	-0.52	-0.87	-0.18	-0.26	-0.21	0.22	0.16	-0.12	-0.12	-0.04	-0.19	-0.07	0.10	-0.18	-0.08	-0.12	-0.09	-0.16	-0.16	-0.15	-0.03
Valvulineria bradyana	0.53	0.40	0.25	0.42	-0.35	0.39	0.25	0.55	-0.41	-0.45	-0.47	-0.44	0.35	-0.29	-0.41	-0.37	-0.47	-0.45	-0.55	-0.35	0.16

APPENDIX III

Table 3.3 Benthic foraminiferal species and their density (n° of individuals/volume) found in the four transects (continuing for the next 6 pages).

STATIONS **SPECIES**	**89**	**137**	**143**	**164**	**199**	**272**	**299**	**410**	**440**	**611**	**77**	**180**	**683**	**513**	**581**	**342**	**776**
Adelosina sp.	0	0	8	18	0	0	128	0	0	0	0	0	0	0	0	0	0
Ammodiscus sp.	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0
Ammobaculites agglutinans	0	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0
Ammonia beccarii beccarii	0	0	0	0	0	0	0	0	0	0	32	12	0	0	0	0	0
Ammonia inflata	0	0	0	0	0	0	0	0	0	0	48	0	0	0	0	0	0
Ammonia parkinsoniana	72	0	0	144	0	0	0	0	0	576	0	0	0	0	0	0	0
Amphicorina scalaris	24	36	64	108	0	4	384	1152	23	1260	16	4	0	384	384	0	0
Asterigerinata mammilla	16	0	0	0	0	0	128	0	0	1836	16	0	0	0	0	0	0
Bigenerina nodosaria	8	4	8	0	0	8	256	256	23	1728	0	12	64	256	352	1	16
Biloculinella labiata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
Bolivina alata	8	44	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0
Bolivina albatrossi	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bolivina attica	96	44	8	54	0	0	0	0	5	36	0	0	0	0	0	0	16
Bolivina catanensis	120	56	16	0	0	16	0	0	0	0	688	0	80	0	64	0	0
Bolivina difformis	0	0	0	0	0	0	0	0	0	36	0	0	0	0	0	0	0
Bolivina dilatata	0	8	8	0	0	0	0	128	36	0	80	0	0	0	0	0	16
Bolivina spatulata	32	44	0	0	2	0	0	0	18	576	64	0	0	0	32	0	0
Bolivina subaenarensis	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0	0
Bolivina subspinesciens	32	16	0	0	2	0	0	128	0	0	48	0	0	0	0	0	0
Bolivina sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	256	0	1	0
Bolivina sp.2	0	0	0	0	0	0	0	0	0	0	16	0	64	3072	0	0	0

STATIONS **SPECIES**	**89**	**137**	**143**	**164**	**199**	**272**	**299**	**410**	**440**	**611**	**77**	**180**	**683**	**513**	**581**	**342**	**776**
Bulimina aculeata	168	64	216	486	2	96	1664	3968	131	3600	400	40	0	384	1440	0	0
Bulimina costata	0	8	24	36	42	48	384	0	81	1260	0	60	48	512	160	0	0
Bulimina denudata	32	28	128	54	2	12	768	0	50	1152	0	0	0	0	0	0	0
Bulimina elongata	8	20	0	180	0	8	512	0	14	0	48	0	0	0	0	0	0
Bulimina gibba	48	0	48	216	0	0	384	768	0	3132	0	0	0	1024	384	0	0
Bulimina marginata	0	32	40	108	26	28	1152	2944	45	252	368	108	64	1408	1568	3	16
Cassidella complanata	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0
Cassidulina carinata	264	92	208	198	4	40	1152	1664	104	2196	336	28	32	1536	352	3	16
Cassidulina crassa	48	36	8	0	34	0	128	0	9	540	0	32	32	128	192	12	240
Cassidulina oblunga	96	40	48	144	0	28	384	384	63	1692	256	28	0	640	288	5	0
Cassidulinoides bradyi	8	0	0	36	0	4	0	0	14	0	0	12	0	0	0	0	0
Chilostomella mediterranensis	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0
Cibicides lobatulus	0	0	0	0	0	0	128	768	5	3456	0	0	16	0	0	0	16
Cibicides refulgens	16	0	40	0	0	0	0	0	27	3636	16	0	48	256	96	0	48
Cibicidoides pachyderma	0	0	0	0	0	12	0	0	32	0	0	8	64	256	0	0	32
Connemarella rudis	0	0	0	0	0	0	0	256	0	0	0	0	0	0	0	0	0
Conorbella patelliformis	0	0	0	0	0	0	0	0	0	576	0	0	0	0	0	0	0
Cornuspira involvens	0	0	0	0	0	0	0	0	0	0	0	0	16	0	32	0	0
Cribromilionella sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32
Cribrostomoides jeffreysii	0	0	0	0	0	0	0	0	0	0	48	0	0	0	0	0	0
Cribrostomoides subglobosum	0	0	0	0	0	0	0	0	0	0	128	0	0	0	64	1	0
Cycloforina sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
Dentalina communis	0	0	8	0	0	0	0	0	9	0	0	4	0	0	32	0	0
Dentalina inflexa	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dentalina sp.	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	16

STATIONS **SPECIES**	**89**	**137**	**143**	**164**	**199**	**272**	**299**	**410**	**440**	**611**	**77**	**180**	**683**	**513**	**581**	**342**	**776**
Dentalina sp.2	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Discammina compressa	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Discorbis sp.	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0	0
Eggerelloides scaber	0	0	0	0	0	0	0	128	0	0	0	4	0	0	96	0	0
Elphidium complanatum	0	0	0	0	0	0	0	0	0	1260	0	0	0	0	0	0	0
Elphidium poeyanum	0	0	0	0	0	0	0	0	0	0	208	8	0	0	0	0	0
Elphidium granosum	0	16	0	0	0	0	384	256	0	648	112	0	0	0	32	0	0
Elphidium macellum	0	0	0	0	0	0	384	0	0	576	0	0	0	0	0	0	0
Elphidium advenum	72	8	0	0	0	0	0	0	0	72	176	12	0	0	0	0	0
Eponides repandus	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0
Eponides repandus concameratus	0	0	0	0	0	8	0	0	0	576	0	0	0	0	0	0	0
Favulina hexagona	0	0	0	0	0	0	0	0	0	36	0	0	16	0	0	0	0
Fissurina castanea	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fissurin eburnea	0	0	0	0	0	0	0	0	0	1728	0	0	0	0	0	0	0
Fissurina lucida	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0
Fissurina neptunii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0
Fissurina orbignyana	24	8	0	0	0	0	0	0	0	1188	0	0	0	0	0	0	0
Fissurina sidebottomi	8	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0
Fissurina sp.	0	0	8	18	0	0	0	0	0	0	0	0	0	256	64	0	0
Florilus boueanum	16	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0
Fursenkoina acuta	0	0	0	0	0	0	0	0	0	0	80	0	0	0	0	0	0
Gavelinopsis praegeri	16	0	8	18	0	0	256	0	9	180	0	12	16	128	160	0	0
Gavelinopsis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	3	0
Globobulimina affinis	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0
Globocassidulina subglobosa	24	20	32	0	12	0	0	0	0	0	96	0	64	256	0	12	192
Globotextularia anceps	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0

STATIONS **SPECIES**	**89**	**137**	**143**	**164**	**199**	**272**	**299**	**410**	**440**	**611**	**77**	**180**	**683**	**513**	**581**	**342**	**776**
Glomospira charoides	0	0	0	0	0	0	0	0	0	0	0	4	0	128	64	0	0
Glomospira gordialis	8	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0
Gyroidina altiformis	0	0	0	0	0	4	0	256	23	2304	0	12	80	640	64	17	80
Gyroidina neosoldanii	0	0	0	0	0	8	0	128	5	0	0	0	0	0	0	0	0
Gyroidina orbicularis	0	0	8	0	14	0	0	0	0	0	0	28	32	0	0	33	32
Gyroidina umbonata	24	16	104	0	0	36	0	0	32	0	0	24	0	384	64	0	16
Gyroidina sp.	8	0	0	36	0	0	128	0	0	0	0	0	0	0	0	0	0
Hanzawaia boueana	8	20	40	0	0	16	768	0	23	4464	16	0	32	384	416	0	0
Hoeglundina elegans	0	4	8	18	0	0	0	0	81	0	0	0	0	0	0	1	0
Hyalinea baltica	72	20	128	162	0	32	640	640	113	0	0	32	64	1280	864	2	32
Lagena sp.	8	0	0	0	0	0	0	0	0	0	64	0	0	0	0	0	0
Lagena striata	0	0	16	0	2	4	0	0	9	576	16	0	16	0	0	0	0
Lagenamina difformis	0	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0
Lagenamina fusiformis	8	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	16
Lenticulina calcar	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0
Lenticulina cultrata	0	0	0	0	0	0	0	0	14	0	16	0	32	0	0	0	0
Lenticulina gibba	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0
Lenticulina orbicularis	0	0	0	0	0	0	0	256	0	576	0	0	0	0	0	0	0
Lenticulina sp.	0	0	8	0	2	4	0	0	0	0	0	0	0	128	0	0	0
Melonis barleanum	40	80	24	378	34	4	0	128	41	1188	0	28	176	256	32	5	32
Melonis pompilioides	0	0	0	0	0	0	0	0	0	0	16	16	0	0	0	0	0
Miliolinella dilatata	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0
Miliolinella elongata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	96	0	16
Miliolinella subrotunda	0	0	8	0	0	0	768	256	9	0	0	0	128	640	320	3	64
Miliolinella sp.	0	0	0	0	2	0	0	0	0	0	0	0	16	0	0	5	0
Neoconorbina terquemi	24	0	0	18	0	0	0	0	0	684	0	0	16	0	0	0	0

STATIONS **SPECIES**	**89**	**137**	**143**	**164**	**199**	**272**	**299**	**410**	**440**	**611**	**77**	**180**	**683**	**513**	**581**	**342**	**776**
Neolenticulina peregrina	16	0	0	18	0	0	0	128	0	0	0	4	0	0	32	0	0
Nonionella opima	0	0	0	0	0	0	0	0	0	0	48	0	0	0	0	0	0
Nonionella turgida	0	0	0	0	0	0	0	0	0	0	160	16	0	0	0	0	0
Nonion sp.	0	0	0	0	0	4	0	0	0	0	0	0	0	0	64	0	0
Oolina compressa	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0	0
Oridorsalis umbonatus	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Planorbulina mediterranensis	0	0	16	0	0	0	128	128	0	576	0	0	0	0	64	0	0
Planulina sp.	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0
Polymorphina sp.	16	0	0	0	2	0	0	0	0	0	48	0	0	0	0	0	0
Pseudoeponides falsobeccarii	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudoclavulina crustata	0	0	0	0	0	0	0	256	0	0	0	0	0	0	0	0	0
Pullenia bulloides	0	0	0	0	0	0	0	0	5	0	0	0	0	0	64	0	0
Pullenia quinqueloba	0	0	0	0	0	0	0	128	0	0	0	0	0	0	0	1	16
Pyrgo denticulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Pyrgo elongata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	16
Quinqueloculina badenensis	0	0	0	0	0	28	0	0	0	0	0	0	0	0	128	0	0
Quinqueloculina laevigata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
Quinqueloculina neapolitana	0	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0
Quinqueloculina seminulum	0	0	40	0	0	0	0	0	0	1296	0	0	0	0	0	0	0
Quinqueloculina stelligera	0	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0
Quinqueloculina sp.	0	0	0	0	0	0	0	128	0	612	0	0	0	128	64	0	0
Quinqueloculina sp.2	0	0	0	0	0	0	0	0	0	36	0	0	0	128	0	0	0
Quinqueloculina sp.3	0	0	0	0	0	0	0	0	0	0	0	0	0	128	0	0	0
Quinqueloculina sp.4	0	0	0	0	0	0	0	0	0	0	0	0	0	384	0	0	0
Quinqueloculina sp.5	0	0	0	0	0	0	0	0	0	0	0	0	0	128	0	0	0
Quinqueloculina sp.6	0	0	0	0	0	0	0	0	0	0	0	0	0	384	0	0	0

STATIONS **SPECIES**	**89**	**137**	**143**	**164**	**199**	**272**	**299**	**410**	**440**	**611**	**77**	**180**	**683**	**513**	**581**	**342**	**776**
Rectuvigerina phlegeri	8	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0
Reophax scorpius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0
Reussella spinulosa	8	16	8	0	0	0	128	0	0	756	32	12	0	0	0	0	0
Rhabdammina abissorum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	192	0	0
Robertinoides bradyi	0	0	0	0	0	0	0	0	0	0	0	4	0	0	32	0	0
Rosalina bradyi	0	0	0	0	0	0	0	0	0	108	0	8	0	0	0	0	0
Rosalina sp.	0	0	0	0	0	0	0	0	0	0	48	0	0	0	32	0	0
Saidovina karreriana	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0
Sigmoilina tenuis	0	0	0	0	4	0	0	128	0	0	0	4	16	0	0	2	0
Sigmoilina sp.	0	0	8	0	0	0	0	0	0	0	0	0	0	0	96	0	0
Sigmoilopsis schlumbergeri	32	8	40	72	4	8	128	512	0	3492	0	8	32	0	96	0	0
Siphonaperta sp.	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0	0
Siphonina reticulata	0	0	0	0	0	0	128	256	0	36	0	0	32	128	0	0	16
Siphotextularia concava	0	0	0	0	0	0	256	0	0	0	0	4	0	0	64	0	0
Sphaeroidina bulloides	0	0	40	18	4	4	256	128	5	72	0	16	48	0	96	7	0
Spiroloculina communis	0	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0
Spiroloculina dilatata	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	16
Spiroloculina excavata	0	0	0	18	0	0	0	0	9	72	0	0	0	0	32	0	0
Spiroloculina henbesti	0	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0
Spiroloculina rostrata	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0	0
Spiroplectinella wrighty	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0
Textularia agglutinans	56	20	88	216	0	12	3072	2560	27	5760	0	4	0	512	832	0	0
Textularia conica	0	0	0	0	0	0	0	640	23	108	0	0	0	0	0	0	0
Trifarina angulosa	16	4	0	0	0	0	0	0	0	0	0	0	0	896	0	0	0
Triloculina marionii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Triloculina tricarinata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	0	0

STATIONS SPECIES	89	137	143	164	199	272	299	410	440	611	77	180	683	513	581	342	776
Uvigerina auberiana	0	0	0	0	0	0	0	0	0	0	0	4	0	896	0	0	16
Uvigerina mediterranea	64	16	96	144	76	80	768	640	117	1152	0	100	496	896	672	53	160
Uvigerina peregrina	16	112	112	396	10	44	384	128	126	108	0	48	272	512	384	27	16
Vaginulinopsis tasmanica	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Valvulineria bradyana	72	36	0	162	0	12	0	0	0	0	384	100	0	0	0	0	0
Miliolid1	16	0	24	0	0	0	384	0	81	0	0	0	0	0	0	0	0
Miliolid2	0	0	0	0	4	8	0	0	5	0	0	0	0	0	0	0	0
Total Foraminiferal Number (in a volume of 28,26 cm^3)	1808	992	1760	3474	308	636	17152	20992	1454	57780	4192	884	2192	19712	10944	208	1200

Table 3.4. Diversity indices of sampled stations, grouped following the coast-wide direction for each transect (identify with an increasing number from 1 to 4 in W-E direction)

	T1					T2					T3				T4		
	164	**272**	**440**	**611**	**776**	**77**	**180**	**342**	**513**	**683**	**137**	**299**	**410**	**581**	**89**	**143**	**199**
Species richness (S)	28	34	42	47	27	37	41	26	36	33	36	36	39	51	45	40	25
Individuals density (TFN)	3474	636	1454	57780	1200	4192	884	208	19712	2192	992	17152	20992	10944	1808	1760	308
Shannon (H')	2.894	3.023	3.24	3.342	2.754	2.993	3.181	2.516	3.198	2.954	3.202	3.124	2.996	3.206	3.318	3.144	2.52
Pielou (J)	0.8684	0.8573	0.8667	0.8679	0.8355	0.8288	0.8567	0.7723	0.8923	0.8448	0.8935	0.8718	0.8179	0.8155	0.8716	0.8523	0.7829

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