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RESEARCH PAPER

BIOCENOSES OF BENTHIC FORAMINIFERA OF THE AVEIRO CONTINENTAL SHELF (PORTUGAL): INFLUENCE OF THE UPWELLING EVENTS AND OTHER SHELF PROCESSES

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Abstract

This work aims to compare the dimensions and composition of benthic foraminiferal biocenoses (living specimens) during two summer sampling events. Forty-four sediment samples were collected on the Aveiro Continental Shelf (Center of Portugal) (latitude of 40º30'N-40º50'N, longitude of 8º46'W-9º20'W) for granulometry, total organic matter (TOM) and living foraminiferal analyses.

The sediment samples were collected during summers of 1994 and 1995, on stations located along transects (east-west direction) and between 10-200 m depth. During the sampling campaigns, measurements of salinity, temperature and density data were recorded in the water column. The results showed that the living assemblages were mainly found in stations located between 20-80 m depth. The abundance of living foraminifera was generally reduced at depths <20 m in the so-called "coastal deposits", where the sediments are frequently remobilized and transported by the littoral drift. Living benthic foraminiferal densities were also reduced in stations at 80-200 m depth, despite the high sedimentary TOM contents.

Results obtained in this work indicate that, in this marine setting, the most determinant factors for the dimension and composition of living foraminifera are not the sediments' granulometry and organic matter content. In fact, the coastal dynamics, sediment stability, availability of food quality, among other factors, such as the bottom salinity oscillations

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and their combination, should better explain the abundance of living foraminifera and the biocenoses composition.

Keywords: Living benthic foraminifera. Upwelling index. Total organic matter. Portuguese continental margin.

1. Introduction

Foraminiferal studies have been very useful in the field of coastal sciences (Scott et al., 2014) and have contributed to a better understanding of the phenomena that shaped the ocean in the past (Hayward et al., 2001) and in the present (Havach and Collins, 1991; Denoyelle et al., 2010; Youssef, 2015). Foraminifera are commonly small in size and extremely abundant in almost all marine environments, even when a small amount of sample is available (Ratcliffe and Zaitlin, 2010).

In general, the composition of living foraminiferal assemblages is different whether they are on the inner, mid or outer continental shelf (Sen Gupta, 1982). Numerous studies have evidenced this distribution. However, depth does not seem to be the main controlling factor but the environmental characteristics that change with it (Havach and Collins, 1991; Murray, 1991 a, b; Sen Gupta, 2002; Culver and Buzas, 2000). The distribution of foraminifera is directly related to the physicochemical characteristics of the environment, which, in some way, vary with depth, substrate granulometry, water temperature, salinity, light, oxygen, nutrients and even with biotic factors (Sen Gupta, 1982, 2002; Mendes et al., 1994; Murray, 2006).

One of the most important aspects of the biotic communities is their diversity (Sanders, 1968). Diversity is a measure of the maturity and stability of an environment (Boltovskoy and Totah, 1985), so there is a clear relationship between the diversity of a foraminiferal assemblage and the environmental conditions in which it lives (Murray, 1976, 1991 a, b). Diversity also provides general information about ecological processes operating in a system, reflecting internal productivity, stability or environmental stress conditions (Bouchet et al., 2012; Fajemila et al., 2015).

The large geographic distribution and the close relationship of the benthic foraminifera to the environment allow the detection of qualitative and quantitative changes of environmental variables (e.g., Kaiho, 1994, 1999; Waelbroeck et al., 2002; Carson et al., 2008). Thus, an assemblage of foraminifera provides information on the physicochemical constituents of the biotope in which it lives and in particular on salinity, temperature, substrate, among other factors (Murray, 2006). The recognition of current biocenoses and the study of their ecology constitute the basic information of the data that allow accomplishing any paleoenvironmental and paleoceanographic reconstruction.

The number of studies of benthic foraminifera on the western Portuguese Continental Shelf is very limited, and the most extended, comprehensive and recently published inventory, also including the Aveiro region, was provided by Levy et al. (1993, 1995). These works presented data of the total assemblages of foraminifera (living plus dead) based on 113 samples collected along 32 transects perpendicular to the coast-line, spaced from north to south of Portugal (between the latitudes of 41º39'-36º50'N). They recognized 245 species of benthic foraminifera and 24 species of planktonic ones.

On Aveiro–Espinho Continental Shelf, Martins et al. (2012) analyzed 98 surface sediment grab-samples, collected between the latitudes 40°31'N and 40°58'N and water depth from 10 m to 700 m. This work analyzed the characteristics of the sediment (grain size, mineralogy and composition) and total foraminiferal assemblages. These authors identified 210 species of benthic foraminifera and observed that the assemblages were composed mostly by rotaliids also including agglutinated species up to 40% and miliolids up to 16%.

Martins et al. (2015 a) analyzed the bottom hydrodynamic conditions on the central western Portuguese Continental Shelf, at south to the study area, between the latitudes of 38ºN-40ºN, based on benthic foraminifera (dead benthic foraminiferal assemblages). In this work, a total of 15,972 specimens belonging to 263 taxa were found in sediments collected at 46 stations located along transects perpendicular to the coasta line, between 15-190 m water depths. The study of Martins et al. (2015 a), based on the distribution of the benthic foraminiferal assemblages as well as sedimentological and environmental data, allowed the identification of two main sets of stations, an Inshore Group and an Offshore Group, which were characterized by different benthic regime characteristics.

1.1 The main goals of this work

The present study is the first carried out on the Aveiro Continental Shelf (Portugal), based on living assemblages of benthic foraminifera and aims to recognize the main biocenoses (in *strict sense*) of benthic foraminifera. It also intends to analyze living benthic foraminifera distribution and to relate the assemblages' abundance, diversity and composition to the sediment granulometry, TOM content

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and the pattern and intensity of upwelling in the study area before the sampling events.

2 Study area

The study area is located in a sector of the Portuguese Continental Shelf, off Aveiro Lagoon, commonly named as Ria de Aveiro (center of Portugal; Fig. 1). From the geological point of view, this area is integrated in a sedimentary basin, located on the western edge of the Hesperic Massif, the Meso-Cenozoic Iberian Coast, formed during the Mesozoic Era, when the North Atlantic opened (Vanney and Mougenot, 1981).

Bathymetrical contours of the studied shelf are generally subparallel to the coastline (Fig. 1). The shelf break lies at a mean depth of about 160 m (Dias, 1987). The shelf-width varies between 38 km (near Aveiro Canyon) and 50 km (off Furadouro). This shelf corresponds to a gently westward plunging monoclinal wherein the substrate is essentially constituted by Cretaceous and Cenozoic formations (Musellec, 1974). To the north of the studied region, off Furadouro, the monotony of this shelf sector is break by two elevations, Pontal da Galega and Pontal da Cartola, corresponding to the outcrop of Cretaceous (carbonate) formations, originated by faults' activity (Fig. 1; Vanney and Mougenot, 1981). At south of the studied area, the continental shelf is abruptly cut (130 m deep) by the Aveiro Canyon, with broad U shape and tectono-sedimentary origin (Fig. 1; Vanney et al., 1979).

The continental region of Aveiro, adjacent to the coast, is flattened and has low altitude (Teixeira and Zbyszewsky, 1976). The landscape in the region is dominated by a barrier-type lagoon, commonly known as "Ria de Aveiro", which is associated with extensive deposits of Holocene sediments, which can reach thicknesses of 40 m in some areas (Gomes, 1992).

The lagoon of Aveiro has a very irregular outline, being separated from the sea by a sandy ridge of variable width (from 220 m to 1500 m). Nowadays, its contact with the ocean is through an artificial opening. The lagoon is the superficial feature of the final stage of filling of the sedimentary basin of Aveiro, the northernmost part of the great Lusitanian sedimentary basin, stretching from Espinho (at north) to Aljezur (at south) and the Iberian Plateau (Gomes, 1992). Several rivers flow into this lagoon, among which the Vouga River is the most important. This river flows into an inland region of the lagoon and does not transport sediments directly to the continental shelf.

According to the Climatological Atlas of Portugal (Atlas Climatológico de Portugal, 1974) the mean annual temperature in the region is ≈14.6°C, being in the coldest month (January) ≈10°C and in the warmest month (July) ≈18.2°C. The mean annual rainfall is ≈913 mm/year, being ≈137.2 mm in January (rainier) and ≈10 mm in July (drier). The wet season, corresponding to 75% of the annual precipitation, is concentrated between October and March.

The wind regime is predominantly from north and northwest, with speeds within the classes 6-20 km/h and 21-50 km/h (Pita and Santos, 1989). The southern and southwestern winds, although representing only 18% of total records, have the highest average velocities (Carvalho and Barceló, 1966). In the region of Aveiro, winds with velocities >35 km/h have, more frequently, directions of S, SW and W, from October to April (Carvalho, 1971).

The thermohaline characteristics of the surface waters of the coastal ocean at the region are determined by factors such as dilution caused by local precipitation and discharges from rivers, the hydrographic network of this region, as well as by atmospheric warming of spring/summer and by cooling of autumn/winter, which influences the thermal stratification of the coastal water column (Peliz et al., 2002, 2003 a, b, 2005). The upwelling phenomena also contribute to the seasonal variability of the waters located on the continental shelf (Fiúza, 1980, 1983). In winter, the sea is homogeneous up to about 200 m deep outside the rivers' plumes (Peliz et al., 2002, 2005). Within these plumes, salinities and densities values are much lower than in the open sea (Fiúza 1980, 1983). On the continental shelf, as a consequence of terrestrial flow, there is a tendency for horizontal stratification of temperature, except during the upwelling events (Fiúza, 1980, 1983).

The location of Portugal, on the edge of the subtropical anticyclonic system and on the eastern margin of a large ocean, is a determining factor for its climatology and oceanography. During summer, the migration of the Azores anticyclone to the central Atlantic region and the weakening of the Iceland High pressure (Fiúza et al., 1982; Ferreira, 1984) generate the necessary conditions for the development of upwelling events. Coastal upwelling on the Portuguese west coast develops commonly from July to September, as a result of the increased intensity and constancy of the northern winds blowing in June, July and August (Lemos and Pires, 2004).

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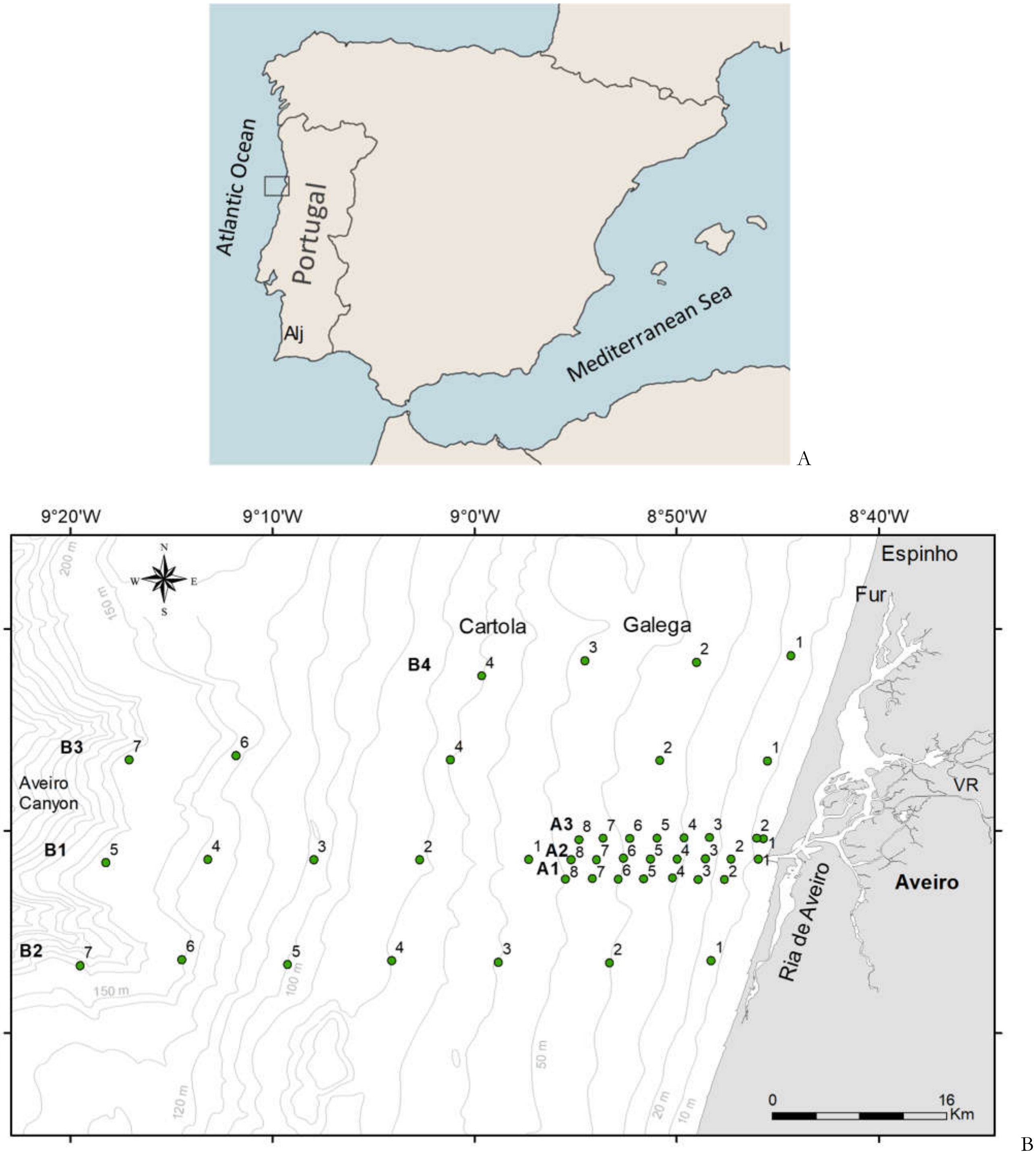

Fig. 1. Map of the study area. The stations location is placed along two groups of transects on the Aveiro Continental Shelf (Center of Portugal): A. close to the mouth of Aveiro lagoon, popularly named Ria de Aveiro; and B. faraway of the Ria de Aveiro mouth. Legend: Alj – Aljesur; P. Cartola - Pontal da Cartola; P. Galega – Pontal da Galega; Fur – Furadouro; VR - Vouga River.

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Along the Portuguese coast, sporadic upwelling events occur in December and January, although with less intensity than in summer (Fiúza et al., 1982). The average coastal upwelling regime in this North Atlantic area has a minimum between March and May and shows a mild transition in June and maximum intensity in August (Fiúza et al., 1982).

Upwelling brings to the surface waters cooler, denser, more saline, lesser oxygenated and richer in phosphates and nitrates than those that previously occupy the continental shelf (Sanchez-Vidal, et al., 2004; Lorenzo et al., 2005). The upwelled water comes from a depth of 120 to 200 m, from the Eastern North Atlantic Central Water and affects the entire western continental shelf of Portugal, as well as part of the slope (Fiúza 1980, 1983). The supply of nutrients to the shallower waters triggers an increase of primary production, the proliferation of phytoplankton and other trophic levels of marine food chains (Suess and Thiede, 1983). Indicators of the occurrence of upwelling include: i) the presence of fauna associated with low temperatures as observed by Thiede (1977, 1980) and Ubaldo and Otero (1978); (ii) the amount of organic matter of marine origin in the sediment (Suess and Thiede, 1983); iii) the ^{18}O and ^{13}C isotopes values in planktonic and benthic foraminiferal tests (Suess and Thiede, 1983); and iv) the abundance and specific composition of diatoms (Monteiro et al., 1983; Abrantes and Sancetta, 1985; Abrantes, 1988; 1991 a, b) and of calcareous nannoplankton (Monteiro et al., 1983).

3. Material and methods

This work analyzed surface sediment samples collected along 7 transects with an East-West orientation, between 10 m and 200 m deep, from a sector of the Portuguese continental shelf off the Ria de Aveiro (Portugal) between the latitudes of 40º30' N and 40º50' N and longitudes of 8º46' W and 9º20' W (Fig. 1).

Transects were established in two zones A and B. The A transects are located near the mouth of the Ria de Aveiro with stations between 10-50 m water depth, and the transects B, further away, with stations distributed over greater depths range (≈10-200 m).

In total, 44 stations were analyzed in this work. The stations of each transect were numbered in ascending order, from the coast to offshore (Fig. 1).

The sampling program was carried out in two oceanographic campaigns on board the oceanographic vessel "NO Côte d'Aquitaine" (CNRS - CIRMAT) of French nationality: for transects A, the first campaign ("Aveiro 94") took place between 21 July and 2 August, 1994; for transects B, the second one ("Aveiro 95") took place between 28 July and 3 August, 1995. The depth and coordinates of each sampling station are referenced in Appendix 1.

Samples of the surface sediment cover were collected with a Reineck sampler equipped with a stainless steel 172 x 85 mm box. Reineck samplers allow sampling of the first centimeters of sediment as the biocenoses of benthic foraminifera develop mostly on the surface of the substrate, disappearing a few centimeters below the water-sediment interface (Boltovskoy, 1965). This type of samplers equipped with a cut-off system offers considerable advantages over others since it allows: i) to obtain a large surface area to prevent disturbance of the sediment; to get a reliable sampling of the surface; to collect living foraminifera.

From the sediment retrieved at each station, two sub-samples of the surface sediments were collected, in PVC tubes, 5 cm in diameter and 30 cm high, to determine the sediments granulometry and total organic matter content and to study benthic foraminifera. For the foraminifera study, a volume 10cm^3 of the first centimeter of surface sediment was sub-sampled.

On board, CTD (temperature, salinity and density) data were recorded along the water column; depth was evaluated with a bathysonde; samples collected for the study of benthic foraminifera were immediately fixed with 4% formaldehyde in sea water (neutralized with sodium bicarbonate) (Boltovskoy, 1965) and stained with rose Bengal (Walton, 1952), for fixing and staining living foraminifera (Corliss, 1991). The rose Bengal is a dye of the protoplasm, making possible to separate the empty tests from those that would presumably be living at the time that the material was collected (Douglas, 1979). The protoplasm is recognized within the test by its pink or violet color, filling the whole test but in the last chamber (Corliss, 1991).

Corliss and Emerson (1990) presented a detailed discussion on rose Bengal. The stained species could be living at the time of sampling or recently dead with the protoplasm preserved inside the test mostly in anoxic fine-grained sediments (Bernhard, 1988). Although the organic carbon could degrade over a period of days, weeks or months, depending on the oxygenation of the sediment, a conservative interpretation of the coloration was chosen.

Thus, it was assumed that the colored tests denounced the presence of the protoplasm, which would still be living at the time of sampling or recently (Corliss, 1991). In the study area, the preservation of the cytoplasm for a long time was not expected, since the water column was oxygenated

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and the sediment samples were composed of sand where the interstitial water may be easily renewed.

3.1 Sediment Granulometry

For granulometric separation, the sediment was dried (in the oven at 50ºC), weighted and sieved using a column of sieves placed on a shaker for 15 min. The percentage of each fraction was determined by comparing the weight of the material obtained in each sieve with the initial total weight (Holme and McIntyre, 1971). Sediment mean grain size was evaluated according to Folk and Ward (1957).

3.2 Determination of Total Organic Matter

The sediment samples for the determination of total organic matter (TOM) content were stored at -20°C (Rodrigues and Quintino, 1993). The material was thawed and dehydrated in an oven at 100°C for about 24 hours (Rodrigues and Quintino, 1993). Porcelain crucibles precalibrated (by exposure in a muffle at 450°C for 5 hours and cooled in a desiccator for 30 minutes) were weighed. The sediment was triturated in a mortar to be homogenized. In calibrated crucibles, 1 g of the sediment was added to each sample. The material was incinerated in the muffle at 450°C for 5 h (Kristensen and Andersen, 1987). The crucibles, taken from the muffle, cooled for 30 minutes in the desiccator, and were weighed again. The weighing was carried out quickly to avoid significant weight variations due to moisture absorption. The TOM content corresponding to the weight loss by the sediment after the incineration was determined, which was expressed as percentage of dry weight of the sample.

3.3 Foraminifera

In the laboratory, the foraminiferal samples were washed with distilled water to remove the formaldehyde, excess dye, the finer and coarser sediments, using 1000 μm and 63 μm sieves. Between each operation, the sieves were carefully washed to avoid contamination of the samples. Screening of living foraminifera was done by wet method using a Pasteur pipette with the help of a brush and using a Zeiss binocular microscope, Model Stemi SVII with a maximum magnification power of 264 times. The specimens collected at each station were stored in foraminiferal microslides, with 60 small subdivisions, identified and counted.

The density of living foraminifera corresponds to the number of living specimens of each species or of the total specimens found in each sample in an initial volume of 10cm³ of sediment. The species richness corresponds to the number of species per sample and was determined in all the analyzed stations. In this work, the ratio of agglutinated /calcareous foraminifera was also calculated.

3.4 Data Analyses

All the data analyses were only based on samples with more than 100 living specimens of foraminifera, a minimum number considered for statistical purposes (Fatela and Taborda, 2002).

The dominance is the tendency of some species to cover a large part of the whole and can be evaluated based on the percentage of species in the sample (Boltovskoy and Totah, 1985). Dominance translates the "weight" that each species has in relation to the total set of each sample. That "weight" can be converted into a semi quantitative data: i) Dominant - more than 20% of the set; ii) Abundant - between 10% and 20%; iii) Relatively abundant - between 5% and 10%; and vi) Low abundant - less than 5%. Boltovskoy and Totah (1985) accepted, 10% as the critical value for the recognition of dominance.

The constancy or presence of species was calculated in terms of percentage of the species occurrence (Sánches-Ariza, 1983): C = p x 100 /P, where p is the number of stations containing a given species and P is the total number of studied stations. According to the above expression, three categories for the value of C were considered: i) Frequent species, present in more than 50% of the samples; (ii) common species present in 25-50% of the samples; and (iii) rare or accidental species present in less than 25% of the samples.

The Shannon Index (H') was determined (Shannon, 1948) with the mathematical formula: $H' = -\sum_{ni=1}^{S} pi \ln pi$, where *pi* is the proportion of the different species *i* in the sample ($pi = \frac{ni}{N}$); *s* is the total number of species; *ni* is the number of individuals of species *i* and; N is the total number of individuals in the sample (Shannon, 1948).

Equitability was determined with the following mathematical expression (Pielou, 1966): $E = \frac{H'}{\ln(S)}$ (1), where E is the measure of species equitability determined by expression (1); H' corresponds to the value of the Shannon index; S is the total number of species.

In this work both R-mode and Q-mode analyses were applied using the complete linkage method and 1-Pearson r correlations. Species with relative abundance >5% in at least

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one station and present in at least 25% of the stations were used in statistical analyses.

Statistical analyzes were performed in Statistica® 12 software. The maps were accomplished with the ArcGis® software 10.2 (datum WGS84).

Upwelling indices were considered for three months before and during the sampling events in 1994 and 1995. Daily upwelling index values were determined using Ekman transport (Ekman, 1905) based on wind stress information obtained from National Oceanic and Atmospheric Administration, U.S., for Vigo (42ºN, 9ºW; N Spain) according to Bakun (1973).

4. Results

4.1 Temperature, salinity and density in the water column

The distribution of temperature, salinity and density data along the B2 transect is shown in Fig. 2. This transect was selected for representing the entire width of the Aveiro continental shelf. Similar values and patterns of those parameters were observed for the other transects. The surface temperature ranged at the stations closest to the coastline between 16.5°C and 17°C, and above the continental shelf break was about 19°C (Fig. 2A). At the surface, salinity ranged from 35.4 to 36.0 (Fig. 2B). The density values, at the surface, varied from 25.4-26.4 and near the bottom or below 50 m, were higher than 27.0 (Fig. 2C).

At the bottom, the temperature was relatively cold, of about 14.5ºC at the stations located near the coast and below 14ºC, at depths >25 m, and descended to 12.5ºC on the shelf break (Martins, 1997). Salinity ranged along the bottom between 36.1-36.2 in the shallowest stations and around of 36.3 on the shelf break. Nuclei of water with relatively low salinity (down to 35.40), resulting from the partial mixing of low saline waters from Ria de Aveiro outflow with marine waters, were observed near the coast. These water nuclei became diluted toward offshore.

4.2. Granulometry and Sediment Composition

The sediments represented several classes of sand from very fine sand to very coarse sand (Fig. 3). The fine and medium sands are present at depths of less than 30 m and in some stations between 90 m and 200 m deep; ribbons of coarse sand were recognized between 30-80 m and between 130-170 m (relative to stations B1-4, B1-5, B2-7), which generally have relatively high gravel particles content (Appendix 1).

The qualitative analysis of the sand composition (63-2000 µm) revealed that: near the coast, remains of organic matter of continental origin (woody material of plants) can be observed and sometimes significant quantities of mollusk shells (broken and well preserved); and up to 100 m deep, the sands were essentially siliceous and composed mainly of quartz. At depths greater than 100 m, the foraminiferal tests and the shells of mollusks (from modern and fossils organisms) became the main constituents of the sediment, reducing the terrigenous component.

4.3 Organic matter content

The percentage of TOM in the sediment samples collected in transects A ranged from 0.39% to 1.63%. The TOM contents in transects B varied from 0.33% (station B4-3, at 47 m deep) to 4.2% (station B1-4, at 132.2 m deep) (Appendix 1). Figure 4 presents the TOM content as a function of depth (Fig. 4A) and a distribution map in the studied stations (Fig. 4B), evidencing an increase of TOM in the deepest stations.

Most of the samples are part of a zone with N-S orientation, whose width is defined by the bathymetric curves of 10 m and 100 m and whose organic matter content varies between approximately 0.5% and 2% (Fig. 4B). Included within this zone, some stations, dispersed between 32 m and 47 m, had values lower than 0.5% (minimum 0.33%). The highest TOM contents (between 2% and 4.5%) were recorded in the deepest stations of transects B, in depths greater than 100 m (Fig. 4, A, B).

4.4 Benthic foraminifera in all stations

Quantitative data of living foraminifera for each station are reported in Appendix 2. Maximum density of living foraminifera was <356 specimens/10cm^3 (Appendix 2; Fig. 5A). No living benthic foraminifera were found in the stations: A2-1, A1-2, A2-2, A3-2, B2-6 and B3-7 (at 10 m, 15 m, 16 m, 131 m and 190 m of depth, respectively). Several stations presented low density of living foraminifera <100 specimens/10cm^3 and are located both in shallow waters, between 10-60 m deep (A3-1, B2-1, A2-3, B3-1, A1-6, B1-1) and at deepest studied stations, between 78-134 m deep (B2-2, B3-6, B1-3, B1-4, B1-5, B3-6, B2-5). The density of living foraminifera was >100 specimens/10cm^3 in 23 stations.

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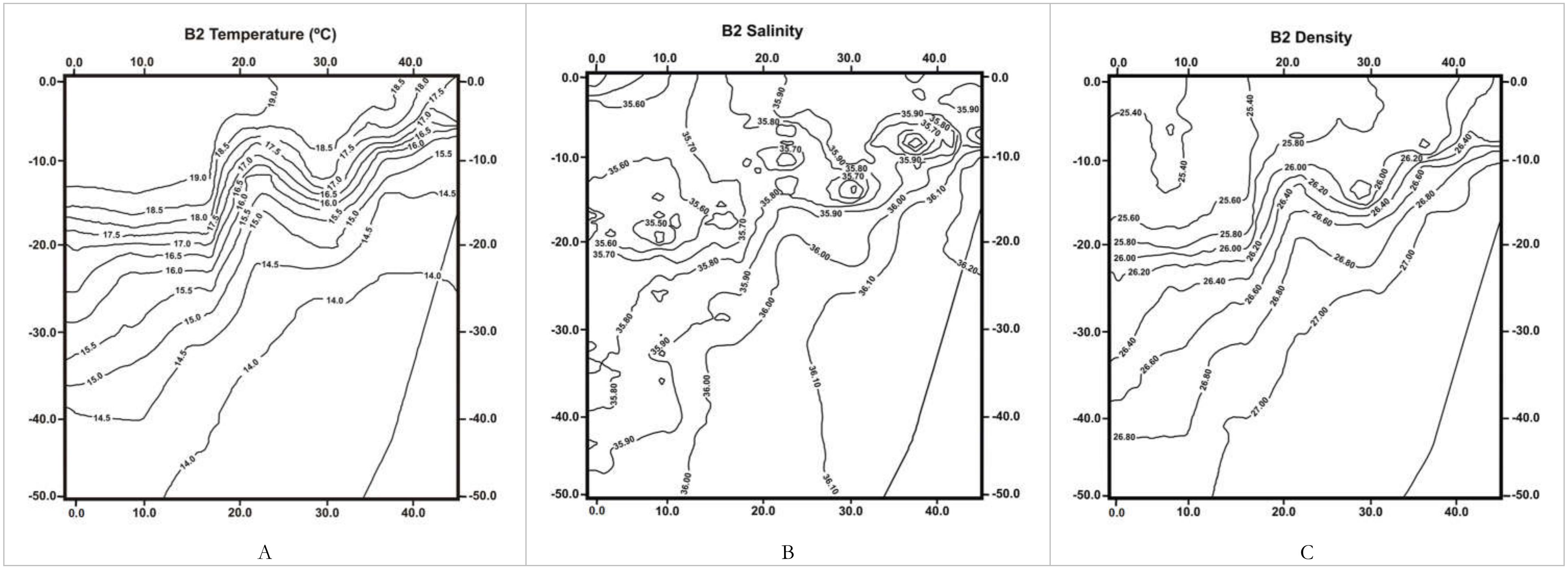

Legend:
X- Distance (km) from the most offshore station
Y - Depth (m)
The bottom line is represented by the line drawn on the right side of each graph

Station	Distance (km)
B 2-1	44.2
B 2-2	36.9
B 2-3	29.4
B 2-4	22.1
B 2-5	14.7
B 2-6	7.3
B 2-7	0.0

Fig. 2. Vertical profile of the water column at the stations of transept B2: A. temperature (ºC); B. salinity and; C. density.

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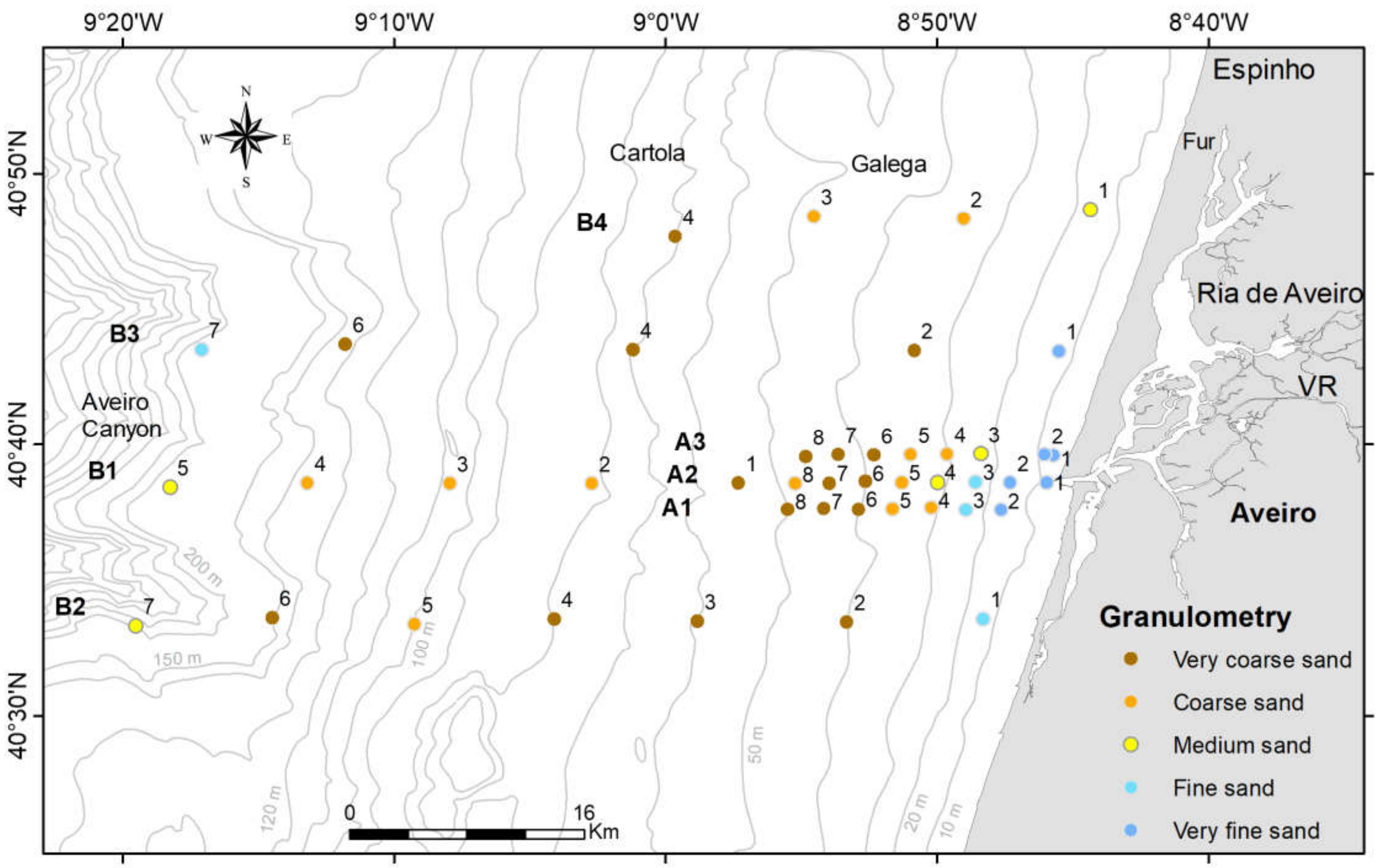

Fig. 3. Spatial distribution of sediment granulometry. Legend: P. Cartola - Pontal da Cartola; P. Galega – Pontal da Galega; Fur – Furadouro.

The highest abundance of living foraminifera was recorded in stations located between 30 m and 80 m deep (A1-4, A1-7, A1-8, A2-6, A2-7, A3-7, A3-8, B1-2, B2-2, B2-3, B3-2, B4-2; Fig. 5A), with TOM contents ranging from 0.36% to 0.61%. The substrate of these stations was composed of fine sand to coarse sand. Species richness was lower than 43 species per sample. The values of species richness and density of foraminifera as a function of depth presented a similar pattern of distribution (Fig. 5B). Species richness reached highest values between 30-80 m deep. The highest values of the ratio between the density of agglutinated (Loftusiida, Lituolida, Spirillinida and Textulariida) and calcareous (Lagenida, Rotaliida, Miliolida, and Robertinida) species were observed between 30-50 m deep, particularly in transects A (Appendix 2).

4.5 Benthic foraminiferal assemblages in 23 stations

The living benthic foraminiferal assemblages in 23 stations (with >100 specimens) were composed of 67 genera and 120 species during the sampling (Appendix 3). Six dominant species with relative abundance >20% were identified in at least one station: *Bolivina pseudoplicata, Cibicides ungerianus, Cribrostomoides jeffreysii, Discorbis mira, Lobatula lobatula* and *Planorbulina mediterranensis* (Appendix 3).

Percentage of agglutinated foraminifera (Loftusiida, Lituolida, Spirillinida, and Textulariida) reached the highest percentages in stations B2-2 and B4-2 (55% and 53%, respectively) located at 39.9 m and 35.1 m, respectively. Relatively high percentages of agglutinated foraminifera were also observed in stations of transects A, in front of the Ria de Aveiro inlet. Miliolida, Lagenida and Robertinida are poorly represented in the study area reaching values ≤5%. Rotaliida is the Order with the highest representation in the study area, reaching more than 90% of the assemblage in some stations.

Shannon index values varied between 1.59 and 3.24 and the equitability between 0.60- 0.89 (Appendix 3; Fig. 6). The highest values of Shannon index (between 2.85- and 3.24) were found between 35-70 m deep especially in stations of transects A3, B2, B3 and B4 (Fig. 6A). Relatively high values of equitability were found in dispersed stations between 15-70 m deep, in transects A2, A3, B2 and B4 (Fig 6B).

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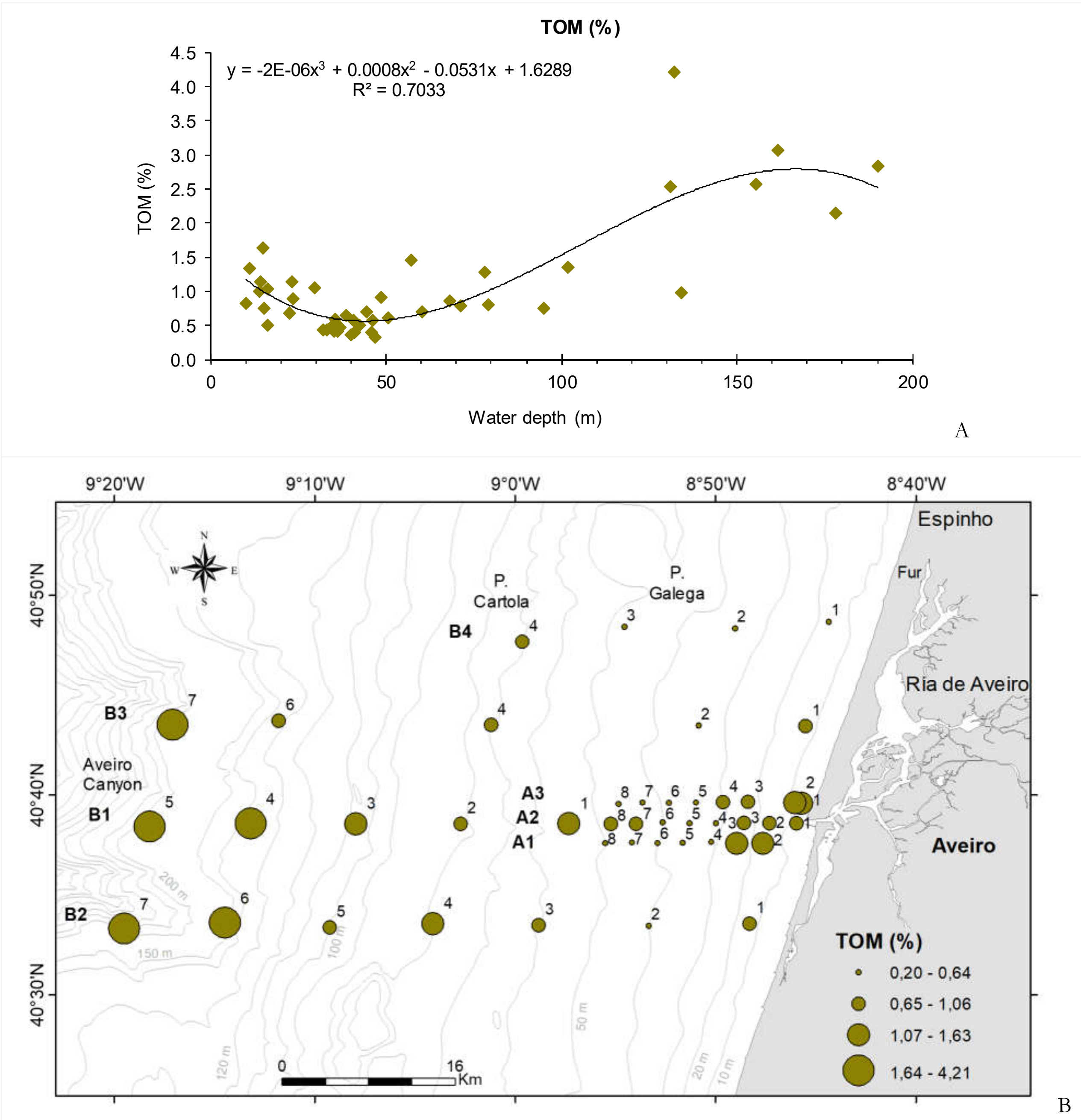

Fig. 4. A. Graph of total organic matter (%; TOM) values as a function of depth at the studied stations. B. Distribution map of TOM (%). Legend: P. Cartola - Pontal da Cartola; P. Galega – Pontal da Galega; Fur – Furadouro.

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Bolivinids were quite common (Fig. 7A), dominating the living foraminifera assemblages between 15-50 m deep, in most of the 23 stations, with TOM content of 1% to 1.5%. In bolivinids, *B. pseudoplicata* reached the highest density and was present in all transects (Fig. 7C). The highest relative abundance of this species (10-51 %) was observed also between 15-50 m deep, mainly in stations of transects A (Appendix 3). Their relative abundance was low both at depths of less than ≈15 m and from ≈60 m towards the deepest stations of Aveiro Continental Shelf (Appendix 3). The other bolivinid species common in the study area was *Bolivina ordinaria*.

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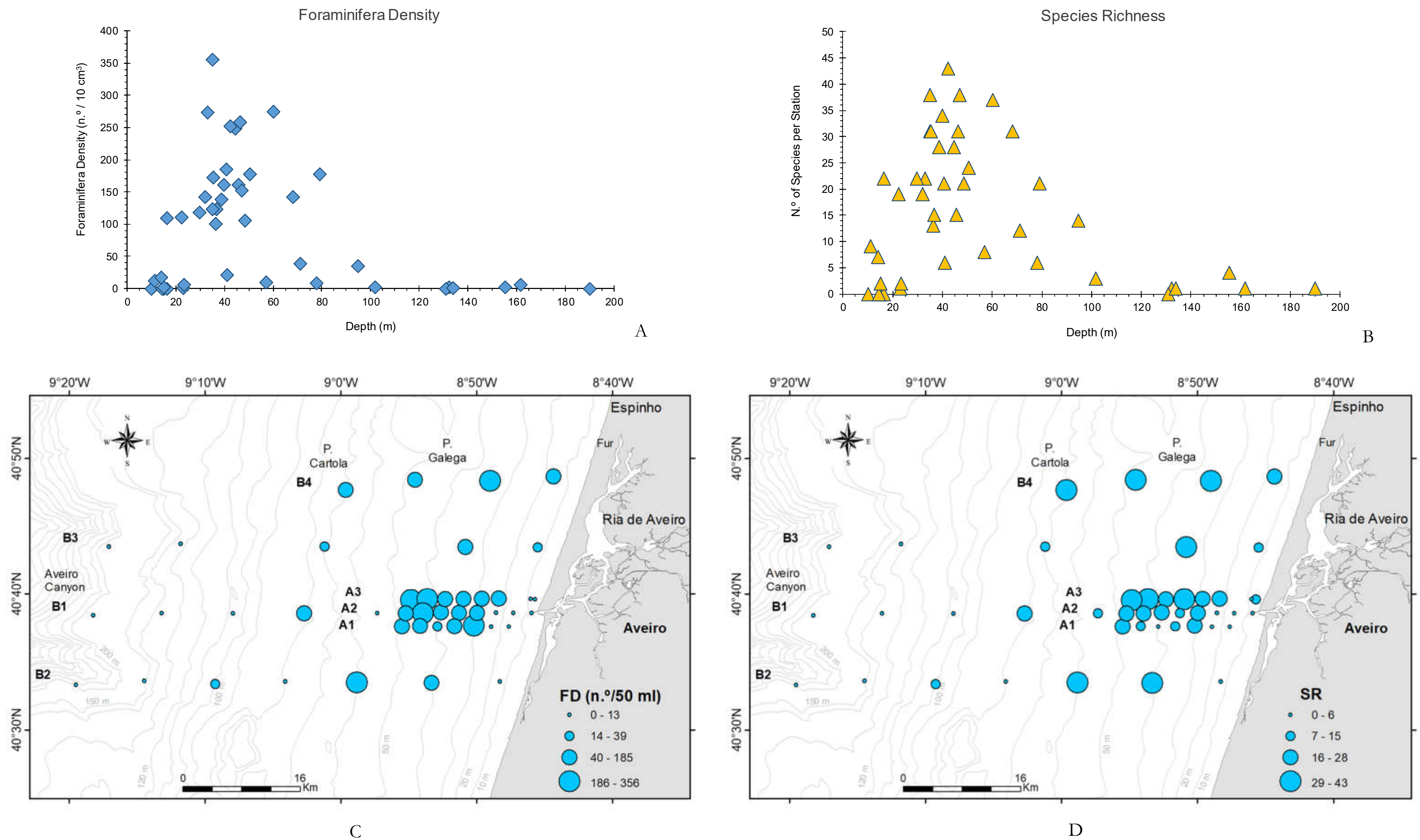

Fig. 5. Graphics as a function of depth of: A. Foraminifera Density (n.º/10cm³); B. Species richness (number of species per station). Distribution maps of: C. FD - Foraminifera Density (n.º/10cm³); D. SR - Species richness (number of species per station). Legend: P. Cartola - Pontal da Cartola; P. Galega – Pontal da Galega; Fur – Furadouro.

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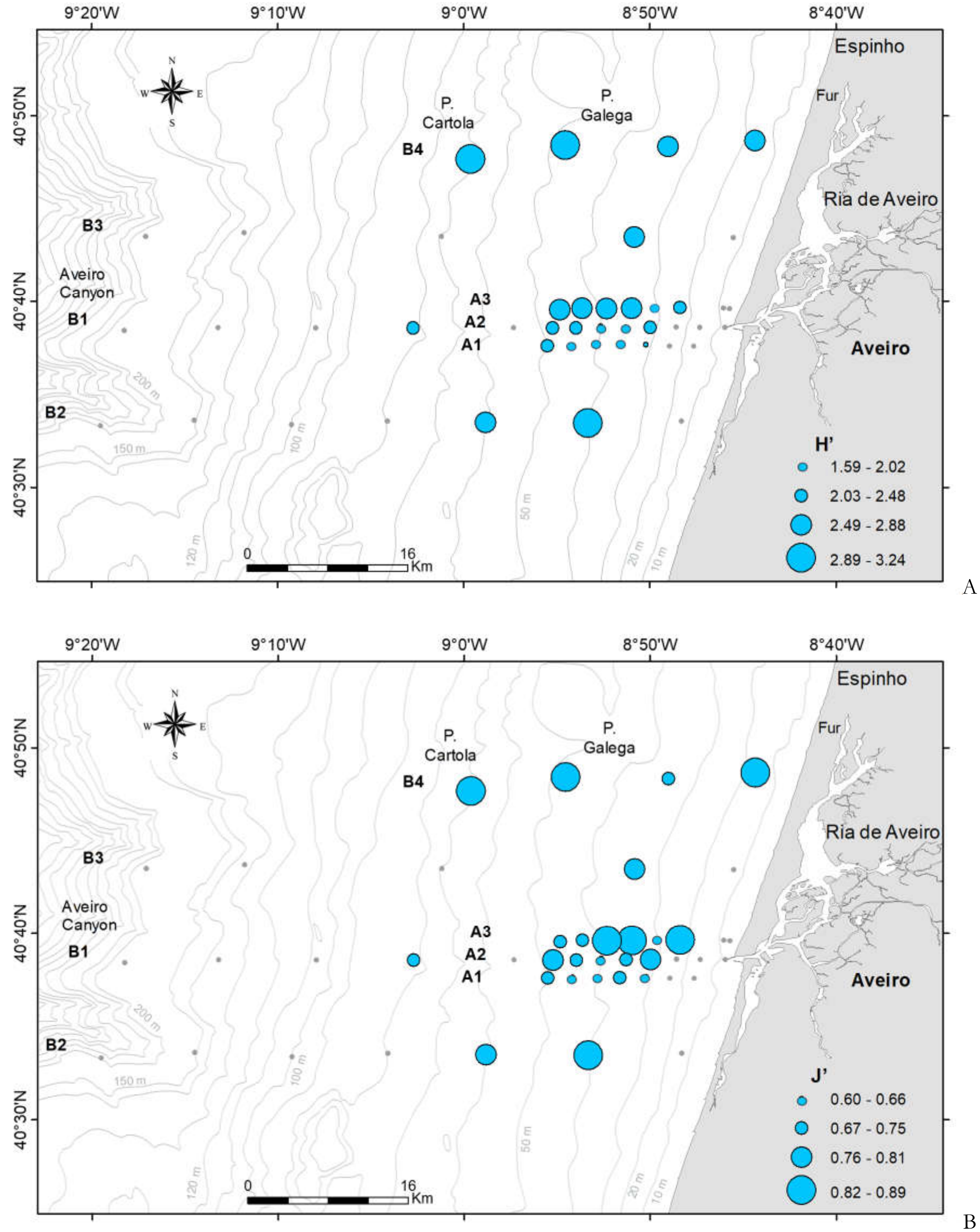

Fig. 6. Distribution maps of: A. H' - Shannon Index; and B. J' - Equitability values. These values were determined in stations where more than 100 living foraminifera were found. Legend: P. Cartola - Pontal da Cartola; P. Galega – Pontal da Galega; Fur – Furadouro.

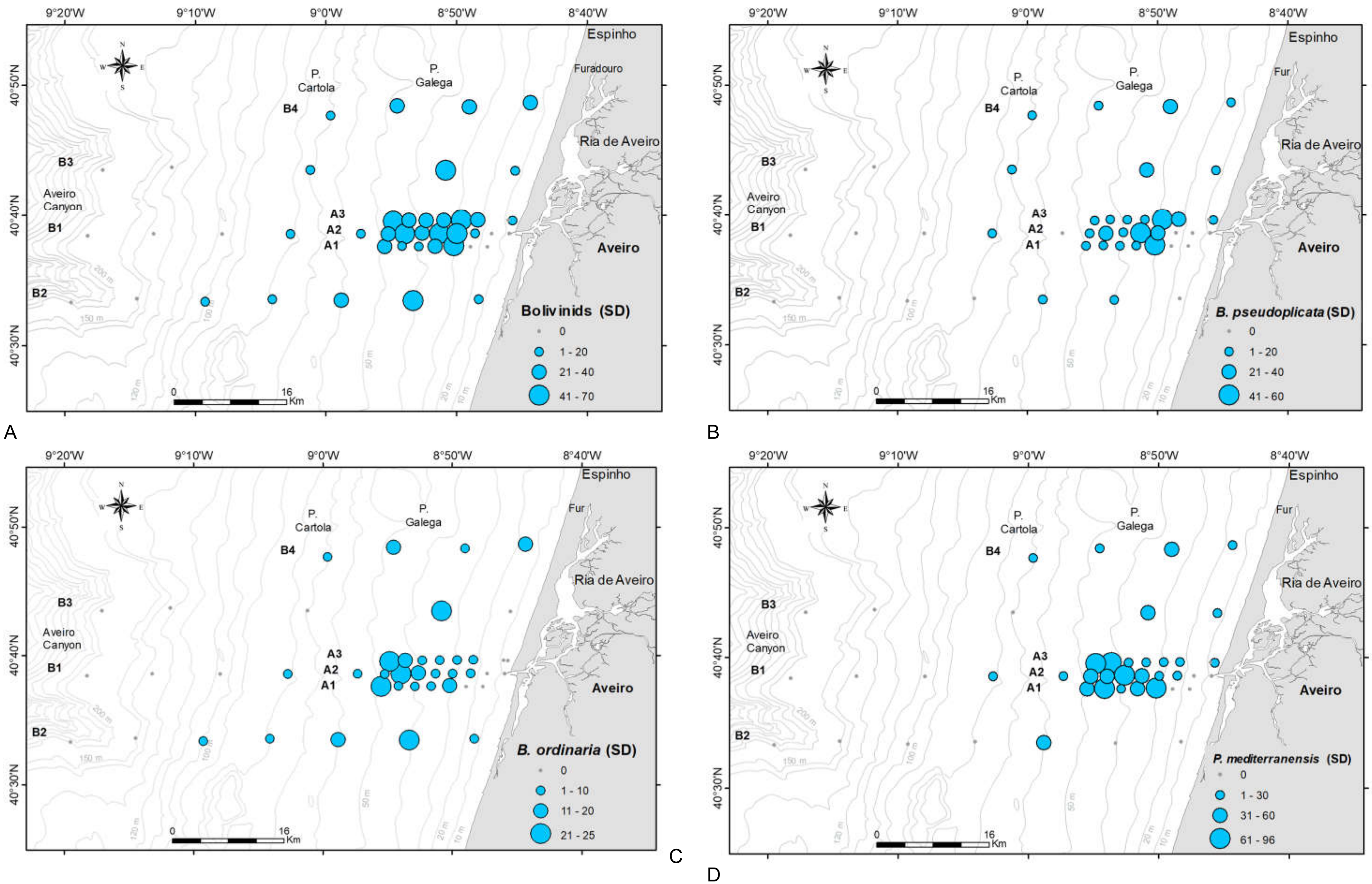

Fig. 7. Distribution maps of the main species /taxa density (SD; n.º/10cm³): A. Bolivinids; B. *B. pseudoplicata*; C. *B. ordinaria* and; D. *P. mediterranensis*. Legend: P. Cartola - Pontal da Cartola; P. Galega – Pontal da Galega; Fur – Furadouro.

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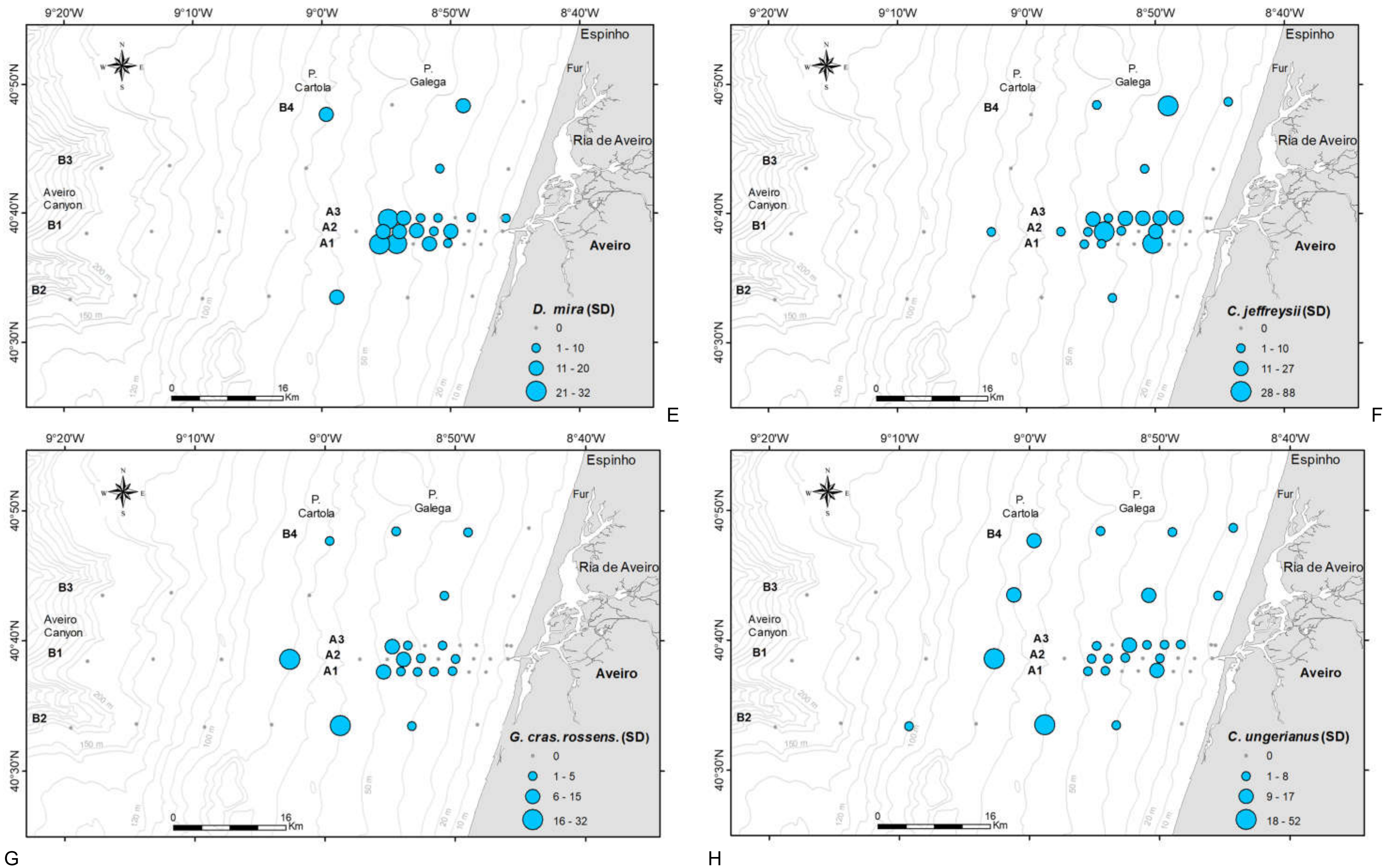

Fig. 7. (cont.) Distribution maps of the main species /taxa density (SD; n.º/10cm³): E. *D. mira*; F. *C. jeffreysii*; G. *G. crassa rossensis* (*G. cras. rossens.*) and; H. *C. ungerianus*. Legend: P. Cartola - Pontal da Cartola; P. Galega – Pontal da Galega; Fur – Furadouro.

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The distribution map of this species density is presented in Fig. 7C. *Bolivina pseudoplicata* reached the highest density around 30 m and *B. ordinaria* at about 40-50 m deep, in front of the Ria de Aveiro outflow.

The highest relative abundance was observed for *P. mediterranensis* (≈10-55%) between 15 to 80 m deep mostly in the transects A; *L. lobatula* (≈10-27%) between 30-70 m deep (but mostly in station B1-2, at 70m deep); *C. jeffreysii* (≈10-25%) at ≈30-45 m deep, mostly in transects A and punctually in station B4-2; *C. ungerianus* (≈10-20%) mostly between ≈60-80 m deep (stations B1-2, B2-3 and B4-4); *D. mira* (≈10-20%) between 30-70 m deep, mainly in stations of transects A (Appendix 3).

Some other species were abundant (10-20%) in the 23 stations with more than 100 living foraminifera specimens such as: *Globocassidulina crassa rossensis, Paratrochammina bartrami, Lepidodeuterammina ochracea* and *Bolivina spathulata* (Appendix 3). The percentage of *G. crassa rossensis* increased in deeper area (B1-2, at about 80 m deep); *P. bartrami* only occurred in some shallower stations in transects A3 and B4, at N of Ria de Aveiro mouth; *L. ochracea* punctually reached relatively high percentage at south of Ria de Aveiro mouth and; *B. spathulata* was mostly present in transect A3, with a gradient of increasing toward the deeper station of this transect.

Some species were relatively abundant (5-10%; Appendix 3) in the mentioned 23 stations, such as: *Hanzawaia boueana, Nodulina dentaliniformis, Gavelinopsis praegeri, Cibicidoides pseudoungeriana, Discorbinella bertheloti, Remaneica anglica, Glomospira gordialis, Rotaliammina siphonata, Rotaliella chasteri* and *Elphidium gerthi.*

4.6 Statistical results

Results of R-mode and Q-mode CA are presented in Fig. 8A and Fig. 8B, respectively. R-mode CA allows the identification of two main clusters (Fig. 8A): I – including variables depending on TOM such as: Bolivinids (Fig. 7A), namely *B. pseudoplicata* (Fig. 7B) and *B. ordinaria* (Fig. 7C) and other taxa, for example, *Planorbulina mediterranensis* (Fig. 7D), *D. mira* (Fig. 7E), *C. jeffreysii* (Fig. 7F), *G. gordialis, B. spathulata, P. bartrami, N. dentaliniformis* and; II – composed by variables depending on depth such as: species richness, Shannon Index (Fig. 6A), equitability (Fig. 6B) and the species *G. crassa rossensis* (Fig. 7G)*, H. boueana, L. lobatula, C. ungerianus* (Fig. 7H)*, D. bertheloti, E. gerthi, R. chasteri, G. praegeri, R. anglica, C. pseudoungeriana, L. ochracea* and *R. siphonata.*

Q-mode CA also defines two main groups of clusters (Fig. 8B). In cluster 1, three sub-clusters can be considered: 1.1 with the stations A1-4, A2-4, A2-7, A3-3 to A3-6, B4-1 and B4-2; 1.2 including the stations A1-5, A1-7, A1-8, A2-5, A2-6, A2-8, A3-7, A3-8 and; 1.3 with stations B2-2, B3-2 and B4-3. Cluster 2.0 contains the stations B1-2, B2-3 and B4-4.

The clusters/sub-clusters of stations identified through the results of Q-mode Cluster Analysis (CA) are mapped in Fig. 9. The mean values of the variables of each group/subgroup of stations of the Q-mode CA (the same used R-mode CA) are presented in Table 1. In this table, the clusters and sub-clusters were placed in series based on depth. The mean values of the analyzed variables in each group/subgroup of stations reveal dissimilarities in torn of different ranges of depth.

5. Discussion

5.1 Bottom conditions in the study region

The results of granulometry in the studied stations confirmed the sediment distribution in very fine and fine sand between 10-20/25 m deep, coarse and very coarse sand between 35-80 m and 100-150 m deep and fine to medium sand in the stations located between 80-100 m. These results are in accordance with that previously obtained on the continental shelf sediment cover between Espinho and Aveiro (Abrantes et al., 1994; Abrantes and Rocha, 2007; Martins et al., 2012). They also focused on the entire Portuguese Continental Shelf or on the continental shelf at north of the Nazaré Canyon that also covers this area (e.g. Dias et al., 1981; Dias and Nittrouer, 1984; Dias, 1985, 1987).

These studies revealed that the “coastal deposits” of the inner continental shelf are located near the coast and extend up to 20 m deep, in the Aveiro region. They consist mainly of fine to very fine sands. These sediments are mostly unimodal sands, composed mostly by quartz grains, which are sub-angular to sub-rounded, with quite clear and bright surfaces, which indicate that they were not subject to more than one sedimentary cycle (e.g. Dias et al., 1981; Dias and Nittrouer, 1984; Dias, 1985, 1987). Once the local river contribution is small because their mouths are located in internal zones of the Ria de Aveiro, the sources of the terrigenous component to the inner Aveiro Continental Shelf is the advective transport of materials provided for the marine system by the rivers located at north of Espinho, especially the Douro River (e.g. Dias et al., 1881; Dias and Nittrouer, 1984: Dias, 1985, 1987).

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Tab. 1. Mean values of the variables composing the groups of stations established by Cluster Analysis (CA) of Figure 10A, in torn of several depths. The highest mean value of each variable is blue shaded. Data were seriated depending on depth rather than the sequential number of the clusters and sub-clusters.

Variables/CA Groups	1.1	1.3	1.2	2.0
Depth (m)	≈30	≈40	≈50	≈70
TOM (%)	0.56	0.46	0.54	0.67
FD (n.º/10cm³)	181	230	182	161
Species Richness (S)	25	34	22	28
Equitability (J')	0.77	0.81	0.70	0.82
Shannon Index (H')	2.48	2.84	2.13	2.73
Bolivinids (%)	27.4	21.7	21.1	11.0
P. mediterranensis (%)	15.7	11.2	37.2	4.8
B. pseudoplicata (%)	19.2	9.7	11.3	3.8
L. lobatula (%)	6.9	4.7	5.8	15.7
C. jeffreysii (%)	15.9	11.0	6.0	2.2
D. mira (%)	3.0	1.5	9.9	3.5
C.ungerianus (%)	3.9	2.8	2.0	11.1
G. crassa rossensis (%)	0.7	0.9	1.8	7.1
B. ordinaria (%)	6.2	10.3	7.1	5.8
P. bartrami (%)	3.6	3.9	0.0	0.2
L. ochracea (%)	0.8	6.0	0.3	3.9
B. spathulata (%)	0.8	0.0	1.5	0.0
H. boueana (%)	0.1	0.1	0.3	1.9
N. dentaliniformis (%)	0.9	3.6	0.7	3.1
G. praegeri (%)	0.6	3.9	0.5	3.4
C. pseudoungeriana (%)	0.7	1.3	0.0	3.1
D. bertheloti (%)	0.0	0.0	0.0	2.1
R. anglica (%)	0.6	1.7	0.0	0.5
G. gordialis (%)	0.4	0.4	1.1	0.4
R. siphonata (%)	0.1	2.6	0.3	2.0
R. chasteri (%)	0.9	0.7	0.4	1.4
E. gerthi (%)	1.1	0.3	0.2	1.5

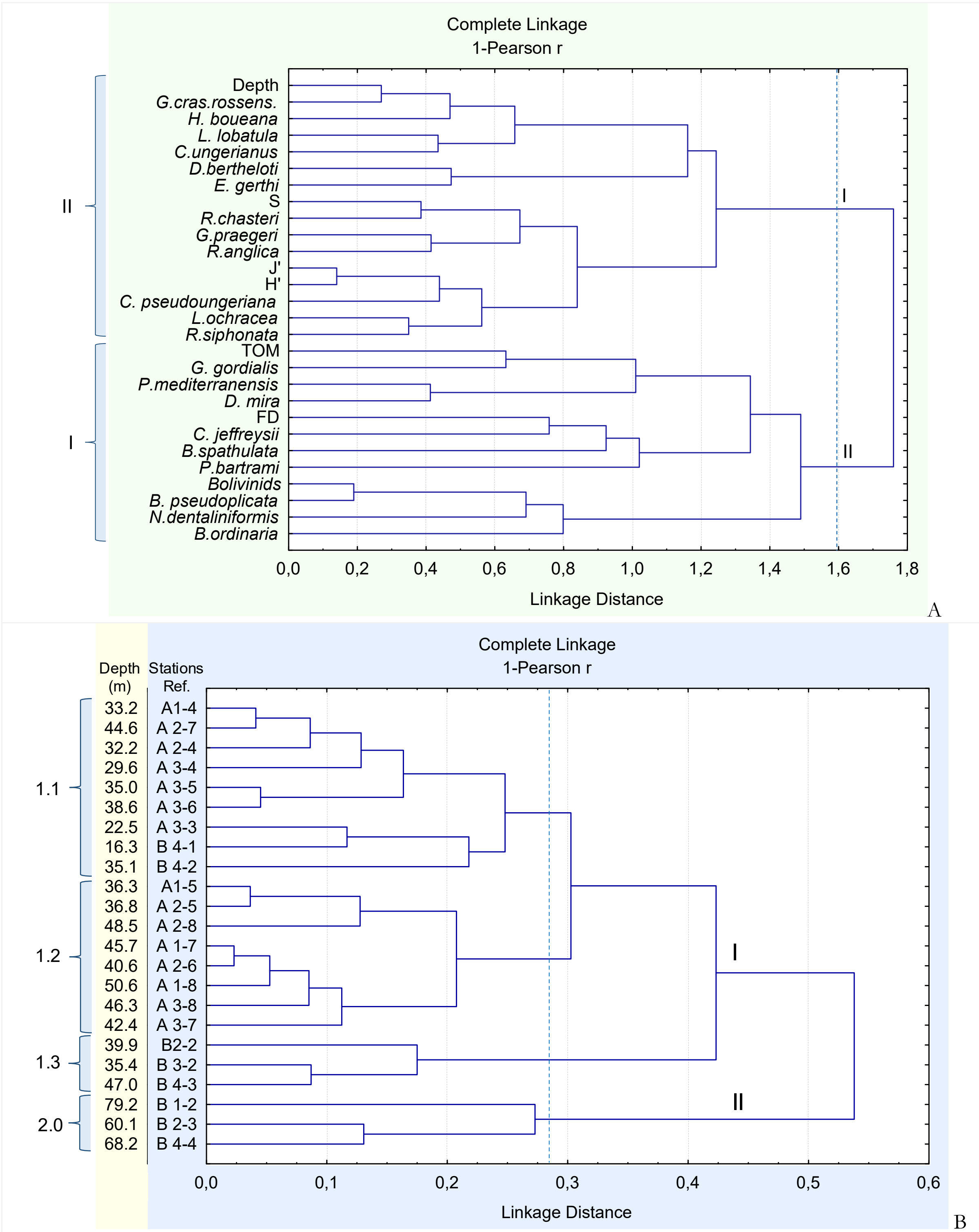

Fig. 8. A. Q-mode CA, clusters of 23 stations and depth (m). B. R-mode CA, cluster of selected variables. Legend: Stations Ref – stations reference; TOM – Total organic matter; FD – foraminifera density (nº/10cm^3); S – species richness; J' – Equitability; H' – Shannon Index*; G. cras. rossens. - G. crassa rossensis; C. pseudoung. - C. pseudoungeriana; P. mediterra. - P. mediterranensis; B. pseudopl. - B. pseudoplicata; N. dentalinif. - N. dentaliniformis.*

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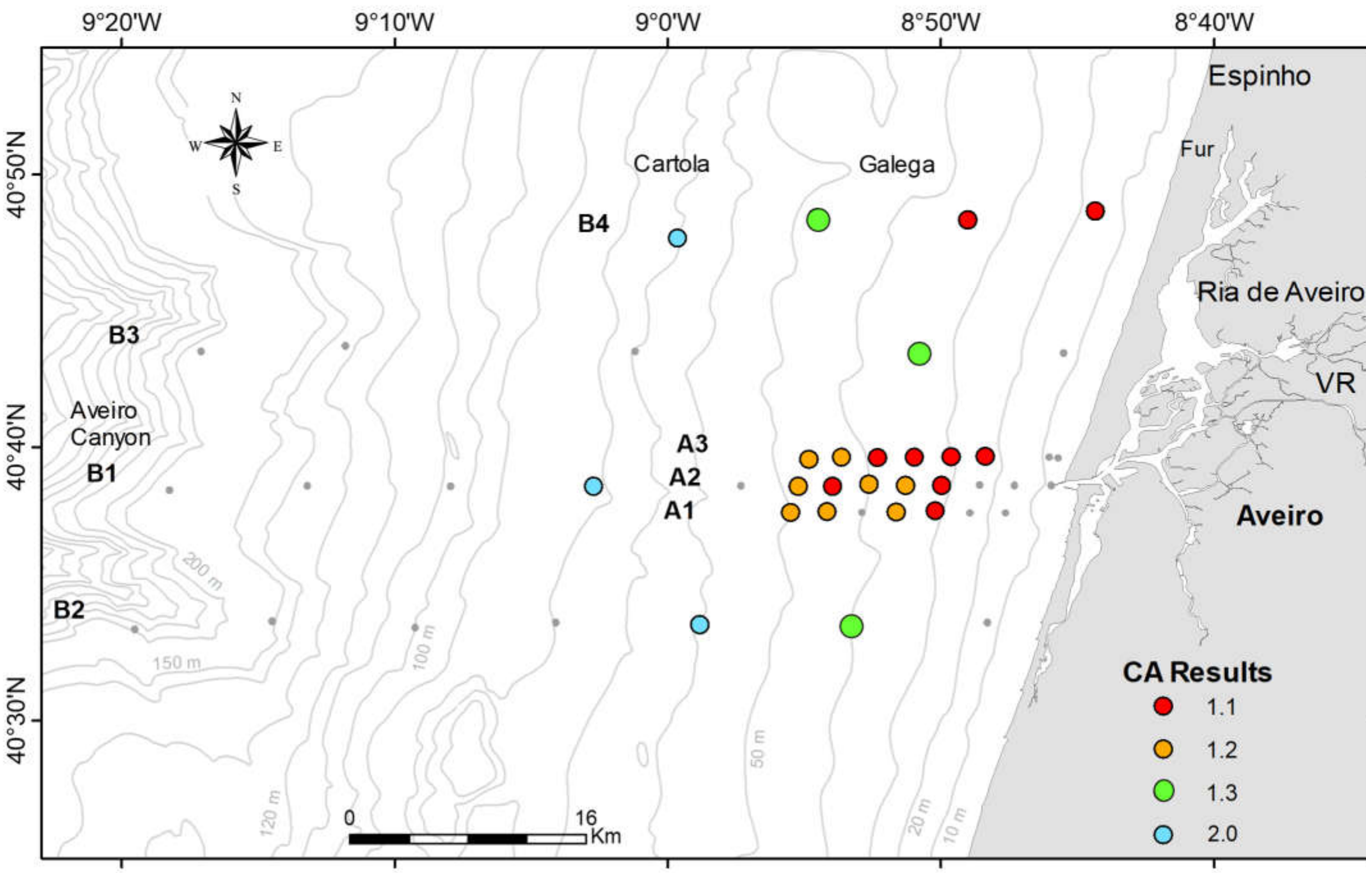

Fig. 9. Map indicating the groups/subgroups of stations identified through the results of Q-mode Cluster Analysis (CA) presented in Figure 8B. Legend: P. Cartola - Pontal da Cartola; P. Galega – Pontal da Galega; Fur – Furadouro; VR - Vouga River.

Other sources include the sands transported by the coastal drift, the transverse movements of sediments resulting from the coastal hydrodynamics, the erosion of the beaches and dunes and the external submarine bank of Aveiro Lagoon (e.g. Dias et al., 1981; Dias and Nittrouer, 1984; Dias, 1985, 1987). The sediments of the "coastal deposits" of the inner continental shelf are frequently remobilized and transported by the coastal drift (Dias et al., 1981).

The coarse and very coarse sand between 35-80 m and 100-150 m deep is rich in gravel (>2 mm) contents. In the first zone, the sediment fraction >63 µm has in general a small biogenic component. These deposits may be related to a paleolittoral because they do not reflect current hydrodynamic conditions (Dias and Neal, 1990). Up to about 80 m deep sand fraction is composed essentially of terrigenous particles. The outer continental shelf deposits between 80-90 m and 150 m deep are essentially made up of fine sand. In these sands, the biogenic component increases as the depth increases.

In the southern sector, located between 100 m and 150 m deep, there is a well-defined zone of relic deposits formed by coarse sand with significant amount of gravel particles, as observed, for instance, by Dias (1987) and Abrantes et al. (1994). These coarse particles are essentially from biogenic origin consisting of fragments of mollusk shells (fossils) and high abundance of foraminifera tests (a mixture of fossils and recent material).

In this zone, the sand and gravel fractions have low occurrence of quartz and mica and significant amount of glauconite (Martins et al., 2012). This outer continental shelf coarse grained deposits were possibly formed during the Last Glacial Maximum, under favorable paleoenvironmental conditions (Dias and Neal, 1990). The sedimentary cover of the continental shelf break and the upper slope consists mainly of medium to very fine sand (Abrantes et al., 1994).

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These data reflect the prevalence of a relatively high hydrodynamic regime caused by waves and tides in this region of the Portuguese continental shelf that remove and transport sediments of the "coastal deposits" trough the littoral drift, avoid the accumulation of fine grained particles (silt and clay fraction) on the inner and mid shelf where this sediment fraction is quite reduced (Dias, 1987; Abrantes et al., 1994).

At depths greater than 80 m, there is an increase in the abundance of the fine fraction (silt + clay) and also of TOM contents. The deposition and accumulation of organic matter are in general associated with relatively low hydrodynamic conditions. The presence of glauconite in the region of Aveiro Continental Shelf indicates that have been occurring high supply of organic matter to the bottom and low accumulation rate of terrigenous sediments (Dias, 1987).

The hydrodynamic conditions of waves and tides should influence the sedimentary characteristics of Aveiro Continental Shelf. According to Carvalho and Barceló (1966), the periods of the most frequent waves on the west coast of Portugal oscillate between 9 and 11 seconds being the most frequent significant wave height, from 1 m to 2 m. On the other hand, waves with significant height exceeding 6 m and reaching 12 m and with periods exceeding 20 seconds are occasionally recorded. Thus, waves are sometimes able to remobilize the fine fractions of the sediments of the surface coverture of the continental shelf (Dias et al., 1981). After being removed by waves, these particles can be transported by unidirectional currents, even if their magnitude is insufficient to put them in motion (Dias et al., 1981). However, conditions of greater hydrodynamism with significant wave height above 5 m occur in general during winter storms, and on average 1 time per year (Pires and Pessanha, 1986). The shelf break is also characterized by relatively high hydrodynamic conditions caused by internal tides and internal waves (Maraldi et al., 2013).

Thus, the bottom sediment of broad areas of the Aveiro Continental Shelf, out of the action of the littoral drift, should remain stable for relatively long periods, a factor that certainly favors the establishment of benthic communities (Sen Gupta, 2002). Nevertheless, the constant instability of the sediment in the inner continental shelf and the occurrence of events that can periodically remove or disturb the sediment in outer shelf, shelf break and slope, may instead constitute unfavorable factors for the development of benthic communities.

5.2 Water column conditions in the study region

Parameters, such as temperature and salinity, which are important factors for benthic foraminifera were typically marine. As referred, during the summer, the occurrence of the upwelling of subsurface waters is an important phenomenon along the Portuguese coast (e.g. Fiúza et al., 1982). The values of Ekman transport determined for Vigo (42ºN, 9ºW; N Spain), at N of the study area, reveal the occurrence of upwelling events both in 1994 and 1995 (Fig. 10 A and B, respectively) on the western Iberian coast.

During the sampling event of 1995, a significant increase in the Ekman transport values was observed (peaking on 1st of August 1995, Julian day 230) indicating the occurrence of an upwelling event. However, at the beginning and at the end of this sampling event (SE), the upwelling indices were quite low (Fig. 10B). Water column parameters obtained along transect B2 (Fig. 2) recorded at the beginning of the sampling event of 1995 did not indicate a typical upwelling feature, which agrees with the low upwelling index values for Vigo (N Spain; Fig. 10B). The Ekman transport values estimated for Spring-Summer of 1994 reveal the occurrence of several upwelling events during this period. The upwelling events occurred during May, June, July and August of 1994 should have contributed to the increase of ocean productivity and the supply of labile organic carbon to the seafloor (Sanchez-Vidal, et al., 2004; Lorenzo et al., 2005).

5.3 Foraminiferal distribution on the Aveiro Continental Shelf

The stations located at the lowest depths (<20 m) of Aveiro Continental Shelf showed none or a few number of living organisms. High hydrodynamism, sediment instability and low availability of food, as mentioned, should have been imposed strong limitations for the establishment of living foraminiferal communities in this zone. In the sediments of this shallow sector, low density of empty tests of foraminifera were found as well. Empty tests of foraminifera (dead organisms) in this region are in general poorly preserved due to transport caused by the action of waves and currents and are generally very damaged and fragmented (Martins et al., 2012).

However, it is known that living foraminifera populations vary in time and space and that the number of living individuals may increase at certain times of the year in response to algae reproduction, the main food source for many foraminifera species (Murray, 1999; Schönfeld and Numberger, 2007; Koho et al., 2008). Seasonal fluctuations in environmental parameters also cause fluctuations in living populations (Schönfeld et al., 2012; Saad and Wade, 2017).

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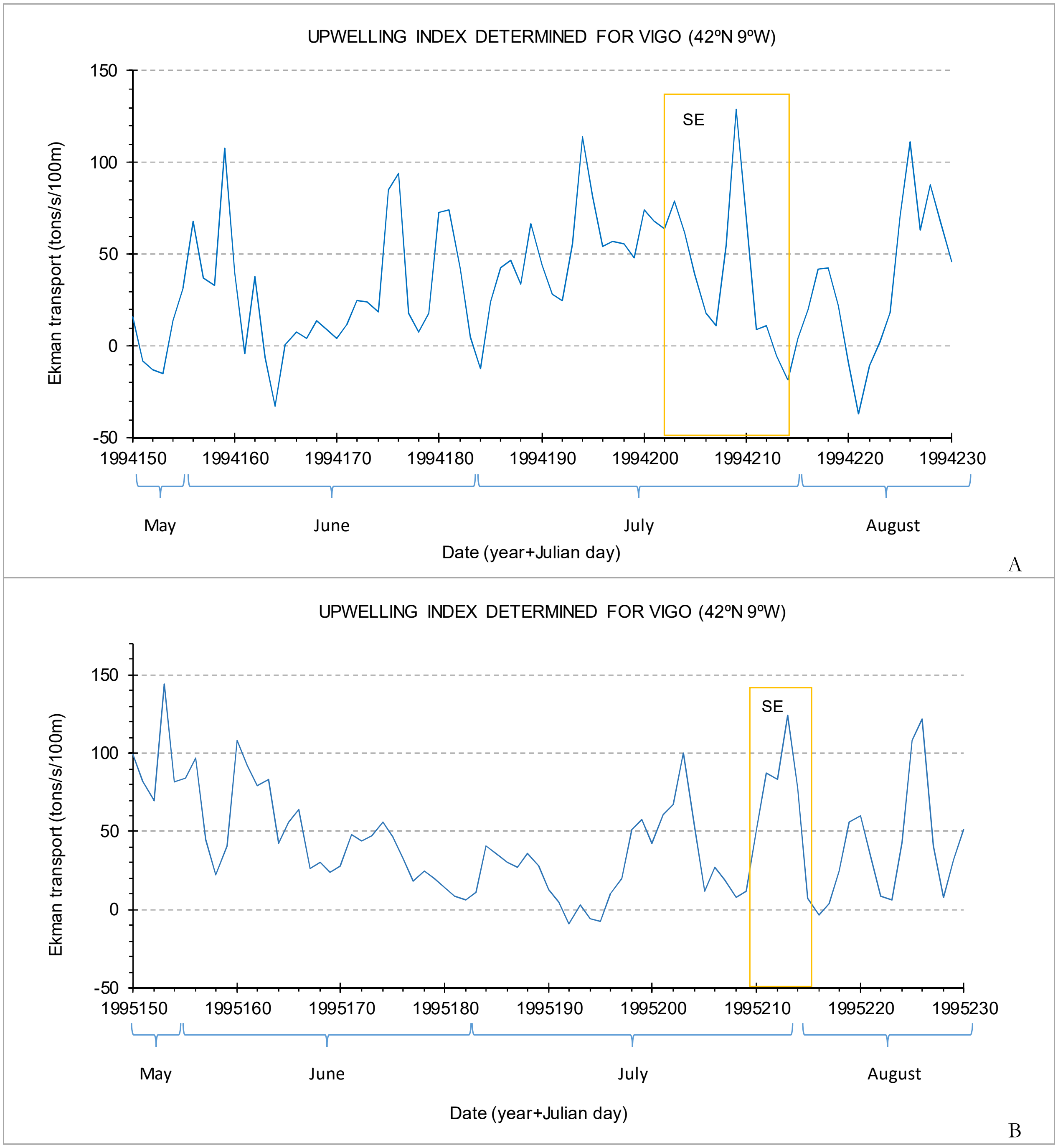

Fig. 10. Daily upwelling index determined for Vigo (42ºN, 9ºW) for three months before and during the sampling events in: A. 1994 and; B. 1995. Legend: SE – sampling events of this work.

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Foraminifera biocenoses marked by the highest density, species richness, Shannon Index and equitability were mostly found on the shelf band between 20-80 m deep, in the stations sampled both in 1994 and 1995, which may indicate healthy environmental conditions (Buzas and Hayek, 2005).

The upwelling events that occurred during May, June, July and August of 1994 should have contributed to the increase in ocean productivity and to the supply of labile organic carbon to the seafloor. The relatively high abundance of foraminifera in transects A (sampled in summer 1994), in the sector located between 20-80 m may be related to the contribution of organic matter from oceanic productivity.

Considering that high TOM contents (potentially food for the benthic communities) were found between 80 m and 200 m deep, along transects B1, B2 and B3, sampled in 1995, it was expected to find large numbers of living foraminifera in the deepest stations. Contrarily, despite the relatively high TOM contents (1-5%) found in these stations, reduced densities of living foraminifera were found in the deepest stations.

The graph showing the upwelling index for spring-summer of 1995 (Fig. 10B), indicates the occurrence of short upwelling events at the beginning of June, during the sampling event (SE) and a week before it. Nevertheless, throughout most of June and July the values of the upwelling index were weak. These data may indicate the occurrence of short and discontinuous upwelling events that should not have allowed development of the oceanic trophic chains, resulting in reduced flow of labile organic matter to the bottom. Thus, we should deduce that the diminished availability of labile organic matter (food of high quality for the benthic fauna) may have prevented the development of large communities of living foraminifera in the deepest stations of the study area (sampled in 1995) despite having a relatively high amount of TOM. This allows us to assume that the organic matter found in these stations was probably essentially refractory, degraded and with poor quality to be used as food for the benthic organisms, such as foraminifera and bacteria.

However, although the upwelling index values were quite low in late spring and early summer of 1995, when transects B were sampled, the stations located between 20-80 m of these transects have relatively large biocenoses of foraminifera. These data suggest that the input of organic matter provided to the Aveiro Continental Shelf should be delivered from other sources including the Ria de Aveiro outflow. Strong ebb currents may have contributed to the introduction of organic matter related to the biological productivity in this lagoon that is a very high productive ecosystem into the oceanic system.

Furthermore, the present Multimunicipal Sanitation System of the Ria de Aveiro (Sistema Multimunicipal de Saneamento da Ria de Aveiro) had not yet come into operation. This sanitation system gathers sewage and collects, treats and rejects domestic and industrial effluents from municipalities of the region of Aveiro. As a result, we can assume that sewage from the settlements located along the coast north and south of the Ria de Aveiro mouth and the runoff from agricultural fields should have also contributed to an additional input of organic matter (relatively fresh and decomposable by the bacterial activity) or to the release of nutrients that may have locally increased the oceanic productivity and the organic carbon flow for the benthic communities.

In general, foraminiferal abundance is small in coarse grained sediments and where TOM contents are low (Martins et al., 2015a). However, the biocenoses of foraminifera from the sector located between ≈20-80 m, were found in medium, coarse and very coarse sands, and in sediments with organic matter content varying between 0.20% and 1.06%. These data suggest that the granulometry and the sedimentary organic matter contents were not for themselves the most relevant conditioning factors for the development of benthic foraminifera assemblages in this marine setting.

5.4 Biocenoses of foraminifera from the sector located between 20-80 m

The results of the cluster analysis based on 23 stations located between 20-80 m, with TOM content ranging from 0.39 to 1.63%, show that some species of benthic foraminifera biocenosis found in the summers of 1994/1995 prefer to live in relatively deep waters. This is the case of instance *G. crassa rossensis, H. boueana, L. lobatula, C. ungerianus, D. bertheloti, E. gerthi, R. chasteri, G. praegeri, R. anglica, C. pseudoungeriana, L. ochracea* and *R. siphonata.* Otherwise species such as *G. gordialis, P. mediterranensis, D. mira, C. jeffreysii, B. spathulata, P. bartrami, N. dentaliniformis* and Bolivinids, namely *B. pseudoplicata* and *B. ordinaria* tend to increase in abundance with the relatively increase of TOM values (up to 1.63%). We should infer that, at least in part, organic matter of these shallow stations was fresh (of high quality as food for the benthic organisms), considering the occurrence of high density of foraminifera and the presence of opportunistic species in assemblages composition.

The H' values <2.70 in most of the stations are indicative of the presence of relatively low-maturity biotic communities

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due to the variability of the environmental conditions (Sanders, 1968, 1969). However, H' values >2.5 (maximum 3.24) found in 11 stations can be considered relatively high when compared with that ranging from 0.11–1.77, found in the river-dominated shelf of the Rhône prodelta (NW Mediterranean), for instance (Goineau et al., 2012).

The H' values of the sector between 20-80 m were not too much different from that based on the total assemblages of benthic foraminifera: varying between 1.7 and 3.4 on Aveiro Continental Shelf and upper slope (Martins et al., 2012); ranging between 2.4 and 3.8 on the Guadiana shelf, Southwestern Iberia (Mendes et al., 2004); ranging from 2-4 offshore Fraser Island, Australia (Schröder-Adam et al., 2008). Therefore, it should be deduced that the biocenoses composition of foraminifera found between 20-80 m were relatively well established and included species common in other regions of the Portuguese Continental Shelf (Mendes et al., 2004; Guerreiro et al., 2009; Martins et al., 2012, 2014).

The results of R-mode CA (Fig. 8B) and the values presented in Table 1 indicate that the biocenosis in the sector between 20-80 m changes in composition in function of depth but also laterally. For instance, the stations closest to the mouth of the Ria de Aveiro and along the transect B4 (sub-clusters: 1.1 with the stations A1-4, A2-4, A2-7, A3-3 to A3-6, B4-1 and B4-2) in depths around of 30 m, with TOM contents of about 0.56%, included mostly Bolivinids, namely *B. pseudoplicata*, as well as *C. jeffreysii.*

Between 35 m and 40 m deep, in stations of transects A (near the lagoon mouth), the ratio between the agglutinated/calcareous foraminifera presents relatively high values. In this zone, the presence of a significant number of euryhaline and eurythermic agglutinated species, also can be found alive in Aveiro Lagoon (Martins et al., 2014, 2015 b, 2016 a, b), such as *C. jeffreysii, Lepidodeuterammina eddystonensis*, *L. ochracea*, *Remaneica plicata* and *Remaneicella gonzalezi* is in agreement with the possible occurrence of salinity and temperature deviances related to the lagoon outflow. The living foraminiferal assemblage found in this sector seems to include mainly opportunistic species, such as some Bolivinids and *C. jeffreysii* that should tolerate environmental disturbance but are benefited by the supply of organic matter from the Aveiro Lagoon.

The biocenosis in stations away from the direct influence of the Ria de Aveiro mouth, located around ≈40 m deep (sub-cluster 1.3, including B2-2, B3-2 and B4-3; with mean values of TOM content of ≈0.46%) reaches the highest FD, species richness and H' values. This assemblage does not have dominant species and is composed mostly by *B. ordinaria, P. bartrami, L. ochracea, N. dentaliniformis, G. praegeri* and *R. siphonata.* The slight reduction of TOM content associated with the highest values of FD suggests that this reduction should not be caused by a rapid turnover of organic matter carried out by the benthic fauna. This biotope is less impacted by the influence of the lagoon outflow.

The living foraminifera assemblages found around ≈50 m deep (sub-clusters 1.2: stations A1-5, A1-7, A1-8, A2-5, A2-6, A2-8, A3-7, A3-8), further away of the Ria de Aveiro mouth (with mean values of TOM content of ≈0.54%), are largely dominated by *P. mediterranensis* and present relatively high abundance of *D. mira* and the lowest H' and equitability values and highest dominance. This assemblage is composed mostly by species that prefer to live on the surface of the sediments. It occurs probably because most part of the organic matter existing in inner sedimentary layers is not of good quality to be used as food.

The biocenosis around 70 m deep (stations of the cluster 2: B1-2, B2-3 and B4-4) and associated with a slight increase of TOM content (≈0.67%) includes relatively high percentages of, for instance, *Globocassidulina crassa rossensis, H. boueana, L. lobatula, C. ungerianus, D. bertheloti, E. gerthi, R. chasteri* and *C. pseudoungeriana.* Most of these species are also epifaunal and suspending feeders. This means that these species develop here, where the competition with much more opportunistic organisms diminish. Most of the species of this cluster may obtain the food from the water column or from the surface of the sediment. Perhaps organic matter present in inner sedimentary layers is also of poor quality.

6. Conclusion

Living foraminiferal density was low in shallower stations under the influence of the continental drift, due to sediments instability. It was also low in the stations of the outer shelf and shelf break probably because of the lack of food quality, conditioned by the occurrence of weak upwelling events during the months preceding the sampling campaigns.

The biocenoses of foraminifera were mainly found in the sector located between 20-80 m. These biocenoses may have been established probably due to the organic matter flux resulting from oceanic productivity and also from other supplementary sources. These supplementary sources may include the Ria de Aveiro ebb outflow, effluents resulting from human activity released into the ocean or from nutrients of agricultural fields runoff that enhance the marine productivity.

The obtained results indicate that the living foraminiferal density does not always have a positive relationship to TOM and or a negative one to sediment granulometry. Probably, the stability of the substrate and the presence of labile organic matter, which can be used as food for benthic organisms, are important factors regulating the size and composition of foraminifera biocenoses in addition to the variability of environmental parameters such as temperature and salinity.

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Appendices 1-3 are attached as supplementary materias (SM1-SM3) in http://www.e-publicacoes.uerj.br/index.php/jse/article/view/28041

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