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Geographical and bathymetric distribution of foraminiferal assemblages from the Alboran Sea (western Mediterranean)

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ABSTRACT

A total of 176 surface sediment samples, recovered in the Alboran Sea by the oceanographic vessel Vizconde de Eza during the 2002 and 2003 campaigns, were analysed for their foraminiferal content. Planktonic and benthic foraminifera were picked up, studied and classified. In addition, a series of diversity indices were calculated. An attempt was made to correlate diversity (Fisher alpha index) with longitude, latitude and depth. Planktonic assemblages are strongly dominated by the species *Globorotalia inflata* (d'Orbigny) together with *Globigerina bulloides* d'Orbigny. Correlation analysis show only a weak relation between planktonic foraminiferal diversity and both longitude and distance to the coast, which in the Alboran Sea are strongly related with depth. Benthic assemblage diversity is correlated with longitude, thus reflecting a West to East diversity increase pattern, and with depth, latitude and distance to the coast, suggesting a diversity decrease with depth. No significant correlation has been found between average chlorophyll concentration and either planktonic or benthic foraminiferal diversities. A Q-mode Hierarchical Cluster Analysis (HCA) recognised four clusters with different bathymetric and geographical distribution: Cluster A, mostly in the easternmost part of the studied area, in the Almeria Gulf, is composed of shallow highly diverse samples, dominated by *Cibicidoides lobatulus* (Walker & Jacob) and *Textularia agglutinans* d'Orbigny, indicating current-influenced environments with close algal or vegetation-covered areas; Cluster B includes the deepest, less diverse assemblages, strongly dominated by the low-oxygen tolerant species *Uvigerina mediterranea* Hofker and *Uvigerina peregrina* Cushman; Cluster C groups many outer shelf-upper bathyal samples along the Malaga and Almeria coast with opportunistic species like *U. peregrina*, *Cassidulina laevigata* d'Orbigny, *Bulimina marginata* d'Orbigny and *U. mediterranea* that reflect abundant organic supply in an upwelling area and, finally, Cluster D, representing shallow relatively diverse samples, mainly located on the Alboran Ridge, and with predominating *Dorothia pseudoturris* (Cushman), *Textularia pseudorugosa* Lacroix, *Elphidium crispum* (Linné) and *C. lobatulus* related with coarse-grained current-influenced sediments and nearby vegetation-covered areas.

1. Introduction

Foraminifera constitute a diversified phylum of unicellular organisms that build a test, which is able to persist in time. Therefore, they are characterised by an extensive fossil record that extends up to the present and are of primary interest for many different specialists, including palaeontologists, biologists and geologists (Boersma, 1978; Haynes, 1981; Culver, 1993).

Some classical foraminiferal studies set in the Mediterranean Sea focused on taxonomical aspects such as that of Hofker (1960) on the benthic foraminifera of the Bay of Naples. More recent are the systematic studies by Cimerman and Langer (1991) for the Adriatic and Tyrrhenian seas and by Rasmussen (2005) for the Aegean.

Distribution and ecology of foraminifera have also been treated by many authors both in the whole Mediterranean Sea (e.g. De Rijk et al., 1999, 2000) and in more limited areas, such as the sea of Marmara (e.g. Armynot du Chatelet et al., 2013; Kirci-Elmas, 2013), the Aegean (e.g. Debenay et al., 2005; Bergin et al., 2006; Dimiza et al., 2016a, 2016b), the Adriatic (e.g. Haake, 1977; Jorissen, 1988; Barmawidjaja et al., 1992; Hohenegger et al., 1993; De Stigter

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et al., 1998; Donnici and Serandrei Barbero, 2002; Serandrei Barbero et al., 2003; Duijnstee et al., 2004; Ernst et al., 2005) or the Thyrrenian (Frezza et al., 2010) among others.

Due to its geographical location, in the westernmost part of the Mediterranean and in direct contact with the Atlantic, the Alboran Sea has been the object of particular interest. The diversity and taxonomy of foraminifera in this area have been studied by different authors (Sánchez-Ariza, 1983a, 1983b; Usera and Alberola, 2009; Usera et al., 2010; Milker and Schmiedl, 2012; Giner-Baixauli et al., 2012; Guillem et al., 2014, 2015; García et al., 2015; García-Sanz and Usera, 2015). In addition, several works based on foraminifera have been developed on its oceanographic and palaeoclimatic characteristics during the Quaternary (Pujol and Vergnaud Grazzini, 1989, 1995; González-Donoso et al., 1991; Linares et al., 1999; Pérez- Folgado et al., 2003, 2004; Milker et al., 2009, 2011).

The aim of the present work is to increase the knowledge on the distribution and composition of the planktonic and benthic foraminiferal assemblages in the Alboran Sea, basing on 168 samples recovered by the oceanographic vessel "Vizconde de Eza" in two cruises carried out in 2002 and 2003. An additional goal is to characterise the eventual relationships between foraminiferal assemblages and several recorded environmental factors (depth, primary productivity, distance from the coast, etc.), which may result in an improved use of foraminifera as palaeoenvironmental proxies in this geographical area.

2. Regional setting

The Alboran Basin formed during the orogenic extension from the Oligocene to the Miocene as a consequence of the collision between the Euroasiatic and African plates (Comas et al., 1999). The current Alboran Sea is approximately 180 km wide (N-S), it extends about 350 km from East to the West and its depth averages 1000 m although more than 2200 m are attained in some places. It can be roughly subdivided in three sub-basins: Eastern, Western and Southern Basins, which lie around the Alboran Ridge, where the Island of Alboran is located. Submarine volcanoes and elevations (such as the Algarrobo, Herradura and Djibouti Banks, or the Maimonides Mount) can also be found.

As in the rest of the Western Mediterranean, shallow subtidal areas are characterised by *Posidonia* meadows with bioclastic sand patches. Deeper zones show red algae and coarse-grained carbonate particles and muddy sands with biotic content prevailing under 90 m depth (Betzler et al., 2011).

High temperatures in summer cause a high evaporation rate, which is combined with an insufficient runoff from the local rivers. This results in a water deficit only compensated by the connection with the Atlantic Ocean through the Strait of Gibraltar, (Sánchez-Ariza, 1983a, 1983b). Consequently, surface waters in Alboran are constituted by incoming Atlantic Waters (AW) that flow over the more dense Levantine Intermediate Water (LIW) and Western Mediterranean Deep Water (WMDW) water masses (Robinson et al., 2001). From the Strait of Gibraltar, the AW enters and forms two anticyclonic gyres: The Western Alboran Gyre (WAG) and the Eastern Alboran Gyre (EAG) (Fig. 1). These two gyres give rise to upwelling conditions and subsequently high nutrient and chlorophyll concentration values on the Spanish coast (Pérez- Folgado et al., 2003, 2004; Milker et al., 2009, 2011; Milker and Schmiedl, 2012).

3. Material and methods

A total of 176 samples were recovered in the Alboran Sea by the oceanographic vessel "Vizconde de Eza" during the 2002 and 2003 campaigns, using a Shipek drag, which collects the uppermost centimetres of the bottom sediment. Each sample was numbered, GPS-localized and its depth was recorded (Usera and Alberola, 2009, 2010; Giner-Baixauli et al., 2012; Guillem et al., 2014, 2015; García et al., 2015; García-Sanz and Usera, 2015).

A constant weight of 50 g per sample was kept in hot water for 24 h in order to disaggregate the substrate and subsequently washed on a 63-μm mesh to preserve the sand-size sediment. Samples were then dried under infrared lamps and stored in paper bags (García-Sanz and Usera, 2015).

At least 300 foraminifera per sample were picked up under a binocular microscope and fixed to micropalaeontological slides. The taxonomical classification was based on several authors (e.g. Barker, 1960; Colom, 1974; Kennett and Srinivasan, 1983; Hemleben et al., 1989; Martins and Dragao Gomes, 2004; Milker and Schmiedl, 2012; Hayward et al., 2017). We have followed the high-rank classification established by Pawlowski et al. (2013).

The next step was to build a database with the identified species. From this database, the Shannon-Wiener H' and Fisher alpha diversity indices were calculated. Their mathematical expressions can be found in several works (e.g. Fisher et al., 1943; Magurran, 1988; May, 1975; Pielou, 1975; Krebs, 1989; Hammer and Harper, 2006). Only samples with at least 100 tests were considered for further statistical analyses. This involved that only 65 samples could be analysed for benthic assemblages (all samples could be included in the analyses for planktonic foraminifera).

In order to estimate primary productivity, average chlorophyll concentration values corresponding to the period 2000–2016 were assigned to the different sampling points basing on annual maps provided by http://www.juntadeandalucia.es/medioambiente/the Junta de Andalucía website.

Diversity Fisher alpha index was then correlated (Pearson index) with the following parameters: depth, distance to the coastline, geographical coordinates (longitude and latitude) and average chlorophyll concentration.

A Hierarchical Cluster Analysis (HCA) was performed on previously log-transformed ($x \longrightarrow \ln(x+1)$) raw abundance data with both planktonic and benthic assemblages to explore possible distribution patterns. The correlation coefficient was employed as similarity index and the unweighted pair-group average (UPGMA) as the clustering algorithm. Only species with relative abundances above 5% in at least one sample were taken into account. PAST software package (version 3.14) was used for all statistical procedures (Hammer and Harper, 2006).

4. Results

4.1. Planktonic foraminifera

A total of 25 species of planktonic foraminifera were identified in the 176 samples studied. *Globorotalia inflata* (d'Orbigny) (Fig. 2.1) is by far the dominant species: it averages 64% of the total abundance in the planktonic assemblages (with a wide range oscillating between 4% and 98%) and represents more than 50% of the preserved tests in 136 samples and more than 90% in 17 samples (e.g. in S-39(02) or S-9(02) az). It is followed by *Globigerina bulloides* d'Orbigny (Fig. 2.2), which is dominant in 20 samples and shows an average relative abundance of 16%. Other species are present in lower percentages but occur in almost all samples, such as *Globigerinoides ruber* (d'Orbigny) (Fig. 2.3) or *Orbulina universa* d'Orbigny (Fig. 2.4), both with an average frequency of 6%, and to a lesser extent *Globigerinella siphonifera* (d'Orbigny) and the right-coiled form of *Neogloboquadrina pachyderma* (Ehrenberg), which average around 1% of the total assemblage.

Richness and diversity values of the planktonic assemblages

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