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Low planktic foraminiferal diversity and abundance observed in a 2013 West-East Mediterranean Sea transect

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Abstract

Planktic foraminifera were collected with 150 µm BONGO nets from the upper 200 m water depth at 20 stations across the Mediterranean Sea between 02 May and 02 June, 2013. The main aim was to characterize the species distribution and size-normalized shell weight (SNW). Average foraminifera abundances and diversity are 1.42 ±1.43 ind.·10 m^{-3} (ranging from 0.11 to 5.20 ind.·10 m^{-3}), with ten overall species found, respectively. Large differences in species assemblages and abundance values are observed between the different Mediterranean sub-basins, with an overall dominance of spinose, symbiont-bearing species indicating oligotrophic conditions. The highest values in absolute abundance are in the Strait of Gibraltar and Alboran Sea. The western basin is dominated by *Globorotalia inflata* and *Globigerina bulloides* at slightly lower standing stocks than in the eastern basin. In contrast, the planktic foraminiferal assemblage in the warmer, saltier and more nutrient-limited eastern basin is dominated by *Globigerinoides ruber* sensu stricto (s.s.). These new collective results in combination with comparison to previous findings, suggest that stratification of the surface water column, nutrient concentration and hence food availability, and temperature seem to be the main factors controlling foraminiferal abundances and distribution. Standing stocks and size-normalized weight (SNW) of *G. ruber* s.s. and *G. bulloides* seem more related to food availability than seawater carbonate chemistry. Increasing temperature, salinity, surface ocean stratification and trophic conditions could be the causes of reduced abundance, diversity and species-specific changes in calcification in planktic foraminifera.

1. Introduction

The single-celled foraminifera comprise the most diverse group of calcareous zooplankton of the modern ocean. The majority of foraminifer species are benthic. About 50 morphospecies are planktic, which have

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a calcareous exoskeleton organized in chambers (e.g., d'Orbigny, 1826; Hembelen et al., 1989; Goldstein, 1999). The species are adapted to different environments due to differences in wall structure, pores, spines and test shape. The distribution of foraminifera is thought to be influenced by food availability, temperature, salinity, turbidity, radiation, and predatory presence; these factors provoke an overall water depth preference for each species, which shifts during ontogeny. Some of them are found only in the photic zone because they are symbiont-bearing and depend on light for photosynthesis. After reproduction, the empty shells sink to the seafloor, where their fossils are useful for paleoceanographic studies (e.g., Shackleton, 1968; Rohling et al., 2004; Mojtahid et al., 2015). Ecological tolerance limits of modern foraminifera are not completely defined, but progressive reduction in abundance (caused by worsening of their organic functions like nutrient uptake, growth and reproduction, until death) is related with their departure from optimum conditions (Arnold and Parker, 1999).

The vast majority of studies on planktic foraminifera globally are based on samples from bottom sediments and cores, mainly for paleoceanographic purposes, with few studies considering modern water column foraminifera, including the Mediterranean. The first modern study of planktic foraminifera in the Mediterranean was based on surface sediment samples collected by the Swedish Deep-Sea expedition of 1947-48. A subsequent study found different species assemblages between the western basin, the eastern basin, and the Aegean Sea (Parker, 1955). The pioneering study of water column foraminifera in the Mediterranean was achieved by Glaçon et al. (1971) in the Ligurian Sea, showing high relative abundance variations of the different species throughout the seasons. Cifelli (1974) was the first to cover the broader Mediterranean, with plankton tows at 250 m depth from west Madeira to the Isle of Rhodes in June 1969; they identified prominent differenced relative abundances of subtropical and subpolar species in different parts of the Mediterranean.

Thunell (1978) studied samples from the upper 2 cm of cores covering the Mediterranean, concluding that distribution of planktic foraminifera is closely linked with the distribution of the different surface water masses, with specific temperature and salinity ranges for each of them, as Bé and Tolderlund (1971) stated for the Atlantic, helped by the partial isolation effect of the different basins and sub-basins inside the Mediterranean. Those phenomena result in different species assemblages in each region. This contradicts somewhat with Pujol and Grazzini (1995), who gained quantitative data with flow-metered plankton tows in the upper 350 m of the water column, through a NW-SE Mediterranean transect from September-October 1986 and February 1988, and the Alboran Sea in April 1990. They concluded that despite the W-E temperature and salinity gradients observed, those were not wide enough and no close correlation was found to justify the extremely variable foraminifera assemblages, with high seasonal and geographical variations in absolute and relative abundances. They suggested that food availability is the main factor controlling their seasonal and geographical distribution and abundance; and when nutrients are sufficient, hydrographic structures like eddies and fronts are the ones that play the main role.

The calcification of foraminifera is affected by the chemical state of their surrounding waters. Its weight is positively related to temperature, pH, $[Ca^{+2}]$, and alkalinity from its ambient water and negatively related with $[CO_2]$ (Schiebel and Hemleben, 2005). Beer et al. (2010) discussed the positive relation between weight and $[CO_3^{-2}]$, suggesting that it is not a significant parameter for calcification. It seems

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that biotic factors like ecological stress do not affect the calcification intensity (Weinkauf et al., 2013). Since the industrial era, anthropogenic emissions of CO_2 have led to ocean acidification, decreasing its pH and $[CO_3^{-2}]$, which provokes reduced stability of $CaCO_3$ that may obstruct the building of foraminiferal tests (Zeebe, 2012; de Moel et al., 2009; Moy et al., 2009).

Mediterranean studies of water column foraminifera and accurate knowledge of its different species ecology remain scarce. Few studies exist covering the Mediterranean Sea; most are focused at specific regions, e.g., the Tyrrhenian Basin (Coppa et al., 1980), the Alboran Sea plus the southwestern Mediterranean (van Raden et al., 2011), among others. Data on live planktic foraminiferal abundances were provided by Cifelli (1974; spring only) and more recently by Pujol and Grazzini (1995). In addition, few size-normalized weight (SNW) studies from water column foraminifera are available in the literature. New data are needed, since environmental conditions of the water column and associated foraminiferal assemblages might have changed over the past 20 years.

In this paper, new quantitative and qualitative data are presented on living planktic foraminifera, across the Mediterranean Sea during May 2013. Comparisons are made with older similar studies from Pujol and Grazzini (1995), Cifelli (1974), and Thunell (1978). The study by Thunell (1978) is based on surface sediments, which can provide information, which might be biased towards faster-sinking and more hydrodynamic tests due to shorter exposition to dissolution processes (Caromel et. al., 2014; Schiebel et al., 2007), and towards more unbreakable tests that are better preserved (Thunell, 1978). In additional, empty tests are passive particles that ocean currents may displace. On the other hand, average drift distances of foraminiferal test are estimated to be less than 10 km in the Mediterranean (Sebille et al., 2015), and correlated results between plankton tows (Pujol and Grazzini, 1995) and surface sediments (Grazzini et al., 1986) at coincident places inside the Mediterranean confirm the data of Thunell (1978).

The objectives here are to (1) delineate new absolute abundance data of spring planktic foraminifera within the different regions of the Mediterranean Sea, (2) characterize, at the species level their ecology through their seasonal and geographical distribution and abundance by comparison with previous studies, and (3) contribute new SNW data for comparisons between basins and with other studies from the literature in the context of ocean warming and acidification over the past 20 to 40 years.

2. Oceanographic Setting

The Mediterranean Sea, with a strong thermohaline and wind-driven circulation, and a surface of approximately 2,500,000 km^2, is divided into two main basins near the Strait of Sicily: the western and eastern basins. These basins are composed of different sub-basins due to partial isolation caused by sills that influence the water circulation, and by different water properties. Natural connection with the World Ocean is through the narrow Strait of Gibraltar, where the nutrient-rich Atlantic surface waters enter the Mediterranean and experience an eastward increase of temperature and salinity (Fig. 1) driven by insolation and evaporation, having a negative hydrological balance (evaporation exceeding precipitation). The Mediterranea also becomes increasingly oligotrophic towards the east (Fig. 1; Fig. 2). In addition, the

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111 incoming Atlantic waters enter the Algero–Provençal Basin until the Tyrrhenian Sea, and contribute to
112 deep water formation in the Gulf of Lion in cold winters (Rohling et al., 2015; Rohling et al., 2009).

113 In the eastern basin, two main sources of deep water formation are active mainly during winter in the
114 Adriatic and the Aegean Seas. Cold dry winds cause evaporation and cooling forming denser and more
115 saline water masses that sink to depth. The same process is active in the Levantine basin, forming an
116 intermediate water mass, which become progressively cooler and fresher toward the western basin. Some
117 waters reach the Tyrrhenian Sea. Waters returning to the Atlantic through the Strait of Gibraltar at depth
118 are cooler and saltier than the inbound waters, and compensate for the inflow from the Atlantic. The
119 Mediterranean Sea has a large physicochemical gradient for such a small marginal sea (Rohling et al.,
120 2015; Rohling et al., 2009; Hassoun et al., 2015b; Fig. 1).

121

122 ## 3. Methodology

123

124 ### 3. 1. Study Area

125 Stratified plankton tow samples were collected during the MedSeA (Mediterranean Sea Acidification in a
126 Changing Climate) cruise from 02 May until 02 June 2013 on board the Spanish R/V *Ángeles Alvariño*.
127 The transect was divided into two legs (Fig. 2). The first leg ranged from the Atlantic Ocean near the
128 Gibraltar Strait (adjacent to the Cadiz Harbour, Spain) until the Levantine sub-basin in the Eastern
129 Mediterranean (3879 km long, 11 sampling sites). The second leg started in Heraklion, Crete (Greece)
130 into the Ionian Sea, south of the Adriatic and Tyrrhenian Seas and finished in the North Algero-Provençal
131 basin, adjacent to Barcelona, Spain (3232 km long, 9 sampling sites, Fig. 2).

132

133 ### 3. 2. Material and methods

134 Twenty samples were collected with BONGO nets (mesh size 150 µm and 40 cm of diameter, for further
135 details see Posgay, 1980) at 200 m depth (Table 1). The sampling device was equipped with a flow-meter.
136 Physical, chemical, and biological parameters of the water column such as temperature, salinity, and
137 fluorescence, were obtained from the upper 200 m of the conductivity-temperature-depth (CTD) stations
138 located near the sampling sites.

139 Plankton samples were preserved by adding a 4 % formaldehyde solution buffered with
140 hexamethyltetramine at pH = 8.2 on board. From each sampling station, the foraminifera were isolated
141 and identified. Samples were counted and separated by species and size (size fractions: 150–350 µm,
142 ≥350–500 µm, >500 µm) to determine the absolute and relative abundances. Selected foraminifera for the
143 SNW study were photographed with a *Canon EOS 650 D* camera device attached to a *Leica Z16 AP0*
144 microscope to measure their diameter and silhouette area. Individuals of the same station and species
145 within a 50 µm diameter size constraint were weighed with a *Mettler Toledo XS3DU* microbalance (±1

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µg of error). A Pearson correlation test was applied to study the relation of foraminiferal SNW and relative abundance with temperature, salinity, pH, [CO_3^{-2}] and fluorescence. Absolute abundances were discarded for Pearson test as the magnitude of the variability observed between each station was much higher than the variability observed within the environmental parameters.

Foraminiferal samples were collected either at daytime or nighttime. Individuals were not necessarily alive when collected and no distinction was made between cytoplasm-bearing tests: alive or dead but still containing cytoplasm (see also Boltovskoy and Lena, 1970) and empty tests (dead). Cytoplasm-filled or empty dry-weighed foraminifera tests were weighted together since dry cytoplasm has no statistically significant effect on the weight of tests >150 µm (Schiebel et al., 2007). Unclassified specimens are not included in the test-size analyses presented in the following.

4. Results

4. 1. Absolute and relative abundance

The absolute abundance of planktic foraminifera collected with BONGO nets has a mean value of 1.42 ±1.43(SD) individuals·10 m^{-3}. A maximum value of 5.2 ind.·10 m^{-3} in the Strait of Gibraltar, is followed by 4.14 ind.·10 m^{-3} in the Alboran Sea, 3.61 ind.·10 m^{-3} in the Tyrrhenian Sea, and 3.00 ind.·10 m^{-3} off southern Crete. With the exception of these four regions, a standing stock of 1.7 ind.·10 m^{-3} is not surpassed at any other station. A minimum standing stock occurs in the Adriatic Sea (0.11 ind.·10 m^{-3}). The westernmost stations (1, 2 and 3) with the highest Atlantic influence have the highest abundance values (3.44 ind.·10 m^{-3} on average), followed by the eastern Mediterranean Stations 9 to 13 (1.31 ind.·10 m^{-3}), and the western Mediterranean (Stations 5, 6, 20, 21 and 22; 0.77 ind.·10 m^{-3}) with a clearer difference within the southwest (Stations 5 and 6; 1.08 ind.·10 m^{-3}) and the northwest (Stations 20 to 22; 0.56 ind.·10 m^{-3}; Fig. 3; Appendix A). Pervasively, the most common size fraction of foraminifera is 150–350 µm (65.57%), especially due to the contribution of *Globigerinoides ruber* sensu strict (s.s.) and *Globigerina bulloides*. The exceptions are at Station 3 with a high presence of 350–500-µm sized *Globorotalia inflata*, and Station 7a mainly due to >500-µm sized *Orbulina universa*, and 350–500-µm sized *Globigerinella siphonifera* and *G. inflata.* The 350-500-µm size fraction dominates in the western Mediterranean and is progressively reduced eastwards, mainly due to the contribution of small *G. inflata* from the 150-350 µm size fraction. In addition, a higher percentage of individuals >500 µm are found in the western part of the first transect (Fig. 4; Fig. S1; Appendix A). However, due to the extremely low standing stocks the above observations are mere snapshots, and may not be generalized.

The most abundant species is *G. ruber* s.s. (with an average of 0.30 ind.·10 m^{-3}, representing the 21.49% of the total sample); its highest abundances are found in the Tyrrhenian Sea (1.69 ind.·10 m^{-3}) and in the eastern Mediterranean (Stations 10 and 13). It is not present in the Adriatic Sea, at Station 16–18, and in

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the northwestern Mediterranean. It is found in low numbers in the southwestern Mediterranean, Atlantic, and Strait of Gibraltar stations. Individuals >350 µm in test diameter are rare (Fig. 3; Fig 4). *G. inflata* is the second most abundant species (0.29 ind.·10 m^{-3}; 20.19%), mainly due to its high abundance in the Alboran Sea (3.5 ind.·10 m^{-3}; 61.08% of the sample). It is present in the western Mediterranean until the Strait of Sicily. East of the Strait of Sicily, it is only found with low abundances at the westernmost stations. The dominant size fraction is 350-500 µm (Fig. 3; Fig 4). *G. bulloides* has an average abundance of 0.24 ind.·10 m^{-3} (17.20 %), mainly due to its abundance in the Strait of Gibraltar (2.31 ind.·10 m^{-3}; 47.34 %). It is slightly most abundant in the southwestern Mediterranean and the Tyrrhenian Sea. It is a quite ubiquitous species being absent at four stations. It is rarely occurs in the >350-µm test-size fraction (Fig. 3; Fig 4).

Globigerinoides sacculifer of the trilobus-type (on average 0.13 ind.·10 m^{-3}; 9.16 %), is especially notable at the Strait of Gibraltar (50.91 %). *O. universa* is ubiquitous in the Mediterranean with the exception of the three Stations 6, 9, and 14. Its average abundance is 0.12 ind.·10 m^{-3} (8.70 %). Its dominant size fractions are ≥350 µm. *G. ruber* sensu lato (s.l.; 0.09 ind.·10 m^{-3}; 6.41 %) is found mostly at the same stations as *G. ruber* s.s., but is usually less abundant. It is most frequent in the ≥350-500-µm test-size fraction, and some individuals >500 µm are found in the Atlantic (Fig. 3; Fig 4).

The other species occur in very low numbers: *Globorotaloides sacculifer* of the quadrocameratus-type (0.07 ind.·10 m^{-3}), *G. siphonifera* (0.03 ind.·10 m^{-3}), *G. ruber* (pink) (0.02 ind.·10 m^{-3}), *Hastigerina pelagica* (0.008 ind.·10 m^{-3}), *Globorotalia menardii* (0.001 ind.·10 m^{-3}) and normal-form *Globigerinoides sacculifer* (0.001 ind.·10 m^{-3}; Fig. 3; Appendix A).

To show the relative abundance of the various species, some stations were grouped together to achieve a minimum number of foraminifera (>95 tests); the grouping was set by location proximity in which foraminiferal assemblages were similar. The stations at the Strait of Sicily and the western Mediterranean (Stations 20, 21, 22) are not shown due to a low number of individuals (< 90; Fig. 5). Some similarities can be seen between the Tyrrhenian Sea and the eastern Mediterranean, and also between the Alboran Sea and the southwestern Mediterranean. The Atlantic and the Ionian–Adriatic–Aegean grouping have similar proportions of species. On the other hand, the rest of the locations have a clearly dominant species (*G. ruber* s.s. at the Tyrrhenian Sea and the eastern Mediterranean; *G. inflata* at the Alboran Sea), whereas in the southwestern Mediterranean the dominance is less clear, which might be due to a low number of individuals (*G.inflata* being the main species followed by *G. bulloides* as at the Alboran Sea station). *G. sacculifer* type trilobus has a high relative abundance in the Atlantic and in the Strait of Gibraltar (being the main and the second most abundant species respectively); elsewhere it is less abundant. *G. bulloides* is most frequent in the entire western Basin and the Atlantic, being the main species at the Strait of Gibraltar. It is less frequent in the Tyrrhenian Sea, and in the eastern Basin and its sub-basins. *G. bulloides* contrasts with *G. ruber* s.s., which always represents a small percentage in the western Mediterranean but dominates the Tyrrhenian Sea and the eastern Basin (Fig. 5; Appendix A).

A Pearson test was applied to the main species to see their relative abundance correlation with temperature, salinity, and fluorescence. The correlations found are: *G. ruber s.s.* is positively correlated

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with temperature and salinity ($p = 0.01$), and negatively with fluorescence ($p = 0.05$). *G. inflata* is positively correlated with fluorescence ($p = 0.05$) and *G. bulloides* has a negative correlation with temperature ($p = 0.01$). Relative abundance was selected instead of absolute abundance to avoid bias due to the big differences between stations' results in absolute abundance. The remaining species did not pass through a Pearson test as they are not present in all the stations, which makes it difficult to assess a relation between abundance and environmental parameters.

4. 2. Size-normalized weight (SNW)

Due to their abundance, *G. ruber* s.s., *G. bulloides*, and *O. universa* where analyzed for their size-normalized weight (SNW). The high two-dimensional (silhouette) area-to-diameter correlation is best fitted by a power regression (Fig. S2). Comparing the average values from different locations sampled within the Mediterranean, *G. ruber* s.s. individuals from the Atlantic have the largest size followed by individuals from the Tyrrhenian Sea, and tests from east of the Strait of Sicily. For the other two species *G. bulloides* and *O. universa*, the results are statistically not significant, but a similar trend is observed regarding the two basins, with the eastern Mediterranean having the smallest individuals, while the largest individuals occurred in the Atlantic and the northwestern Mediterranean (Fig. S2). The different locations were grouped using the same criteria as in Fig. 5.

The diameter-to-weight relation of *G. ruber* s.s. specimens yielded an $r^2 = 0.842$ (linear regression throughout this paragraph; Fig. S3), followed by *O. universa* ($r^2 = 0.630$), and *G. bulloides* ($r^2 = 0.516$; Fig. S3). *O. universa* was finally discarded for comparisons between SNWs at different locations due to a low area-weight correlation, while data from *G. ruber* s.s. correlate well (Fig. S4a). The eastern Mediterranean specimens are the lightest for both species (*G. ruber s.s.*, *G. bulloides*), with more extreme W-E differences for *G. ruber s.s.* (Fig. S4d-e).

G. ruber s.s. specimens from six locations were compared in a SNW study (Fig. 6). The eastern Mediterranean individuals have the lowest median SNW (approximately between $7.5 \cdot 10^{-5}$ and $9 \cdot 10^{-5}$ $\mu g \cdot \mu m^{-2}$), with lower values eastward, and a small interquartile range ($IQR = Q_3 - Q_1$). The Atlantic individuals of *G. ruber* s.s. show the highest median value ($1.55 \cdot 10^{-4}$ $\mu g \cdot \mu m^{-2}$) and IQR. The SNW of Tyrrhenian individuals ranges between those from the eastern Mediterranean and Atlantic Ocean ($1.2 \cdot 10^{-4}$ $\mu g \cdot \mu m^{-2}$). A Pearson correlation test was done to assess the correlations between the SNW values and the environmental parameters of the section above plus pH and $[CO_3^{-2}]$. In the Pearson correlation test, *G. ruber* s.s. shows a negative correlation with salinity, $[CO_3^{-2}]$ ($p = 0.01$), pH ($p = 0.05$) and a positive correlation with fluorescence ($p = 0.01$).

For *G. bulloides* specimens, seven locations were compared (Fig. 6). The Atlantic has the lowest median SNW ($8.75 \cdot 10^{-5}$ $\mu g \cdot \mu m^{-2}$) and the smallest IQR, showing an opposite trend as in *G. ruber* s.s. Also contrary to *G. ruber* s.s. individuals, the eastern Mediterranean individuals yield the highest median SNW ($9.75 \cdot 10^{-5}$ $\mu g \cdot \mu m^{-2}$) and IQR. The differences in SNW between the eastern and western Mediterranean are

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smaller in *G. bulloides* than in *G. ruber s.s*. *G. bulloides* is positively correlated with pH and [CO_3^{-2}] ($p = 0.05$) in the Pearson test.

5. Discussion

5. 1. Abundance and diversity patterns

The absolute abundance values of up to 4.2 individuals per 10 m^{-3} (≥150 µm) on average are low in comparison with other water column foraminifera studies found in the literature, even for oligotrophic regions. For example, in the oligotrophic northern Red Sea, less than 100 ind.·10 m^{-3} (>125 µm) were not reported from surface waters, and standing stocks were much higher than 100 ind.·10 m^{-3} at most of the sites sampled in 1984 and 1985 (Auras-Schudnagies et al., 1989). In the oligotrophic to mesotrophic Caribbean and Sargasso Seas, standing stocks were up to 786 ind.·10 m^{-3} (>100 µm) and 907 ind.·10 m^{-3} (>202 µm), respectively (Schmuker and Schiebel, 2002, and references therein). In the more proximal Atlantic, south of the Azores Islands, Schiebel et al. (2002) counted an average of 66.15 ind.·10 m^{-3} for the upper 100 m in August 1997, and 422.97 ind.·10 m^{-3} in January 1999 (>100 µm). Other similar studies continue to show results with one or two orders of magnitude higher abundance (e.g. Sousa et al., 2014; Boltovskoy et al., 2000; Kuroyanagi and Kawahata, 2004; Rao et al., 1991; Ottens, 1992; Schiebel et al., 1995). At higher latitudes, in the Fram Strait (Arctic Sea), Pados and Spielhagen (2014) obtained approximate values of 117 ±74 ind.·10 m^{-3} from the upper 500 m in late June-early July of 2011. Mortyn and Charles (2003), in February-March 1996, at 200 m depth range in the Atlantic sector of the Southern Ocean, found as a minimum value 0.1 ind.·10 m^{-3}, with an approximate mean of 73 ±160 ind.·10 m^{-3}.

Within the Mediterranean, a previous study with comparable results sampled the upper 350 m (Pujol and Grazzini, 1995). For the Alboran Sea, samples were obtained at a similar time of the year (April 1990) with values around 16, 6 and 9 ind.·10 m^{-3}, greater than our Station 3 with 4.14 ind.·10 m^{-3}. The rest of their samples occurs in a different season of the year and also have notably higher abundances, with larger ones in February than during September-October. Their sampling mean is also higher and approximates to 9.3 ±8.9 ind.·10 m^{-3}. Regarding Pujol and Grazzini (1995), western Mediterranean abundances are higher than the eastern ones overall, due to more eastern oligotrophic conditions and higher temperature and salinity values that limit foraminiferal production both, during winter and late summer. In concordance with Pujol and Grazzini (1995), no significant differences are observed between samples collected during day and night.

Ten different species are recognized in our study, accounting for a single species (to have comparable results with previous studies) the three varieties of *G. ruber*: sensu stricto, sensu lato (containing different cryptic species; Aurahs et al., 2009a), and the pink variety. To facilitate comparison, the different *G. sacculifer* morphotypes *trilobus* and *quadrocameratus* are here treated separately, despite belonging to the same genotype (André et al., 2013). Our findings contrast with previous studies covering the

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Mediterranean, where more species were found: 18 species with Cifelli (1974), and 17 species with Pujol and Grazzini (1995) and with the surface sediments of Thunell (1978). Some of the species not found reach high frequencies in the aforementioned studies: e.g., *Turborotalita quinqueloba*, *Neogloboquadrina pachyderma*, and *Globorotalia truncatulinoides*. The fact that these species were not sampled in the present study may be caused by their absence or presence at extremely low abundances of adult specimens at the sampled stations in May 2013. *G. sacculifer* type *quadrocameratus* was not found in previous studies working with plankton tows in the Mediterranean, despite its abundance in sedimentary cores (i.e. Živkovic and Glumac, 2007).

The lower absolute abundance of individuals in our study compared with Pujol and Grazzini (1995), together with low species diversity in the Mediterranean, may indicate a trend of changing conditions in recent years, as it has been reported for temperature and salinity (Yáñez et al., 2010), alkalinity (Cossarini, 2015; Hassoun et al., 2015a), and water mass mixings (Hassoun et al., 2015b). These changing conditions could also imply changes in the ecology and distribution of planktic foraminifera, as discussed below.

The western part of the first leg transect (from the Atlantic to the Strait of Sicily) has a higher percentage of larger size fractions than the eastern part; the main cause of that trend is the species composition. The results are conditioned by the presence of *G. inflata* (especially in the 350-500 µm fraction) with higher abundances in the west. The same is true for the presence of large *O. universa* (especially in the >500 µm), plus the contribution of *G. siphonifera*, which grow largest at stations in which they are most frequent (Fig. 4).

5. 2. Factors controlling the abundance of the main species

This discussion is focused on the five main species of our results. The spinose and symbiont-bearing species: *G. ruber*, *O. universa*, and *G. sacculifer* (always referring to the *trilobus* type), which mainly inhabit tropical and subtropical waters. *G. ruber* is found as the main species of the Atlantic. *O. universa* has a quite cosmopolitan standing stock, also being present in warm transitional Atlantic waters (Bé and Tolderlund, 1971). The spinose and nonsymbiotic species *G. bulloides*, typical of subpolar and transitional regions as well as upwelling areas, but also found in subtropical and tropical waters at a much lower abundance, highlighting its wide temperature range (Thunell, 1978; Bé and Tolderlund, 1971). The non-spinose species *G. inflata* is considered indigenous from the transitional region in the Atlantic (Bé and Tolderlund, 1971).

5. 2. 1. *Globigerinoides ruber*

Both varieties *G. ruber* sensu stricto (s.s.) and sensu lato (s.l.) are warm water shallow-dwellers and share similar habitats. Regarding some studies, *G. ruber* s.s. is found slightly shallower than *G. ruber* s.l. (Kuroyanagi and Kawahata, 2004; Wang, 2000); a reason could be that *G. ruber* s.l. may be less dependent on symbiont activity than *G. ruber* s.s. (Kuroyanagi and Kawahata, 2004).

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328 *G. ruber* s.s. and s.l. varieties are found in the Atlantic with slightly larger absolute abundances and
329 higher relative abundances than in the western Mediterranean Basin, where it is found in low abundances.
330 Temperature may be the main cause, with warmer Atlantic waters (16.1 ºC) with respect to the western
331 Mediterranean (14.3 ºC in the SW, 14.0 ºC in the NW; Fig. 1), as demonstrated by positive significant
332 correlations with temperature in the *G. ruber* s.s. variety ($p = 0.01$). The *G. ruber* results confirm the
333 findings of the June 1969 cruise of Cifelli (1974), where it was by far more abundant in the eastern than
334 the western Mediterranean Basin, clearly being the main species found in the Levantine Basin and the
335 south Ionian Sea; for these two locations it seems present during the different seasons, winter included,
336 which is also true for pink variety of *G. ruber* (see also Thunell, 1978; Pujol and Grazzini, 1995). The
337 dominance of *G. ruber* s.s. in the eastern Mediterranean Basin relative to the western Basin causes a
338 strong positive correlation with salinity ($p = 0.01$) in our data set. Its higher relative abundance in the
339 eastern basin may result from symbiont activity in *G. ruber*, supporting survival in oligotrophic regions,
340 and some independence from chlorophyll-*a* and macronutrient concentrations (Watkins et al., 1996). The
341 findings of Watkins et al. (1996) are supported by the negative correlations of standing stocks of *G. ruber*
342 s.s. and fluorescence data of our study ($p = 0.05$).

343 The dominance of *G. ruber* and abundance peaks in May in the eastern Mediterranean coincides with the
344 positive temperature gradient between Station 9 and Station 13 (16.2–17.3 ºC; Fig. 1), being more evident
345 for the *G. ruber* s.s. than for the *G. ruber* s.l. morphotype. In late summer, *G. ruber* experiences its largest
346 expansion and presence owing to warmer temperatures, clearly being the main species from the north of
347 Algeria to the Levantine Basin. *G. ruber* (pink) is the dominant species at the Strait of Sicily and
348 eastwards (Pujol and Grazzini, 1995), whereas in May it only has residual presence in some locations
349 (especially around Crete). In February, presumably due to temperature decrease, *G. ruber* (pink) almost
350 disappears from the Mediterranean and the other morphotypes are present in low numbers (Pujol and
351 Grazzini, 1995), suggesting that *G. ruber* s.s. and s.l. have wider cold temperature ranges than the pink
352 variety. Hydrographic conditions and consequently food availability seem to be the factors limiting more
353 its abundance once it has reached its habitable temperature range.

354 5. 2. 2. *Globorotalia inflata*

355 The presence of *G. inflata* is related with cool waters and high food availability (Pujol and Grazzini,
356 1995), following high phosphate concentrations (Ottens, 1992). This explains its higher abundance at the
357 cooler nutrient-rich western basin, and its progressive scarcity in the warmer oligotrophic eastern
358 Mediterranean (Fig. 1; Cifelli, 1974; Thunell, 1978). The same pattern is observed in late summer. From
359 spring to late summer shows a displacement from the eastern Alboran Sea to the northwestern
360 Mediterranean, decreasing frequency at the Algero–Provençal Basin and the southwestern Mediterranean
361 Basin, maintaining the residual presence at the eastern basin. In winter, with cooler temperatures, the
362 opposite process happens, and *G. inflata* becomes the dominant species at the southwestern basin, with
363 high frequencies in the Strait of Sicily and just east of it. Eastwards its presence is maintained at only
364 residual levels (Pujol and Grazzini, 1995). Its distribution along the seasons shows that *G. inflata* is
365 scarce or absent in warmer, stratified and nutrient-depleted regions in the Mediterranean.

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Despite having similar temperature ranges than the southwestern Mediterranean, *G. inflata* is absent in the Tyrrhenian Sea and the northwestern Mediterranean, and it had also found to be scarce in June (Cifelli, 1974). In addition, *G. inflata* shows a positive correlation with fluorescence ($p = 0.05$), suggesting that food depletion plays a more important role in limiting its distribution than warm temperatures.

Alboran Sea spring distribution of *G. inflata*, with *G. bulloides* as a clear secondary species, matches with other studies (Pujol and Grazzini, 1995; Raden et al., 2011). *G. inflata* peak abundances appear more to the west than those reported by Cifelli (1974) to the east of the Balearic Islands. Those peaks can be associated with nutrient-rich upwelling areas rich in foraminifer prey inside its temperature range (Fig. 1; Fig. 2).

5. 2. 3. *Globigerina bulloides*

Following Cifelli (1974), *G. bulloides* is the dominant specie in the Atlantic stations close to the Strait of Gibraltar, whereas in our study it shares presence with other species (Station 1; Fig. 3a). The *G. bulloides* dominance at the Strait of Gibraltar during late spring–early summer confirms the finding of Cifelli (1974). The abundance peak of *G. bulloides* at the Strait of Gibraltar coincides with high nutrient concentration and upwelling (Figs. 1, 2, and 3), making Station 2 the most rich in planktic foraminifera of all the transect. This confirms its association with upwelling areas, where phyto- and zooplanktonic blooms control its abundances, as it is an opportunistic species (Pujol and Grazzini, 1995; Sousa et al., 2014). It correlates with fluorescence peaks since it feeds on phytoplankton (Mortyn and Charles, 2003; Fig. 1).

In April (Pujol and Grazzini, 1995; van Raden et al., 2011) and May, it is found to be the second most abundant species, surpassed by *G. inflata*, in the westernmost Alboran Sea. One month later it is found to be the dominant species displacing *G. inflata*, which is still dominant in the eastern Alboran Sea (Cifelli, 1974). Its ubiquity and its higher abundance in the western basin with respect to the east is supported by previous studies (i.e., Cifelli, 1974; Thunell, 1978), with a higher difference in abundance in February than in September–October (Pujol and Grazzini, 1995). In late summer, its presence is more secondary, with abundance peaks around the Strait of Sicily and south of Sardinia. Abundance peaks at the same locations plus the Gulf of Lion occur during winter, but with larger absolute abundances (Pujol and Grazzini, 1995).

G. bulloides decreases in abundance when food is depleted, observable in the eastern Mediterranean, where it always has lower absolute abundances than in the west. During spring to late summer in the eastern basin, *G. bulloides* has a minor presence, being more present at the near east of the Strait of Sicily (Cifelli, 1974; Pujol and Grazzini, 1995). During winter its abundance increases and it becomes the second main species in the Levantine Basin preceded by *G. ruber*, and also it is one of the main species in the Ionian Sea. Levantine waters have permanent eddies that can help phytoplankton blooms, explaining the presence of *G. bulloides* in winter (Pujol and Grazzini, 1995). It is noticeable that northwards of the Levantine Basin and the Aegean Sea its abundances are comparable to those in the western basin regarding surface sediment data from Thunell (1978).

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G. bulloides has more affinity for cooler upwelled waters than warmer more stratified waters (Sousa et al., 2014; Thunell, 1978), being present in subtropical waters only in cooler months (Ottens, 1992). The coldest station of the first leg (Strait of Gibraltar, 14.2 ºC) tracked by BONGO nets coincides with its abundance peak, and it is absent in the warmest station (off the Nile Delta, 17.6 ºC; Fig. 1a), which also is one of the scarcest in foraminiferal prey (Fig. 1c; Fig. 2). Its negative correlation with temperature ($p = 0.01$) matches with its low abundance in the eastern basin and its higher abundances in the western basin (northwestern basin included, despite its low absolute abundances but being the main species there), and with its seasonal distribution. Its presence and distribution seems to be limited by a combination of low nutrient concentration and limited food availability, caused by stratification of the surface water column, and increased sea surface temperatures (SSTs).

5. 2. 4. *Orbulina universa*

O. universa was found ubiquitous by Pujol and Grazzini (1995), being present at all the stations and seasons, reaching peak abundances in the southwestern Mediterranean both in late-summer and winter. Regarding our data, it follows the same pattern during spring, only absent from three stations. No peak area is clear in spring in our data and that of Cifelli (1974), but slightly higher abundances in the western basin compared to the east are modest. That small difference can be caused by more nutrient-rich upwelling areas (Sousa et al., 2014; Morard et al., 2013) in the western basin or by high salinities in the eastern basin.

5. 2. 5. *Globigerinoides sacculifer* type *trilobus*

In June, the distribution of *G. sacculifer* is quite ubiquitous and has 5 % presence at the Strait of Gibraltar (Cifelli, 1974); meanwhile our results show a 25 % presence one month before and absence at seven stations. Also, lower percentages are found in April at the Alboran Sea (Pujol and Grazzini, 1995). In September–October it shows high abundances and is one of the main species from north of Minorca to the southwestern Mediterranean until the Strait of Sicily, where it is rarely found, presumably due to warmer waters than in May, even if this is not supported by our Pearson correlation. In late summer it decreases considerably and progressively eastwards, where the highly dominant *G. ruber* is maintained as the most important species (Pujol and Grazzini, 1995), probably due to slightly higher temperature and salinity tolerance (see also Bijma et al., 1990). On the other hand, in February *G. sacculifer* disappears from the north Levantine Basin and its abundances lowers considerably, being a residual species in terms of relative abundance in all the Mediterranean (Pujol and Grazzini, 1995), suggesting temperatures too cold for it.

5. 3. Factors controlling planktic foraminiferal test weight

The size-normalized weight (SNW) of tests of both *G. ruber* s.s. and *G. bulloides* are statistically significant, and follow a systematic change from the Atlantic towards the eastern Mediterranean (Fig. 6). Therefore, the SNW of these two species is interpreted and discussed for environmental effects and

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biological prerequisites in the following. In contrast, changes of the SNW of *O. universa* are statistically insignificant (Figs. S2c, S3c, and S4c), and cannot be used to identify and quantify particular environmental effects.

5.3.1 Unknown control of the SNW of *O. universa*

The lack of statistical significance in the SNW data of *O. universa* in our data set possibly caused by an insufficient understanding of the ecology of the different morphotypes and genotypes of *O. universa*. Despite the finding that only one out of three genotypes (i.e. Type III, after Darling and Wade, 2008) occurs in the Mediterranean Sea (Mediterranean species, after de Vargas et al., 1999), Weight-area relation data do not show any statistically significant systematic distribution (Fig. S4c). The Mediterranean Type III has been found to include two sub-types, Type IIIa and Type IIIb (André et al., 2014). The different genotypes and morphotypes of *O. universa* tolerate wide ranges of salinity and temperature in surface waters (e.g., de Vargas et al., 1999). Whereas the various types of *O. universa* differ in the size of pores (de Vargas et al., 1999; Morard et al., 2009), their pore-size is also affected by environmental conditions including water temperature (e.g., Bé et al., 1973). Likewise, thickness of the test wall has been described to vary between types (de Vargas et al., 1999; Morard et al., 2009), and is as well affected by environmental conditions and ontogenetic stage of specimens. Adult *O. universa* have been show to continuously add calcite layers to the proximal surface of the same sphere (Spero, 1988; Spero et al., 2015). Since environmental and biological factors may affect individuals of the different genotypes of *O. universa* to varying degrees, we could not detect any systematic change in SNW in the data presented here.

The various interfering effects, which control the SNW of *O. universa* in the Mediterranean Sea, may also explain differences in the weight-diameter relation data reported from other regions of the world ocean: Bijma et al. (2002) weighed *O. universa* of the 500–600 µm size fraction in the Caribbean Sea and report a weight ranging at 28–60 µg. Lombard et al. (2010) give a weight of 20–70 µg for specimens sampled off Catalina Island, California, in the same size fraction of the 500–600 µm. Our weight-diameter relation data range at 24–45 µg (Fig. S3c) for the same size fraction of the 500–600 µm, ranging at the lower limit of the weight-diameter relations measured in the Caribbean (Bijma et al., 2002) and off California (Lombard et al., 2010), which may be caused either by differences in genotypes or environmental conditions, or both. In our samples from the Mediterranean, individuals exceeding 60 µg have diameters larger than 650 µm. The reason why the SNW of *O. universa* is particularly low and highly variable in the Mediterranean despite of high carbonate ion concentration ($[CO_3^{2-}]$) and pH (Fig. 1) might be sought in factors other than, and in addition to, chemical and physical conditions, namely the changing availability of food along the transect from the Atlantic Ocean to the Levantine Basin.

5.3.2 Factors affecting the SNW of *G. ruber* and *G. bulloides*

In the same way as in *O. universa*, the SNW of *G. ruber* s.s. seems not to be controlled by carbonate chemistry, and to be affected by other factors like nutrient concentration and food availability. However, in contrast to *O. universa*, the SNW data of *G. ruber* and *G. bulloides* follow systematic distributions,

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478 which are statistically significant. High SNW in the Atlantic and Tyrrhenian Sea correlates with enhanced
479 primary production: enhanced fluorescence (Fig. 1d) and presumably enhanced food availability (Fig. 6;
480 Fig. 2, also noticeable in Fig. S2d-e and Fig. S4d-e). At the same sites, larger IQR indicates more
481 variability in test calcite production of *G. ruber* s.s. specimens, although a limited number of samples
482 together with the low and uneven sampling size impede any further interpretation of the data (Fig. 6).
483 Under more oligotrophic conditions, low SNW of *G. ruber* s.s. might be caused by limited food
484 availability.

485 The relationship between food availability and SNW in *G. bulloides* is opposite to that in *G. ruber* s.s.
486 (Fig. 6). The SNW of *G. bulloides* tests increases from the Atlantic toward the eastern Mediterranean. At
487 the same time, variability in SNW data increases with increasing absolute SNW, which resembles the
488 distribution of data in *G. ruber* s.s. (Fig. 6): In both species *G. ruber* s.s. and *G. bulloides* larger IQRs are
489 found toward higher absolute SNW.

490 An opposite trend in SNW of the two species *G. ruber* s.s. and *G. bulloides* had earlier been described
491 from the Arabian Sea, and could neither be assigned to changes in $[CO_3^{-2}]$ of ambient seawater nor
492 growth conditions. Due to its symbionts, *G. ruber* would rather have an advantage over symbiont-barren
493 *G. bulloides* in oligotrophic waters, and support formation of test calcite through CO_2 consumption and
494 increasing $[CO_3^{-2}]$ and pH (see also Köhler-Rink and Kühl, 2005). Those finding may still point toward
495 differences in growth conditions: Reproduction of both *G. ruber* and *G. bulloides* might be retarded under
496 less optimal conditions, and additional calcite layers might be added to the proximal text surface before
497 reproduction, similar to the process described for *O. universa* (see above). Therefore, tests may grow
498 heavier under less optimal than optimal alimentation, given that carbonate chemistry of ambient seawater
499 does not limit the formation of test calcite.

500 Comparing weight-diameter relations, *G. ruber* (255–350 µm size fraction) from plankton tows of the
501 western Arabian Sea have an average weight of 11.5 ±0.69 µg (de Moel et al., 2009), which is heavier
502 than the individuals from our study (5.9 ±0.31 µg; Fig. S3a; Appendix A). The difference in weight-
503 diameter relation may indicate that *G. ruber* was produced under more ideal conditions for shell calcite
504 formation in the Arabian Sea especially during non-upwelling periods and still higher overall primary
505 productivity and food availability. However, the comparison might be biased by the fact that *G. ruber* s.s.
506 and s.l. morphotypes were analyzed together in the study of de Moel et al. (2009).

507 Data for supra-regional comparison of weight-diameter relation of *G. bulloides* from the water column are
508 found for the 200–250 µm size fraction: in the north Atlantic (56-63 °N) in June 2009 (Aldridge et al.,
509 2012) with a range of 1.75–2.92 µg ($r^2 = 0.52$). For that size fraction our results (36 °N) show heavier
510 tests in the Alboran Sea (3.46 ±0.15 µg), and similar weights at the Strait of Gibraltar (2.57 ±0.00 µg; Fig.
511 S3b). For the same water depth as in our samples, Schiebel et al. (2007) found a heavier average weight-
512 diameter relation in fall (5.19 ±0.25 µg) than during spring (4.21 ±0.2 µg) in the eastern north Atlantic
513 (47 °N), and 5.51 ±0.31 µg during the SW monsoon in the Arabian Sea (16 °N). In general, higher SNW
514 occurs at lower latitudes and lower SNW at higher latitudes (see also Schmidt et al., 2004). All of these
515 findings support our idea of an effect of limited alimentation on reproduction. Increased longevity and

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ongoing production of additional calcite layers at the proximal side of shells may result in an increased SNW, given that carbonate chemistry does not limit calcite formation in planktic foraminifera.

6. Conclusions

Absolute and relative abundances of planktic foraminifera were studied from plankton tow samples across the Mediterranean in May 2013. The samples reflect high differences in species abundance and assemblages between the different basins and sub-basins of the Mediterranean Sea. Absolute abundance and diversity of planktic foraminifer assemblages are low in comparison to other regions of the world ocean. Average standing stocks in the upper 200 m of the water column range from 1.42 ±1.43 ind.·10 m^{-3}, including ten morphospecies in total. Planktic foraminifer assemblages are indicative of changing temperatures and salinities, as well as trophic conditions, between the eastern and the western Mediterranean Sea. Highest standing stocks of total planktic foraminifera occurred in the Strait of Gibraltar and the Alboran Sea. Overall, the largest foraminifera occurred in the western part of the transect, caused by the assemblages composition, and the presence of large *G. inflata*.

G. ruber was the most abundant species, including more *G. ruber* s.s. than s.l. morphotypes. Its dominance in the east compared to the west, is assumed to be caused by stratification of the surface water column, enhanced SST, and trophic conditions. *G. ruber* is a symbiont-bearing species, which might be an advantage over symbiont-barren species like *G. bulloides* under oligotrophic and food-limited conditions as in the Levantine Basin. *G. bulloides* was most abundant in upwelled waters in the Strait of Gibraltar, in the Alboran Sea, and in the western Mediterranean. *O. universa* was present at rather balanced standing stocks along the entire transect from the west to the east. In general, distribution patterns of the main planktic foraminiferal species in the Mediterranean seem to be mainly related to a combination of food availability and temperature.

Production of the shell and the size-normalized weight (SNW) of tests of the most frequent species *G. ruber* s.s. and *G. bulloides* are most affected by trophic conditions and food availability, given that carbonate chemistry in the Mediterranean does not limit calcite test formation. *G. ruber* is more affine to oligotrophic conditions, and grows heaviest tests in less food-limited waters in the west near Gibraltar and the Tyrrhenian Sea. In contrast, *G. bulloides* grows heaviest tests under more food-limited conditions in the eastern Mediterranean Sea. We speculate that reproduction is hindered when the species-specific food sources are limited, while individuals continue adding calcite to the outer shell, and grow heavier tests than individuals that reproduced earlier in ontogeny.

These observations highlight the need for more interdisciplinary studies on the causes of changing foraminiferal assemblages and decreasing shell production, especially in the Mediterranean as a marginal basin, which is assumed particularly sensitive to changes of the environment and global climate.

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Appendices

Appendix A. Planktic foraminifera data from BONGO nets: relative and absolute abundances, and weight and size parameters.

Location	Atlantic	Gibraltar	Alboran Sea	South-Central Western Med.	Strait of Sardinia	Strait of Sicily	South of Ionian Sea	Off Southern Crete	Eastern Basin	Off Nile Delta	Off Lebanon	Antikythera Strait	Eastern Ionian Sea	Adriatic Sea	Otranto Strait	Northern Ionian Sea	Tyrrhenian Sea	North-Central Western Med.	Central Western Med.	Catalano-Balear
Station	1	2	3	5	6	7a	9	10	11	12	13	14	15	17	16	16-18	19	20	21	22
Absolute abundance (individuals*10 m^{-3})																				
Total numbers																				
G. ruber s.s.	0.079	0.037	0.007	0.022	0	0	0.212	1.314	0.403	0.247	1.260	0.389	0.102	0	0.338	0	1.688	0	0	0
G. ruber s.l.	0.118	0.019	0.007	0	0.024	0	0	0.282	0.054	0.027	0.202	0.269	0	0	0.182	0.070	0.537	0	0.025	0
G. sacculifer trilobus-type	0.236	1.323	0.028	0	0.047	0	0.047	0.219	0.027	0.082	0.050	0	0	0.023	0.234	0	0.256	0	0.025	0
G. bulloides	0.148	2.311	0.456	0.501	0.142	0	0.165	0.094	0.054	0	0.076	0	0.102	0	0.052	0.023	0.307	0.197	0.102	0.147
G. inflata	0.118	0.503	3.514	0.545	0.449	0.358	0.071	0.125	0.027	0	0	0	0	0.023	0	0	0	0	0	0
O. universa	0.128	0.093	0.014	0.218	0	0.291	0	0.219	0.054	0.027	0.050	0	0.077	0.023	0.468	0.141	0.281	0.028	0.179	0.177
G. siphonifera	0.029	0.056	0.043	0.022	0	0.313	0	0.063	0	0	0.025	0	0	0	0	0	0	0	0.102	0
G. sacculifer quadrocameratus-type	0.010	0.335	0.007	0.087	0	0.045	0.118	0.063	0.027	0	0	0	0	0.023	0	0	0.230	0.112	0.204	0.236
H. pelagica	0	0	0	0	0	0	0	0.125	0	0.027	0	0	0	0	0	0	0	0	0	0
G. sacculifer sacculifer-type	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.026	0	0	0
G. ruber (pink)	0	0.075	0	0	0.024	0	0.024	0.125	0	0.027	0	0.120	0	0	0	0	0	0	0	0
G. menardii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.029
Unknowns	0.118	0.447	0.064	0.065	0.024	0	0.047	0.375	0.108	0	0.025	0.120	0.026	0.023	0.208	0.023	0.281	0.028	0	0.088
Total	0.985	5.120	4.141	1.460	0.709	1.006	0.683	3.003	0.753	0.439	1.689	0.898	0.307	0.114	1.482	0.258	3.607	0.365	0.638	0.678
150-350 µm size fraction																				
G. ruber s.s.	0.030	0.037	0.007	0.022	0	0	0.212	1.314	0.403	0.247	1.109	0.389	0.102	0	0.338	0	1.560	0	0	0
G. ruber s.l.	0.020	0	0	0	0.024	0	0	0.282	0.054	0.027	0.202	0.269	0	0	0.182	0.047	0.460	0	0.026	0
G. sacculifer trilobus-type	0.148	1.174	0.029	0	0.047	0	0	0.188	0.027	0.082	0.050	0	0	0.023	0.234	0	0.230	0	0.026	0
G. bulloides	0.128	2.199	0.449	0.415	0.142	0	0.165	0.094	0.054	0	0.076	0	0.102	0	0.052	0.023	0.307	0.197	0.077	0.118
G. inflata	0.069	0.335	1.176	0.109	0.095	0.022	0	0.063	0	0	0	0	0	0.023	0	0	0	0	0	0
O. universa	0	0.075	0.007	0.087	0	0	0	0.094	0	0	0	0	0	0	0.208	0	0.026	0	0.026	0
G. siphonifera	0	0.019	0.029	0	0	0.022	0	0	0	0	0.025	0	0	0	0	0	0	0	0.102	0
G. sacculifer quadrocameratus-type	0.010	0.280	0.007	0.087	0	0	0.071	0.063	0.027	0	0	0	0	0.023	0	0	0.230	0.112	0.204	0.236
H. pelagica	0	0	0	0	0	0	0	0.063	0	0	0	0	0	0	0	0	0	0	0	0
G. ruber (pink)	0	0.075	0	0	0.024	0	0.024	0.125	0	0.027	0	0.120	0	0	0	0	0	0	0	0
Total	0.404	4.193	1.703	0.719	0.331	0.045	0.471	2.284	0.564	0.384	1.462	0.778	0.205	0.068	1.014	0.070	2.814	0.309	0.459	0.354
350-500 µm size fraction																				
G. ruber s.s.	0.049	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.051	0	0	0
G. ruber s.l.	0.088	0.019	0.007	0	0	0	0	0	0	0	0	0	0	0	0	0.023	0.077	0	0	0
G. sacculifer trilobus-type	0.079	0.130	0	0	0	0	0.047	0.031	0	0	0	0	0	0	0	0	0.026	0	0	0
G. bulloides	0.020	0.112	0.029	0.022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.026	0.029
G. inflata	0.049	0.149	2.138	0.414	0.307	0.313	0.071	0.031	0.027	0	0	0	0	0	0	0	0	0	0	0
O. universa	0.049	0.019	0.007	0.109	0	0.067	0	0.125	0.027	0	0	0	0	0.023	0.130	0.023	0.153	0.028	0.051	0.118
G. siphonifera	0.020	0.019	0.007	0.022	0	0.201	0	0.031	0	0	0	0	0	0	0	0	0	0	0	0
G. sacculifer quadrocameratus-type	0	0	0	0	0	0.022	0.047	0	0	0	0	0	0	0	0	0	0	0	0	0
H. pelagica	0	0	0	0	0	0	0	0.063	0	0.027	0	0	0	0	0	0	0	0	0	0
G. sacculifer sacculifer-type	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.026	0	0	0
G. menardii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.029
Total	0.354	0.447	2.188	0.567	0.307	0.604	0.165	0.282	0.054	0.027	0	0	0	0.023	0.130	0.047	0.333	0.028	0.077	0.177

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554 (**Appendix A**, cont.).

Location	Atlantic	Gibraltar	Alboran Sea	South-Central Western Med.	Strait of Sardinia	Strait of Sicily	South of Ionian Sea	Off Southern Crete	Eastern Basin	Off Nile Delta	Off Lebanon	Antikythera Strait	Eastern Ionian Sea	Adriatic Sea	Otranto Strait	Northern Ionian Sea	Tyrrhenian Sea	North-Central Western Med.	Central Western Med.	Catalano-Balear
Station	1	2	3	5	6	7a	9	10	11	12	13	14	15	17	16	16-18	19	20	21	22
>500 µm size fraction																				
G. ruber s.l.	0.010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G. sacculifer trilobus-type	0.001	0.019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G. inflata	0	0.019	0.135	0.022	0.047	0.022	0	0.031	0	0	0	0	0	0	0	0	0	0	0	0
O. universa	0.079	0	0	0.022	0	0.224	0	0	0.027	0.028	0.050	0	0.077	0	0.130	0.117	0.102	0	0.102	0.059
G. siphonifera	0.010	0.019	0.007	0	0	0.089	0	0.031	0	0	0	0	0	0	0	0	0	0	0	0
G. sacculifer quadrocameratus-type	0	0	0	0	0	0.022	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0.108	0.056	0.143	0.044	0.047	0.358	0	0.063	0.027	0.027	0.050	0	0.077	0	0.130	0.117	0.102	0	0.102	0.059
Relative abundance (%)																				
G. ruber s.s.	8.00	0.72	0.17	1.49	0	0	31.03	43.75	53.57	56.25	74.63	43.33	33.33	0	22.81	0	46.81	0	0	0
G. ruber s.l.	12.00	0.36	0.17	0	3.33	0	0	9.38	7.14	6.25	11.94	30.00	0	0	12.28	27.27	14.89	0	4.00	0
G. sacculifer trilobus-type	24.00	25.45	0.69	0	6.67	0	6.90	7.29	3.57	18.75	2.99	0	0	20.00	15.79	0.00	7.09	0	4.00	0
G. bulloides	15.00	44.44	11.02	34.33	20.00	0	24.14	3.13	7.14	0	4.48	0	33.33	0	3.51	9.09	8.51	53.85	16.00	21.74
G. inflata	12.00	9.68	84.85	37.31	63.33	35.56	10.34	4.17	3.57	0	0	0	0	20.00	0	0	0	0	0	0
O. universa	13.00	1.79	0.34	14.93	0	28.89	0	7.29	7.14	6.25	2.99	0	25.00	20.00	31.58	54.55	7.80	7.69	28.00	26.09
G. siphonifera	3.00	1.08	1.03	1.49	0	31.11	0	2.08	0	0	1.49	0	0	0	0	0	0	0.00	16.00	0
G. sacculifer quadrocameratus-type	1.00	6.45	0.17	5.97	0	4.44	17.24	2.08	3.57	0	0	0	0	20.00	0	0	6.38	30.77	32.00	34.78
H. pelagica	0	0	0	0	0	0	0	4.17	0	6.25	0	0	0	0	0	0	0	0	0	0
G. sacculifer sacculifer-type	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.71	0	0	0
G. ruber (pink)	0	1.43	0	0	3.33	0	3.45	4.17	0	6.25	0	13.33	0	0	0	0	0	0	0	0
G. menardii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.35
Unknowns	12.00	8.60	1.55	4.48	3.33	0	6.90	12.50	14.29	0	1.49	13.33	8.33	20.00	14.04	9.09	7.80	7.69	0	13.04
Weight and size																				
G. ruber s.s.																				
size fraction (µm)	250-300							200-250	200-250		200-250	250-300			250-300		200-250			
n° of individuals	1							4	4		4	2			4		4			
average size (µm)	285							221	215.25		221.5	281			268		218.5			
average weight (µg)	4.667							1.583	2.417		2	3.167			5.5		2.083			
SD (µg)	0.577							0.144	0.289		0	0.577			0		0.144			
size fraction (µm)	350-400							250-350	250-300		250-300	300-350					250-300			
n° of individuals	4							5	1		3	1					5			
average size (µm)	390							267	261		264	317					280.6			
average weight (µg)	14.333							3.867	2.667		5.111	6.667					4.8			
SD (µg)	0.289							0.115	0.577		0.192	0.577					0.2			
size fraction (µm)	400-450							300-350	350-400		300-350						300-350			
n° of individuals	1							3	1		2						5			
average size (µm)	412							313.333	356		323.5						343.4			
average weight (µg)	14.667							7.444	5.667		11						9.867			
SD (µg)	1.155							0.385	1.155		0						0.231			
size fraction (µm)								350-400									350-400			
n° of individuals								2									4			
average size (µm)								374									366			
average weight (µg)								8.833									9.083			
SD (µg)								0.764									0.144			

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556 (**Appendix A**, cont.).

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Station	1	2	3	5	6	7a	9	10	11	12	13	14	15	17	16	16-18	19	20	21	22
size fraction (µm)																	400-450			
n° of individuals																	2			
average size (µm)																	413			
average weight (µg)																	16.167			
SD (µg)																	1.258			
G. bulloides																				
size fraction (µm)	300-350	200-250	200-250	350-400	300-350														400-450	300-350
n° of individuals	2	7	8	1	1														1	3
average size (µm)	326.5	228.143	227.875	364	337														414	318.333
average weight (µg)	4.5	2.571	3.458	4.667	4														11.667	8.222
SD (µg)	0.5	0	0.144	0.577	1														0.577	0.385
size fraction (µm)		250-300	250-300																	400-450
n° of individuals		12	2																	1
average size (µm)		263.75	270																	441
average weight (µg)		2.833	2.833																	20.333
SD (µg)		0	0.289																	1.155
size fraction (µm)		300-350	350-400																	
n° of individuals		2	4																	
average size (µm)		310.5	386.5																	
average weight (µg)		4.5	9.667																	
SD (µg)		0.5	0.144																	
size fraction (µm)		350-400	400-450																	
n° of individuals		2	2																	
average size (µm)		375.5	429																	
average weight (µg)		5.833	11																	
SD (µg)		0.289	0																	
size fraction (µm)		400-450	450-500																	
n° of individuals		1	1																	
average size (µm)		447	477																	
average weight (µg)		9.333	7.333																	
SD (µg)		0.577	0.577																	
O. universa																				
size fraction (µm)	350-400	250-300	500-550	400-450		450-500		300-350	350-400	700-750	650-700		700-750	450-500	300-350	400-450	400-450	400-450	450-500	350-400
n° of individuals	3	1	1	2		1		1	1	1	1		2	1	1	1	1	1	2	1
average size (µm)	390	286	501	445		479		342	398	719	687		722.5	452	347	444	441	441	479.5	377
average weight (µg)	17.667	7	20.667	11.667		31		3	6.333	47	43		24.167	14.333	5.333	18.667	24.333	22.667	31	20
SD (µg)	0.333	0	0.577	0.289		1		0	0.577	1	0		0.289	0.577	0.577	0.577	0.577	0.577	0.5	1
size fraction (µm)	400-450			450-500		500-550		350-400	500-550		750-800		750-800		350-400	550-600	450-500		550-600	400-450
n° of individuals	1			3		2		3	1		1		1		1	1	1		1	2
average size (µm)	444			479		539.5		373.667	539		781		785		369	559	455		571	425.5
average weight (µg)	28.667			22.889		33.833		6.556	25.667		54.667		53.667		6.667	34.333	23.667		45	24.167
SD (µg)	1.155			0.192		0.289		0.385	0.577		0.577		0.577		0.577	0.577	0.577		1	0.577
size fraction (µm)	500-550			650-700		600-650		400-450							400-450	600-650	500-550		650-700	450-500
n° of individuals	1			1		1		1							1	2	6		2	1
average size (µm)	527			656		603		439							412	640	534.5		676	482
average weight (µg)	36.667			25.667		50.667		13.667							13	54.833	30.278		84.333	35
SD (µg)	0.577			1.155		0.577		1.155							0	0.289	0.096		0.289	1
size fraction (µm)	550-600					650-700		450-500							450-500	650-700			750-800	500-550
n° of individuals	6					6		1							1	2			1	1
average size (µm)	578.667					674.333		460							476	656.5			762	509
average weight (µg)	45.389					47.889		17.333							24	63.333			136	42
SD (µg)	0.096					0.096		1.155							1	0.289			0	0
size fraction (µm)	600-650					700-750									500-550					
n° of individuals	1					2									3					
average size (µm)	605					720									527.333					
average weight (µg)	48.667					34									21.778					
SD (µg)	0.577					0									0.192					

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558 (**Appendix A**, cont.).

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Station	1	2	3	5	6	7a	9	10	11	12	13	14	15	17	16	16-18	19	20	21	22
size fraction (µm)	650-700					750-800									550-600					
n° of individuals	1					1									1					
average size (µm)	651					772									570					
average weight (µg)	50.667					48									17.333					
SD (µg)	0.577					1									1.528					
size fraction (µm)															600-650					
n° of individuals															1					
average size (µm)															625					
average weight (µg)															23					
SD (µg)															0					
size fraction (µm)															650-700					
n° of individuals															2					
average size (µm)															654.5					
average weight (µg)															31.167					
SD (µg)															0.289					

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Tables

Table 1. Date, time, location, volume filtered and environmental parameters of the sampled stations. Sea surface temperature (SST) and sea surface salinity (SSS) measured at 5 m depth. The remaining parameters are averaged from 5 to 200 depth with their respective SDs in parenthesis.

Leg	Station Code	Station Name	Day (DD/MM/YYYY)	Time	Latitude	Longitude	Volume (m^3)	Temperature (ºC)	SST (ºC)	Salinity (PSU)	SSS (PSU)	Fluorescense (µg/l)	pH	$[CO_3^{-2}]$ (mmol/kg)
1	1	Atlantic	03/05/2013	0:03	36º03'	-6º65'	1016	16.08 (0.84)	17.88	36.27 (0.10)	35.95	0.36 (0.32)	8.06 (0.05)	178.89 (22.25)
	2	Gibraltar	03/05/2013	12:47	35º94'	-5º56'	537	14.22 (1.05)	17.11	37.51 (0.81)	36.35	0.11 (0.06)	8.06 (0.02)	179.90 (6.15)
	3	Alboran Sea	05/05/2013	20:55	36º12'	-4º19'	1403	15.06 (1.17)	16.87	37.13 (0.68)	36.37	0.45 (0.44)	8.09 (0.03)	191.50 (13.84)
	5	South-Central Western Mediterranean	08/05/2013	10:44	38º54'	5º56'	459	14.33 (1.19)	16.99	37.95 (0.23)	37.65	0.18 (0.22)	8.10 (0.02)	200.36 (10.06)
	6	Strait of Sardinia	09/05/2015	20:34	38º27'	8º69'	423	14.34 (1.16)	17.50	38.23 (0.19)	37.77	0.19 (0.26)	8.08 (0.03)	199.89 (15.38)
	7a	Strait of Sicily	11/05/2013	0:20	37º04'	13º18'	447	15.12 (0.86)	17.27	38.16 (0.52)	37.43	0.23 (0.23)	8.09 (0.01)	207.14 (3.38)
	9	South of Ionian Sea	12/05/2013	11:31	35º12'	18º29'	425	16.17 (1.01)	19.53	38.78 (0.10)	38.64	0.13 (0.14)	8.12 (0.02)	232.36 (3.30)
	10	Off Southern Crete	14/05/2013	14:40	33º81'	24º27'	320	16.51 (1.44)	19.58	39.00 (0.39)	36.60	0.12 (0.19)	8.11 (0.01)	232.38 (8.43)
	11	Eastern Basin	15/05/2013	13:01	33º50'	28º00'	372	17.21 (1.30)	20.59	38.80 (0.44)	36.19	0.10 (0.07)	8.12 (0.02)	243.57 (10.26)
	12	Off Nile Delta	17/05/2013	3:14	33º22'	32º00'	364	17.59 (1.46)	21.82	38.99 (0.25)	37.45	0.15 (0.12)	8.11 (0.02)	239.99 (9.93)
	13	Off Lebanon	17/05/2013	16:15	34º23'	33º23'	397	17.35 (1.33)	21.58	38.73 (1.48)	no data	0.16 (0.13)	8.11 (0.02)	238.28 (7.52)
2	14	Antikythera Strait	20/05/2013	6:06	36º70'	23º42'	334	16.66 (1.21)	20.00	39.07 (0.03)	39.15	0.12 (0.08)	8.13 (0.01)	241.84 (6.26)
	15	Eastern Ionian Sea	21/05/2013	21:25	36º40'	20º81'	391	16.52 (1.31)	20.27	39.05 (0.01)	39.10	0.15 (0.15)	no data	no data
	17	Adriatic Sea	23/05/2013	21:09	41º84'	17º25'	440	14.67 (1.30)	18.76	38.82 (0.05)	39.12	0.20 (0.21)	8.10 (0.02)	218.53 (14.65)
	16	Otranto Strait	24/05/2013	23:49	40º23'	18º84'	385	15.67 (1.15)	19.49	38.70 (1.34)	30.47	0.16 (0.15)	8.13 (0.01)	236.93 (12.88)
	16-18	Northern Ionian Sea	25/05/2013	9:30	39º07'	18º70'	426	no data	no data	no data	no data	no data	no data	no data
	19	Tyrrhenian Sea	27/05/2013	12:40	39º83'	12º52'	391	14.74 (1.47)	18.60	38.30 (0.20)	37.97	0.18 (0.24)	8.12 (0.02)	216.97 (11.27)
	20	North-Central Western Mediterranean	29/05/2013	20:00	41º32'	5º66'	356	13.88 (0.94)	15.52	38.29 (0.20)	33.75	0.36 (0.24)	8.14 (0.02)	219.89 (11.27)
	21	Central Western Mediterranean	30/05/2013	10:30	40º07'	5º95'	392	13.98 (0.95)	16.78	37.66 (1.74)	37.37	0.17 (0.21)	8.11 (0.01)	204.41 (7.70)
	22	Catalano-Balear	31/05/2013	13:55	40º95'	3º32'	339	14.08 (1.33)	16.81	38.43 (0.08)	38.34	0.25 (0.39)	8.13 (0.02)	218.43 (13.11)

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Figures

Fig. 1. **(a)** Temperature (ºC), **(b)** salinity, **(c)** fluorescence ($\mu g \cdot l^{-1}$), **(d)** pH, and **(e)** $[CO_3]^{-2}$ ($\mu mol \cdot kg^{-1}$) values of the water column of the transect. Values follow a color scale (under every graph), also values shown in the isometric lines. X axis: water depth. Y axis: longitude (degrees). Measurement locations indicated with white dots, with the coinciding stations numbered at top. The station number and the map section correlates with the map at right of this description. Note reversed color scale at (d) and (e).

Fig. 2. Sampled stations with BONGO nets (dots). The numbers in the picture represent the station codes: First leg: 1 to 13, second leg: 14 to 22. Colour scale at right represents the values of surface chlorophyll concentration (in µg/l), retrieved from *MODIS Aqua (L2),* from the closest day as possible of the first leg transect.

Fig. 3. Absolute abundance of planktic foraminifera from BONGO nets during (a) leg 1 and (b) leg 2. Category 'Others' is comprised of *G. siphonifera*, *G. sacculifer* quadrocameratus-type, *H. pelagica*, *G. ruber* (pink), *G. menardii* and *G. sacculifer* sacculifer-type. Note different Y axis scale in the graphs.

Fig. 4. Percentage of each planktic foraminifera size fraction in each station from (a) leg 1 and (b) leg 2.

Fig. 5. Relative abundance of planktic foraminifera. Category 'Others' is comprised of *G. siphonifera*, *G. sacculifer* quadrocameratus-type, *H. pelagica*, *G. ruber* (pink), *G. menardii* and *G. sacculifer* sacculifer-type. Less than 1% values are not shown. Number in parenthesis indicates the total individuals of each location.

Fig. 6. Size-normalized weight of *G. ruber* s.s. and *G. bulloides* in box-and-whisker plots representation for the different location groupings in the Mediterranean. Box extends from the lower (Q_1) to upper (Q_3) quartiles values of the data, with a line at the median (Q_2). Whiskers extend from the quartiles to values comprised within a 1.5 interquartile range (IQR = $Q_3 - Q_1$) distance: $Q_1 - 1.5 \cdot IQR$; $Q_3 + 1.5 \cdot IQR$.

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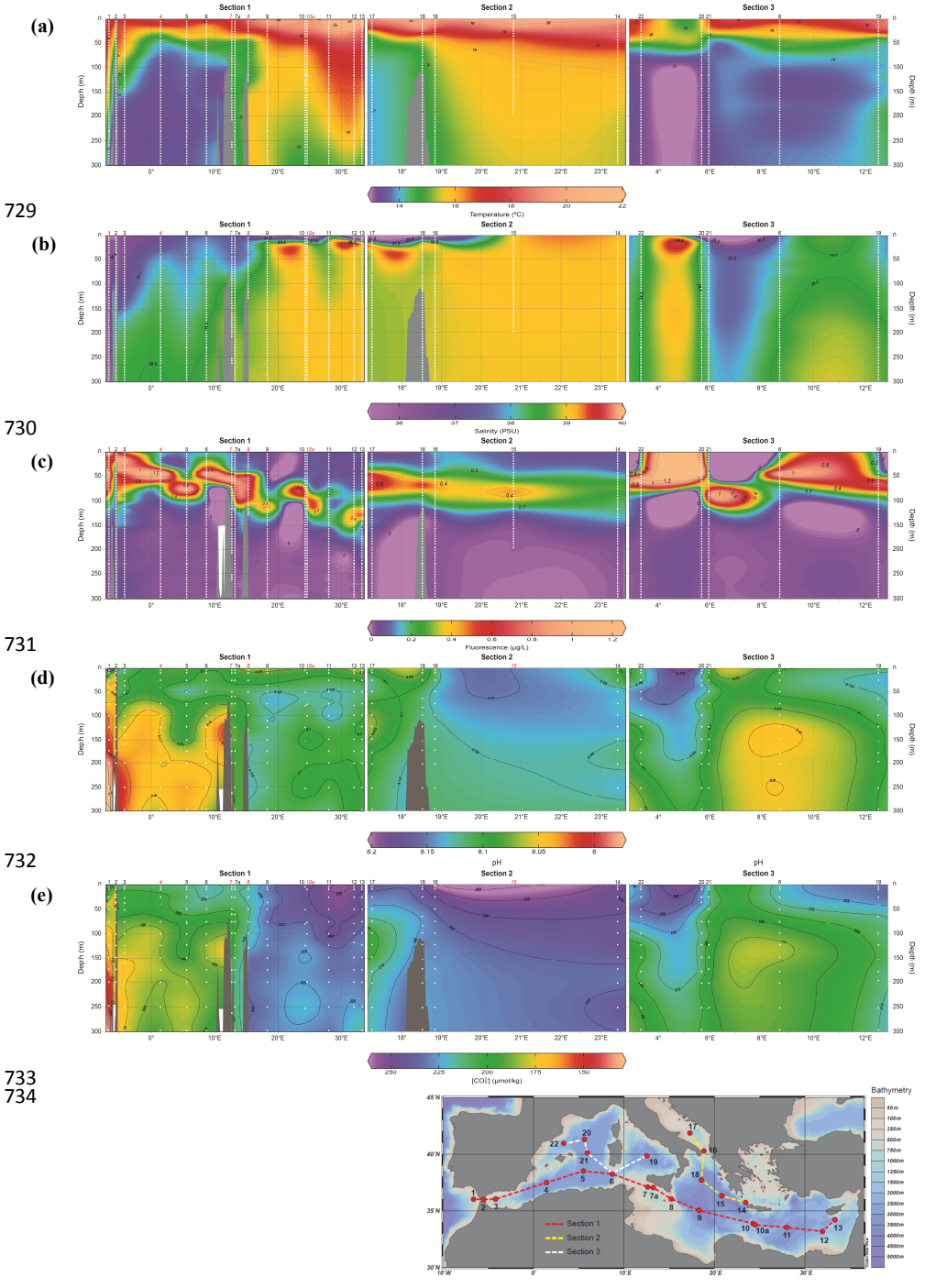

Figure 1

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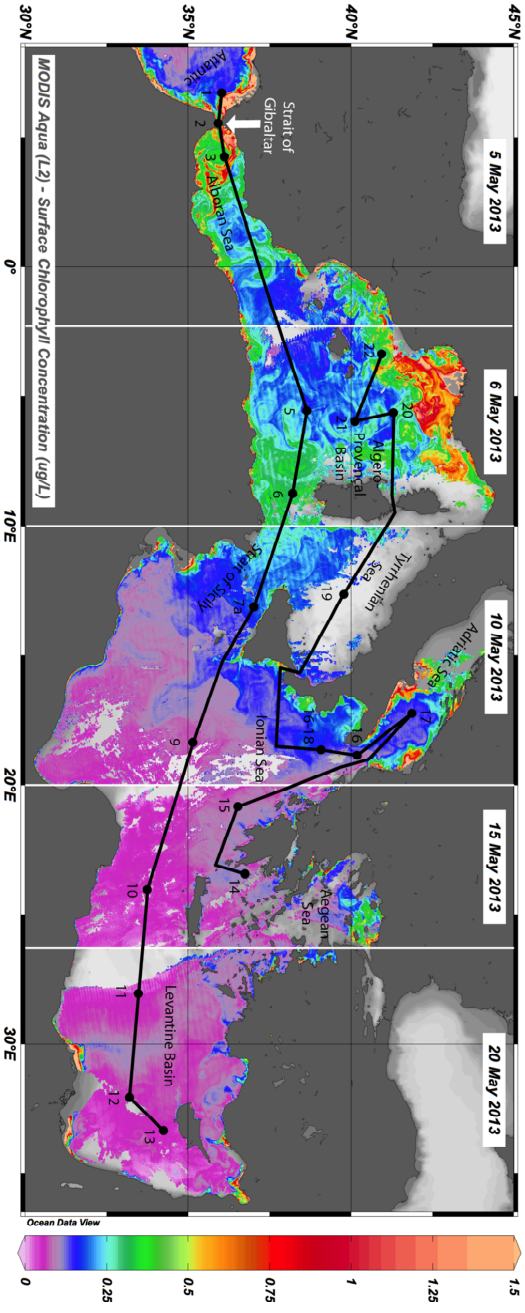

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Figure 2

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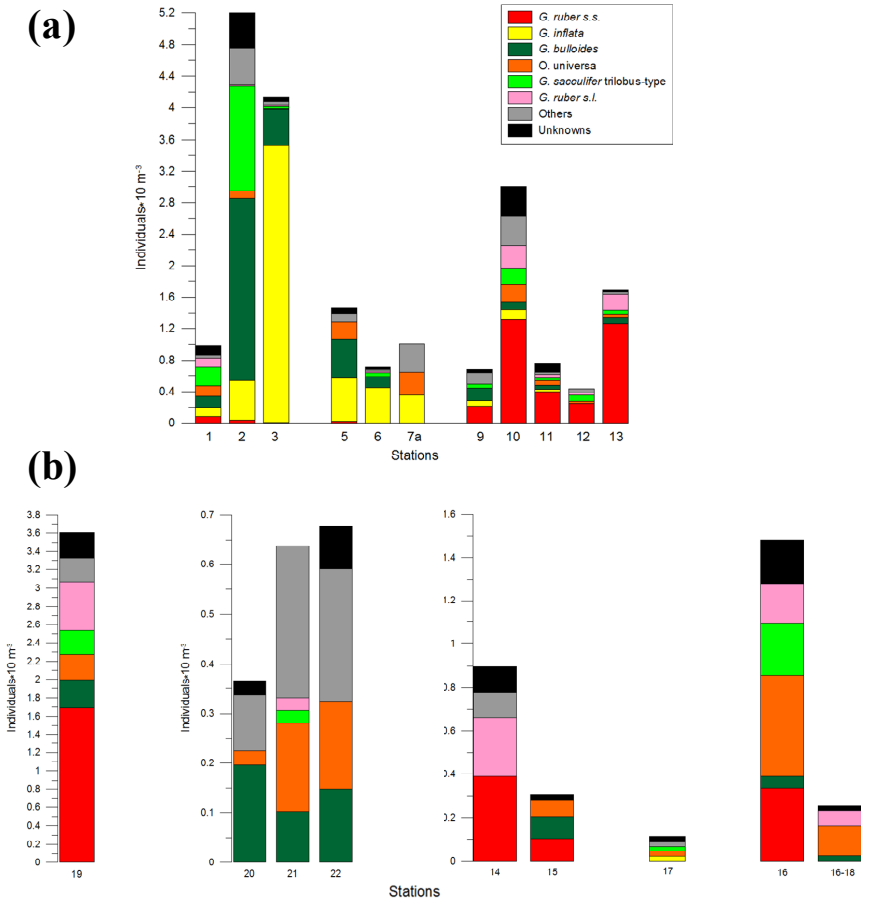

Figure 3

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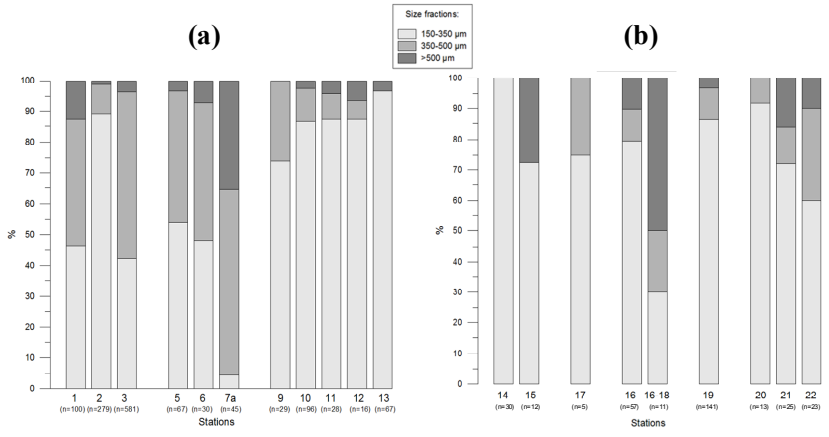

Figure 4

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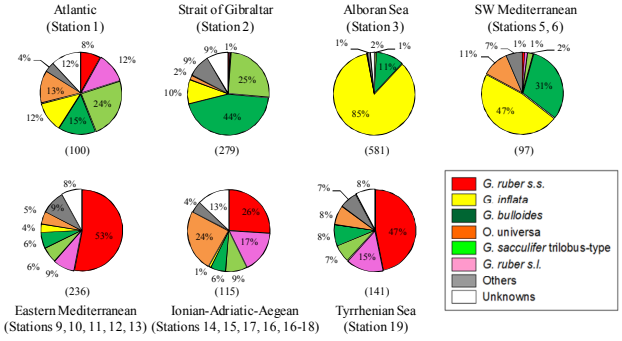

Figure 5

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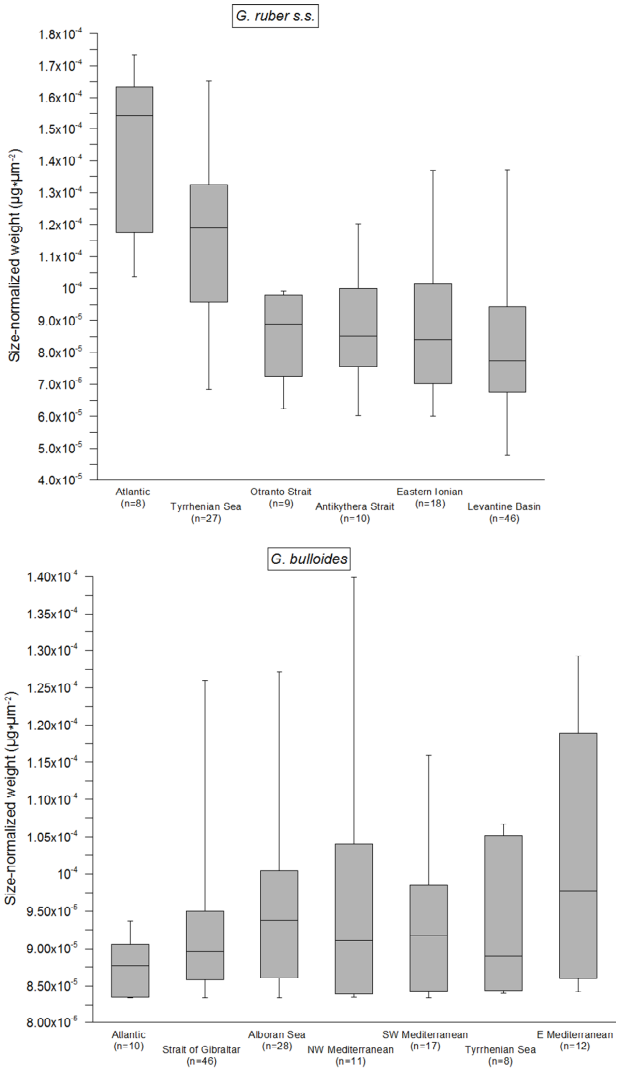

Figure 6