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

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12 Abstract

13 Planktic foraminifera were collected with 150 µm BONGO nets from the upper 200 m water depth at 20 14 stations across the Mediterranean Sea between 02 May and 02 June, 2013. The main aim is to 15 characterize the species distribution and test the covariance between for aminiferal area density (ρ_A) and 16 seawater carbonate chemistry in a biogeochemical gradient including ultraoligotrophic conditions. 17 Average for a bundances are 1.42 ± 1.43 ind. 10 m⁻³ (ranging from 0.11 to 5.20 ind. 10 m⁻³), 18 including twelve morphospecies. Large differences in species assemblages and total abundances are 19 observed between the different Mediterranean sub-basins, with an overall dominance of spinose, 20 symbiont-bearing species indicating oligotrophic conditions. The highest values in absolute abundance 21 are found in the Strait of Gibraltar and the Alboran Sea. The western basin is dominated by Globorotalia 22 inflata and Globigerina bulloides at slightly lower standing stocks than in the eastern basin. In contrast, 23 the planktic foraminiferal assemblage in the warmer, saltier and more nutrient-limited eastern basin is 24 dominated by *Globigerinoides ruber* (white). These new results when combined with previous findings, 25 suggest that temperature-induced surface water stratification, and food availability are the main factors 26 controlling foraminiferal distribution. In the oligotrophic and highly alkaline and supersaturated with 27 respect to calcite and aragonite Mediterranean surface water, standing stocks and ρ_A of G. ruber (white) 28 and G. bulloides are affected by both food availability and seawater carbonate chemistry. Rapid warming 29 increased surface ocean stratification impacting food availability and changes in trophic conditions could 30 be the causes of reduced foraminiferal abundance, diversity, and species-specific changes in planktic 31 foraminiferal calcification.

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33 1. Introduction

34 The single-celled foraminifera comprise the most diverse group of calcareous zooplankton of the modern 35 ocean. The majority of foraminifer species are benthic. About 50 morphospecies are planktic, which have 36 a calcareous test organized in chambers (i.e., d'Orbigny, 1826; Hemleben et al., 1989; Goldstein, 1999). 37 The species from different environments can be characterized by differences in wall structure, pore size 38 and spatial density, spines and test shape, which are partly related to adaptation. The distribution of 39 for aminifera is thought to be influenced by food availability, temperature, salinity, turbidity, sunlight, and 40 predatory presence; these factors provoke an overall water depth preference, which shifts during 41 ontogeny, and seasonal preference for each species (i.e., Schiebel and Hemleben, 2005; Hemleben et al., 42 1989). Some species are found only in the photic zone because they are symbiont-bearing and depend on 43 light for photosynthesis. After reproduction, the empty shells sink to the seafloor, where the fossils are 44 useful for paleoceanographic studies (e.g., Shackleton, 1968; Rohling et al., 2004; Mojtahid et al., 2015). 45 Ecological tolerance limits of modern foraminifera are not completely defined, but progressive reduction 46 in abundance (caused by worsening of their organic functions like food uptake, growth and reproduction, 47 until death) is related with their departure from optimum conditions (Bé, 1977; Arnold and Parker, 1999). 48 The absolute abundance of foraminifera is also affected by a predictable and distinct seasonal cycle for 49 each species driven by the food content and temperature of the water mass (Hemleben, 1989; Bé and 50 Tolderlund, 1971; Jonkers and Kučera, 2015; Žarić et al., 2005; for Mediterranean examples see: Pujol 51 and Vergnaud-Grazzini, 1995; Bárcena et al., 2004; Hernández-Almeida et al., 2011; Rigual-Hernández 52 et al., 2012; de Castro Coppa et al., 1980).

53 A vast majority of studies on planktic foraminifera are based on samples from bottom sediments and 54 sediment cores, mainly for paleoceanographic purposes, with few studies considering the modern 55 population in the water column, including the Mediterranean Sea. The first modern study of planktic 56 foraminifera in this specific area was based on surface sediment samples collected by the Swedish Deep-Sea expedition of 1947-48 (Pettersson, 1953). A subsequent study found different species assemblages 57 58 between the western basin, the eastern basin, and the Aegean Sea (Parker, 1955). The pioneering study of 59 foraminifera population variability in the water column of the Mediterranean was conducted by Glaçon et 60 al. (1971) in the Ligurian Sea, showing large seasonal variations of the relative abundances of the 61 different species. Such variations of planktic foraminiferal assemblages in the water column were also 62 reported for the Bay of Naples (de Castro Coppa et al., 1980). Cifelli (1974) was the first to cover the 63 broader Mediterranean, with plankton tows of the upper 250m of the water column from west Madeira in 64 the Atlantic Ocean to the Isle of Rhodes in June 1969; they identified different relative abundances of 65 subtropical and subpolar species in different parts of the Mediterranean.

Thunell (1978) studied the upper 2 cm of sediment cores retrieved from different sites of the Mediterranean Sea and concluded that the distribution of planktic foraminifera was closely related to the distribution of the different surface water masses. Each water mass has a characteristic range of temperature and salinity (Brown et al., 2001) and a partial isolation effect in the different basins and subbasins of the Mediterranean. Those hydrographic differences result in different species assemblages in each region. This contradicts somewhat with Pujol and Vergnaud-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 large enough and no close correlation was found to justify the extremely variable foraminifera

- were not large enough and no close correlation was found to justify the extremely variable foraminiferaassemblages, with high seasonal and geographical variations in absolute and relative abundances. They
- 77 suggested that food availability is the main factor controlling their seasonal and geographical distribution
- 78 and abundance. Hydrographic structures like eddies and fronts exert control on the distribution of species
- in case food is present in ample amounts.

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- 80 Despite no recent plankton tow study being carried out in the entire Mediterranean Sea, three regional 81 studies based on sediment traps were realized in the Alboran Sea (Bárcena et al., 2004; Hernández-82 Almeida et al., 2011) and the Gulf of Lion (Rigual-Hernández et al., 2012). The one-year time-series study of the Alboran Sea sediment traps (July 1997 - May 1998) shows big differences in the main 83 84 species distribution and daily export production, driven by food availability (related with water 85 mixing/stratification periods) and temperature (Bárcena et al., 2004; Hernández-Almeida et al., 2011). 86 The 12-year sediment trap foraminifera flux record in the Gulf of Lion (October 1993 – January 2006) 87 shows a strong seasonal pattern, with more than 80% of the annual export production recorded from 88 winter to spring related to higher food supply and mixing state of the water column (Rigual-Hernández et 89 al., 2012).
- 90 The calcification of foraminifera is affected by the chemical state of ambient seawater. Theoretically, 91 their shell mass is positively related to temperature, pH, $[Ca^{2+}]$, alkalinity, and $[CO_3^{2-}]$, and negatively 92 related to the [CO₂] of ambient seawater (Schiebel and Hemleben, 2005). Different studies conducted on 93 water column foraminifera show differential results, as their shell mass can either be positively (Aldridge 94 et al., 2012; Beer et al., 2010a; Marshall et al., 2013; Moy et al., 2009) or negatively related to [CO₂] 95 (Beer et al. 2010a). Also, other studies report a positive effect of the temperature on foraminifera shell 96 mass (Mohan et al. 2015; Aldridge et al., 2012; Marshall et al., 2013; Weinkauf et al., 2016). Beer et al. 97 (2010a) suggest a species-specific relation between shell mass and $[CO_3^{2-}]$, depending on the presence or 98 absence of symbionts. Some authors suggest that other factors like ecological stress do not affect the 99 calcification intensity (Weinkauf et al., 2013). For further studies that relate foraminiferal calcification 100 with environmental parameters see Weinkauf et al. (2016); Table 7. From the onset of the industrial era, 101 anthropogenic emissions of CO_2 have led to ocean acidification, decreasing seawater pH and $[CO_3^{2-}]$, 102 which provokes reduced stability of CaCO₃ that may reduce the formation of foraminiferal test calcite 103 (Zeebe, 2012; de Moel et al., 2009; Moy et al., 2009).
- 104 Studies of the ecology of foraminifera in the Mediterranean waters remain scarce. Few studies exist 105 covering the entire Mediterranean Sea. Most studies are focused on specific regions, i.e., the Gulf of 106 Naples (de Castro Coppa et al., 1980), the Alboran Sea plus the southwestern Mediterranean (van Raden 107 et al., 2011). Data on living planktic foraminiferal abundances are provided by Cifelli (1974; spring only) 108 and more recently by Pujol and Vergnaud-Grazzini (1995). In addition, few size-normalized weight 109 (SNW) and area density (ρ_A) studies to infer the calcification intensity of water column foraminifera are 110 available in the literature (see Schiebel et al., 2007; Beer et al., 2010a; Aldridge et al., 2012; Marshall et 111 al., 2013; Mohan et al., 2015; Marshall et al., 2015; Weinkauf et al., 2016). New data are needed, since

environmental conditions of the water column and associated foraminiferal assemblages might havechanged over the past 20 years.

114 In this study, new quantitative and qualitative data are presented on living planktic foraminifera across the 115 Mediterranean Sea during spring 2013. Comparisons are made with previous studies from Pujol and 116 Vergnaud-Grazzini (1995), Cifelli (1974), de Castro Coppa et al. (1980), Bárcena et al. (2004), 117 Hernández-Almeida et al. (2011), Rigual-Hernández et al. (2012) and Thunell (1978). The study by 118 Thunell (1978) is based on surface sediments, but might be biased by differential transportation and 119 dissolution of tests (Thunell, 1978; Caromel et. al., 2014; Schiebel et al., 2007). Although core top 120 samples (0-2 cm) are suitable to infer variability of modern conditions (Thunell; 1978), they can cover the 121 last few decades to few centuries, depending on the sedimentation rate, while our plankton tow sampling 122 represents a "snap shot" of the modern water column (Mortyn and Charles, 2003), in this case the 123 Mediterranean. Correlated results between plankton tows (Pujol and Vergnaud-Grazzini, 1995) and 124 surface sediments (Vergnaud-Grazzini et al., 1986) at coincident places in the Mediterranean confirm the 125 results obtained by Thunell (1978).

126 The objectives here are to (1) delineate new absolute abundances of planktic foraminifera within the 127 different regions of the Mediterranean Sea during spring, (2) characterize ecological demands at the 128 species level by comparison with previous studies, and (3) provide new ρ_A data for comparisons between 129 sub-basins of the Mediterranean Sea and with other studies, in the context of ocean warming and 130 acidification over the past 20 to 40 years.

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132 2. Oceanographic Setting

133 The Mediterranean Sea, with a strong thermohaline and wind-driven circulation, and a surface of 134 approximately 2,500,000 km², is divided into two main basins near the Strait of Sicily: the western and 135 eastern basins. These basins are composed of different sub-basins due to partial isolation caused by sills 136 that influence the water circulation, and by different water properties (Rohling et al., 2015; Rohling et al., 137 2009). Natural connection with the ocean is through the narrow Strait of Gibraltar, where nutrient-rich 138 Atlantic surface waters enter the Mediterranean and experience an eastward increase of temperature and 139 salinity (Fig. 1) driven by insolation and evaporation, having a negative hydrological balance 140 (evaporation exceeding precipitation). The Mediterranean becomes increasingly oligotrophic towards the 141 east (Fig. 1; Fig. 2). In addition, the incoming Atlantic waters enter the Algero-Provencal Basin as far as 142 the Tyrrhenian Sea, and contribute to deep water formation in the Gulf of Lion in cold winters (Rohling et 143 al., 2015; Rohling et al., 2009).

In the eastern basin, two main sources of deep-water formation are active mainly during winter in the
Adriatic and the Aegean Seas. Cold dry winds cause evaporation and cooling forming denser and more
saline water masses that sink to depth (Rohling et al., 2015; Rohling et al., 2009; Hassoun et al., 2015b).

- 147 The same process is active in the Levantine basin, forming an intermediate water mass, which becomes
- 148 progressively cooler and fresher toward the western basin. Some waters reach the Tyrrhenian Sea. Waters

returning to the Atlantic through the Strait of Gibraltar at depth are cooler and saltier than the inbound
waters, and compensate for the inflow from the Atlantic. The Mediterranean Sea has a large
physicochemical gradient for such a small marginal sea (Rohling et al., 2015; Rohling et al., 2009; Fig.
1).

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154 **3. Methodology**

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156 **3. 1. Study Area**

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

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165 **3. 2. Material and methods**

166 Twenty samples were collected with BONGO nets (mesh size 150 µm and 40 cm diameter, for further 167 details see Posgay, 1980). Those nets sampled primarily 200 m depth, but also caught foraminifera during 168 the net descent and ascent to the ocean surface, which both involve negligible towing and capturing time 169 compared to the sampling at 200 m depth (Table 1). The sampling device was equipped with a flow-meter 170 allowing the estimation of the volume filtered in each tow. The data for temperature, salinity, oxygen, and 171 fluorescence were integrated over the upper 200m from the nearest CTD stations retrieved during the 172 same cruise (for the complete dataset see Ziveri and Grelaud, 2015). Seawater carbonate data (total 173 alkalinity (AT), and dissolved inorganic carbon (DIC)) were obtained from water samples retrieved at 174 various depths during the CTD casts (see Goyet et al., 2015). These data were used to calculate pH, pCO₂, 175 and $[CO_3^{2-}]$ using the software CO2Sys (Lewis and Wallace, 1998) with the equilibrium constants of 176 Mehrbach (1973) refitted by Dickson and Millero (1987). These three parameters of the carbonate system 177 were then integrated for the upper 200 m water depth. The nutrient concentrations ([PO₄] and [NO₃]) 178 were measured by OGS (Italaian National Institute of Oceanography and Experimental Geophysics). The 179 water samples were filtered on glass fiber filters (Whatman GF/F; 0.7 µm) and then kept at -20°C 180 onboard. The samples were then analyzed in the laboratory with a Bran+Luebbe3 AutoAnalyzer (see 181 Grasshoff et al., 1999). Surface chlorophyll a concentration was obtained from MODIS Aqua L2 satellite 182 data (NASA Goddard Space Flight Center: http://oceandata.sci.gsfc.nasa.gov/).

183Foraminiferal samples were collected either at daytime or nighttime. Plankton samples were preserved by184adding a 4 % formaldehyde solution buffered with hexamethyltetramine at pH = 8.2 on board. Individuals

185 were not necessarily alive when collected and no distinction was made between cytoplasm-bearing tests: 186 as alive or dead but still containing cytoplasm (see also Boltovskoy and Lena, 1970), and empty tests 187 (dead) were considered for this study. From each sampling station, the foraminifera were isolated and 188 identified at the species level. When necessary, samples were split into aliquots of 1/4 and 1/6. For each 189 sample, each species was counted and isolated according to 3 size fractions (150-350 µm, 350-500 µm, 190 and >500 µm) to determine the absolute and relative abundances. Foraminifera smaller than 150 µm 191 and/or with tests partially broken, making them unrecognizable or unmeasurable, were discarded.

- 192 We classified the different foraminifera species by visual identification using incident light microscopy. 193 Following the morphometric guidelines and taxonomic nomenclature proposed by Aurahs et al. (2011) 194 for Globigerinoides ruber (white), Globigerinoides ruber (pink) and Globigerinoides elongatus. For 195 Trilobatus sacculifer (with sac) and T. sacculifer (without sac) we followed Spezzaferri et al. (2015). The 196 taxonomy of Hemleben et al. (1989) was applied to classify Globigerina bulloides, Orbulina universa, 197 Globorotalia inflata, Globorotalia menardii, and Hastigerina pelagica. Trilobatus sacculifer morphotype 198 quadrilobatus was inferred from Spezzaferri et al. (2015) after André et al. (2013); this morphotype is 199 referred as T. quadrilobatus in this study and is treated separately from T. sacculifer (without sac). The 200 Globigerinella siphonifera/G. calida/ G. radians plexus (see Weiner et al., 2015) is treated as G. 201 siphonifera in our study.
- 202 For the area density (ρ_A) study, we selected three main species: G. ruber, G. bulloides, and O. universa. 203 All specimens, without partially broken tests and/or with organic matter attached, of these three species 204 were photographed with a Canon EOS 650 D camera device attached to a Leica Z16 AP0 microscope to 205 measure their long axis and silhouette area using the software ImageJ (Schneider et al., 2012). For each 206 station and each of the three selected species, the individuals were weighed together by triplicate with a 207 Mettler Toledo XS3DU microbalance ($\pm 1 \mu g$ of nominal precision) within 50 μm size fraction increments 208 (150-200 µm, 200-250 µm, etc.). Cytoplasm-filled or empty dry-weighed foraminifera tests were 209 weighted together since dry cytoplasm has no statistically significant effect on the weight of tests >150 210 μm (Schiebel et al., 2007). Specimens containing notable organic matter attached to the outside of the test 211 were discarded. The maximum number of individuals weighed together was five. At some stations, 212 individuals were measured individually in case more than one specimen was not available. In all cases, 213 the mean weight per specimen of the three weightings was applied. The silhouette area obtained was then 214 used to calculate the ρ_A (Weinkauf et al., 2013; Marshall et al., 2013; Marshall et al., 2015).
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3.3. Statistical methods

217 Principal component analysis (PCA; Varimax rotation) of the environmental parameters (temperature, salinity, oxygen, fluorescence, NO₃, PO₄, pH, pCO₂ and CO₃⁻²) characterizing the 20 stations was 218 219 extracted using SPSS Statistic 23 software. The two first PCA factors explain about 77 % of the total 220 variance in environmental parameters (Fig. 3). The first factor exhibited positive loadings on the nutrients 221 and the fluorescence and negative loadings on temperature and salinity (and to a lesser degree on $[CO_3^{2-}]$; 222 Table 2). The first factor explains 56.99% of the total variance and depicts well the general trend 223 observed in the Mediterranean Sea with in general colder and more productive waters in the western basin 224 and warmer and less productive waters in the eastern one. The second factor explains about 20.02% of the 225 total variance and is characterized by positive loadings of pH and oxygen concentrations (and to a lesser 226 degree on [CO₃-²]) and negative loading of the pCO₂ (Table 2). It is interpreted as variations of the 227 carbonate system in the Mediterranean Sea with in general lower pH/[CO3-2] in the western basin 228 compared to the eastern basin. The sample scores of the first two factors with an overlay of absolute 229 abundances of foraminifera species (G. ruber (white), G. bulloides, G. inflata, O. universa and T. 230 sacculifer (without sac)) and area density (G. ruber (white), G. bulloides and O. universa) are shown in 231 Figure 3.

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233 **4. Results**

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235 4. 1. Absolute and relative abundance

236 The absolute abundance of planktic foraminifera collected with BONGO nets has a mean value of 1.42 237 ± 1.43 (SD) individuals 10 m⁻³. A maximum value of 5.2 ind. 10 m⁻³ in the Strait of Gibraltar is followed 238 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 239 southern Crete (Fig. 4; Fig. 3a). With the exception of these four regions, a standing stock of 1.7 ind. 10 240 m⁻³ is not surpassed at any other station. A minimum standing stock occurs in the Adriatic Sea (0.11 241 ind. 10 m⁻³). The westernmost stations 2 and 3, with the highest Atlantic influence, have the highest 242 abundance values (4.67 ind. 10 m⁻³ on average), followed by the eastern Mediterranean Stations 9 to 13 243 (1.31 ind. 10 m⁻³; Fig. 4; Fig. 3a; Appendix A). Pervasively, the most common size fraction of 244 foraminifera is 150–350 µm (65.57%; Fig. 5), especially due to the presence of G. ruber (white) and G. 245 bulloides. The 350-500-µm size fraction in the first leg dominates in the western Mediterranean and is 246 progressively reduced eastwards (Fig. 5). Higher percentages of individuals >500 µm in the first leg are 247 found in the western part of the Mediterranean compared to the eastern part (Fig. 5). The highest 248 percentages of >500 µm tests are found at the Strait of Sicily and the Northern Ionian Sea (St. 7a, 16-18; 249 Fig. 5; Fig. S1; Appendix A). In concordance with Pujol and Vergnaud-Grazzini (1995), no differences 250 are observed between samples collected during day and night. However, due to the extremely low 251 standing stocks the above observations are mere snapshots, and may not be generalized.

252 The most abundant species is G. ruber (white) (with an average of 0.30 ind. 10 m⁻³, representing 21.49% 253 of the total assemblage); its highest abundances are found in the Tyrrhenian Sea (St. 19, 1.69 ind. 10 m⁻³) 254 and in the eastern Mediterranean (Stations 10 and 13). Globigerinoides ruber (white) is not present in the 255 Adriatic Sea, at Station 16–18, and in the northwestern Mediterranean. It is found in low numbers in the 256 southwestern Mediterranean, Atlantic, and Strait of Gibraltar stations (Fig. 4; Fig. 3d). Individuals >350 257 µm in long test axis are rare (Appendix A). G. inflata is the second most abundant species (0.29 ind. 10 258 m⁻³; 20.19%), mainly due to its high abundance in the Alboran Sea (3.5 ind. 10 m⁻³; 61.08% of the 259 sample). It is mainly present in the western Mediterranean (Fig. 4; Fig. 3b). The dominant size fraction is 260 350-500 μm (Appendix A). G. bulloides has an average abundance of 0.24 ind. 10 m⁻³ (17.20 %), mainly 261 due to its abundance in the Strait of Gibraltar (2.31 ind. 10 m⁻³; 47.34 %). It is slightly more abundant in the southwestern Mediterranean and the Tyrrhenian Sea than in the eastern Mediterranean. It is a quite
ubiquitous species being absent at four stations (Fig. 4; Fig. 3e). It rarely appears in the >350-μm test-size
fraction (Appendix A).

265 Trilobatus sacculifer (without sac on average 0.13 ind. 10 m⁻³; 9.16 %), is especially notable at the Strait 266 of Gibraltar (50.91 %; Fig. 4; Fig. 3c). O. universa is ubiquitous in the whole Mediterranean Sea with the 267 exception of the three Stations 6, 9, and 14 (Fig. 4; Fig. 3f). Its average abundance is 0.12 ind. $\cdot 10$ m⁻³ 268 (8.70 %). Its dominant size fractions are >350 µm (Appendix A; Fig. 5). G. elongatus (0.09 ind. 10 m⁻³; 269 6.41 %) is found mostly at the same stations as G. ruber (white), but is usually less abundant (Fig. 4). It is 270 most frequent in the 350-500-µm test-size fraction, and some individuals >500 µm are found in the 271 Atlantic (Appendix A). The other species and morphotypes appear in very low numbers: T. quadrilobatus 272 (0.07 ind. 10 m⁻³), G. siphonifera (0.03 ind. 10 m⁻³), G. ruber (pink) (0.02 ind. 10 m⁻³), H. pelagica (0.008 273 ind. 10 m⁻³), G. menardii (0.001 ind. 10 m⁻³) and T. sacculifer (with sac) (0.001 ind. 10 m⁻³; Fig. 4; 274 Appendix A).

275 The PCA performed on the environmental parameters and the sample scores of the two first components 276 shows a clear separation, between the western and eastern Mediterranean stations in Factor 1 (Fig. 3). The 277 western basin is characterized by higher food availability to the foraminifera, lower temperatures, lower 278 salinities, and highest absolute planktic foraminifera abundances (Fig. 3a). In the eastern basin, station 10 279 is an exception with a considerable contribution of G. ruber (white) to the absolute abundances (Fig. 3a). 280 In PCA Factor 2, the stations influenced by the incoming waters from the Atlantic and lowest $[CO_3^{-2}]$ 281 values score highest. The stations where absolute abundances show some affinity for higher $[CO_3^{-2}]$ 282 values conditions are in the NW Mediterranean, the Tyrrhenian Sea, and in the northern Ionian Sea 283 (stations 14, 15 and 16). Overall, highest absolute abundances of the total planktic foraminifera 284 assemblage seems to be related to food availability, and only secondarily to the carbonate system (Fig. 285 3a).

With the exception of the Tyrrhenian Sea (St. 19), *G. ruber* (white) abundance is related with warmer and
saltier waters, and lower pH (St. 9, 10, 11, 12, 13, 14, 15; Fig. 3d). The opposite is observed for *G. bulloides*, and higher abundances occur where more food is available and at stations where pH is higher
(Fig. 3e). *O. universa* shows an ubiquitous distribution with no remarkable trends within the two PCA
factors (Fig. 3f). The more patchy abundance distribution of *T. sacculifer* (without sac) does not follow
any trend (Fig. 3c). *G. inflata* positively correlates with food availability, and the regional distribution
follows the path of Atlantic waters (Fig. 3b).

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 low numbers of individuals (< 90; Fig. 6). The Tyrrhenian Sea and the eastern Mediterranean stations were dominated by *G. ruber* (white), the Alboran Sea by *G. inflata*. The dominance of a single species in the southwestern Mediterranean is less clear, which might be due to low numbers of individuals (*G.inflata* being the main species followed by *G. bulloides* as in the Alboran Sea). *T. sacculifer* (without sac) has a high relative abundance in the Atlantic Ocean and in the Strait of Gibraltar, being the main and the second most abundant species, respectively. At all other stations analyzed, *T. sacculifer* (without sac) is less abundant. *G. bulloides* is most frequent in the entire western Basin and the Atlantic Ocean, being the main species in 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* (white), which always represents a small percentage of the assemblage in the western Mediterranean but dominates the Tyrrhenian Sea and the eastern Basin (Fig. 6; Appendix A).

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308 4. 2. Area density (ρ_A)

309 Due to their high abundance, G. ruber (white), G. bulloides, and O. universa were analyzed for their area 310 density (pA: Fig. 7 including their Coefficient of Variation (CV); Fig. 3g-i). The two-dimensional 311 (silhouette) area-to-long axis correlation is best fitted by a power regression (Fig. S2). Similar growth 312 patterns can be seen in G. ruber (white), G. bulloides, and O. universa with that correlation, graphically 313 represented by the shape of a power function (Fig. S2). Planktic foraminifera grow faster when they are 314 younger and smaller (steepest in the lower left part of the regression line) and slower when they are older 315 and bigger (less steep in the upper right part of the regression line; Fig. S2). The specimens of G. ruber 316 (white) from the Atlantic have a significantly larger area than those from the Tyrrhenian Sea ($p \le 0.003$), 317 which in turn have significantly larger area than those from the East Ionian Sea grouping ($p \le 0.001$). In 318 the other two species G. bulloides and O. universa, a similar trend is observed regarding the two basins, 319 with the eastern Mediterranean hosting the smallest individuals, while the largest individuals occurred in 320 the Atlantic and the northwestern Mediterranean (Fig. S2). The different locations were grouped using the 321 same criteria as in Fig. 6.

The long axis-to-weight relation of *G. ruber* (white) specimens yielded an $r^2 = 0.841$ (linear regression throughout this paragraph; Fig. S3), followed by *O. universa* ($r^2 = 0.63$), and *G. bulloides* ($r^2 = 0.516$; Fig. S3). *O. universa* was finally discarded for comparisons between ρ_A at different locations due to a low area-weight correlation and no remarkable trend observable between locations (Fig. S4c; Fig. 3i); while data from *G. ruber* (white) correlate well (Fig. S4a). The eastern Mediterranean specimens are the lightest in both species (*G. ruber* (white), *G. bulloides*), with more extreme W-E differences in *G. ruber* (white) than in *G. bulloides* (Fig. S4d-e).

329 The ρ_A of G. ruber (white) specimens from six locations were compared (Fig. 7). The data of all the 330 locations show a similar CV value. The eastern Mediterranean individuals have the lowest median ρ_A (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 331 332 interquartile range (IQR = $Q_3 - Q_1$). The Atlantic individuals of G. ruber (white) show the highest median 333 value $(1.55 \cdot 10^{-4} \,\mu g \cdot \mu m^{-2})$ and IQR. The ρ_A of Tyrrhenian individuals ranges between those from the 334 eastern Mediterranean and Atlantic Ocean $(1.2 \cdot 10^{-4} \,\mu g \cdot \mu m^{-2})$. The ρ_A of G. ruber (white) for each station 335 was compared with the two PCA factors; higher ρ_A are related to slightly lower pH and to higher food 336 availability in the western Mediterranean and Atlantic stations (Fig. 3g).

For *G. bulloides* specimens, seven locations were compared (Fig. 7). The data from these locations show similar CV values. Specimens from the Atlantic have the lowest median ρ_A (8.75·10⁻⁵ µg·µm⁻²) and the

- 339 smallest IQR, showing an opposite trend than G. ruber (white). Also contrary to G. ruber (white), G.
- 340 *bulloides* from the eastern Mediterranean tend to have a higher median ρ_A (9.75·10⁻⁵ µg·µm⁻²) and a larger
- 341 IQR. The differences in ρ_A between the eastern and western Mediterranean are smaller in *G. bulloides*
- than in *G. ruber* (white). The ρ_A of *G. bulloides* at each station was compared with the two PCA factors.
- 343 Results show a less clear overall trend for G. bulloides than for G. ruber (white), with higher ρ_A
- associated with slightly higher pH in the eastern Mediterranean (Fig. 3h).
- 345

346 5. Discussion

347

348 5. 1. Abundance and diversity patterns

349 Absolute abundance values of 4.2 individuals per 10 m⁻³ (>150 µm) on average are low in comparison 350 with earlier studies, even in oligotrophic regions. For example, in the oligotrophic northern Red Sea, less 351 than 100 ind.·10 m⁻³ (>125 μm) were reported from surface waters, and standing stocks were much higher 352 than 100 ind. 10 m⁻³ at most of the sites sampled in 1984 and 1985 (Auras-Schudnagies et al., 1989). In 353 the oligotrophic to mesotrophic Caribbean and Sargasso Seas, standing stocks were up to 786 ind. \cdot 10 m⁻³ 354 (>100 µm) and 907 ind. 10 m⁻³ (>202 µm), respectively (Schmuker and Schiebel, 2002, and references 355 therein). In the Atlantic, south of the Azores Islands, Schiebel et al. (2002) counted an average of 66.15 356 ind. 10 m⁻³ for the upper 100 m in August 1997, and 422.97 ind. 10 m⁻³ in January 1999 (>100 μ m). 357 Similar studies show higher abundances of one or two orders of magnitude (i.e. Sousa et al., 2014; 358 Boltovskoy et al., 2000; Kuroyanagi and Kawahata, 2004; Rao et al., 1991; Ottens, 1992; Schiebel et al., 359 1995). At higher latitudes, in the Fram Strait (Arctic Ocean), Pados and Spielhagen (2014) obtained 360 approximate values of 117 ind. 10 m⁻³ from the upper 500 m in late June-early July of 2011. Mortyn and 361 Charles (2003), in February-March 1996, at 200 m depth range in the Atlantic sector of the Southern 362 Ocean, found as a minimum value 0.1 ind. 10 m⁻³, with an approximate mean of 73 ind. 10 m⁻³.

363 Within the Mediterranean, a previous study with results comparable to the data presented here, sampled 364 the upper 350 m of the water column (Pujol and Vergnaud-Grazzini, 1995). In the Alboran Sea, samples 365 were obtained during a similar period of the year (April 1990) with values around 16, 6 and 9 ind. 10 m⁻³, 366 greater than in the Station 3 (4.14 ind. 10 m⁻³). Samples from different seasons have higher abundances, 367 with highest values in February (Pujol and Vergnaud-Grazzini, 1995), and a high annual average of 9.3 368 ind. 10 m⁻³. Regarding Pujol and Vergnaud-Grazzini (1995), western Mediterranean abundances are 369 higher than the eastern ones, due to more oligotrophic conditions and higher temperature and salinities in 370 the east that limit foraminiferal production during winter and late summer.

371 Comparing with previous studies that covered the Mediterranean, we notice that Thunell (1978, surface
372 sediments) and Pujol and Vergnaud-Grazzini (1995, water column) did not find *G. menardii*, while the

373 species was reported by Cifelli (1974) in very low abundances. The fact that G. menardii, which has a 374 preference for tropical waters, is not found in the surface sediments suggests that it is a new species in the 375 Mediterranean Sea (Cifelli, 1974). Its recent presence in the Mediterranean Sea could be related to the 376 warming of surface waters. All other species found in our study were also found in the past studies 377 covering the Mediterranean Sea (Cifelli, 1974; Thunell, 1978; Pujol and Vergnaud-Grazzini, 1995). It 378 remains unclear whether Thunell (1978) found G. elongatus and T. sacculifer (without sac) and classified 379 them as G. ruber and G. sacculifer, respectively. Also, it is not certain if Cifelli (1974) found G. calida 380 and classified it with G. aequilateralis (older synonym of G. siphonifera). From the figures in Cifelli 381 (1974), we suspect that G. elongatus was classified with G. ruber. In the same way, we do not find any 382 evidence of T. sacculifer (with sac) from the figures presented by Cifelli (1974), but we cannot discard 383 the possibility that this species was classified as Globigerinoides trilobus.

384

385 Trilobatus quadrilobatus was not found in any previous plankton tow studies in the Mediterranean, but is 386 abundant in sedimentary cores (i.e. Margaritelli et al., 2016; Lirer et al., 2013; Cramp et al., 1988; Rio et 387 al., 1990); there exists the possibility to classify it with T. sacculifer or T. trilobus in previous studies as 388 suggested by Hemleben et al. (1989). Some species, which are absent from our samples, reached high 389 frequencies in the aforementioned studies, i.e., Turborotalita quinqueloba, Neogloboquadrina 390 pachyderma, and Globorotalia truncatulinoides. The fact that these species were not sampled in the 391 present study may be due to their absence or presence at extremely low abundances of adult specimens at 392 the sampled stations in May, as they present generally low abundances in spring according to a 12-year 393 sediment trap record in the Gulf of Lion (Rigual-Hernández et al., 2012). Another possibility is their 394 presence in test sizes smaller than 150 µm (our BONGO nets). For example, Pujol and Vergnaud-395 Grazzini (1995) used a mesh size of 120 µm for sampling, which included T. quinqueloba.

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397 To propose a quantitative comparison of the number of species found in previous studies in the 398 Mediterranean, we used the morphospecies identified in them by the authors of each study. We identified 399 12 morphospecies, which is clearly less than Cifelli (1974), Thunell (1978) and Pujol and Vergnaud-400 Grazzini (1995), reporting 18 morphospecies in total. The lower absolute abundance of individuals in our 401 study compared to Pujol and Vergnaud-Grazzini (1995), together with low species diversity in this study, 402 may indicate a trend of changing conditions over the last decades, as it has been reported for temperature 403 and salinity (Yáñez et al., 2010), alkalinity (Cossarini et al., 2015; Hassoun et al., 2015a), and water mass 404 mixing (Hassoun et al., 2015b). These changing conditions could also imply changes in the ecology and 405 distribution of planktic foraminifera, as discussed below; see also Field et al. (2006). Note that our mesh 406 size is larger than that of Pujol and Vergnaud-Grazzini (1995), but similar to that of Cifelli (1974) who 407 used a mesh size of 158 µm. A larger mesh size would explain the lower numbers in absolute abundance 408 and reduced diversity. In contrast, the higher diversity observed by Cifelli (1974) using a wider mesh for 409 sampling in June supports our idea of changing ecological conditions.

410

411 The western part of the first transect (from the Atlantic to the Strait of Sicily) has a higher percentage of 412 larger size fractions than the eastern part. The main cause of the increase in test size is a change in species

- 413 composition. For example, large sized *G. inflata* (especially in the 350-500 μ m fraction) are present with 414 higher abundances in the west than in the east. The same is true for the presence of large *O. universa* 415 (especially in the >500 μ m size fraction), plus the contribution of *G. siphonifera*, which is larger at 416 stations where it is more frequent (Appendix A; Fig. 5).
- 417

418 5. 2. Factors controlling the abundance of the main species

419 Abundance is discussed for the five most frequent species in our samples. The spinose and symbiont-420 bearing species G. ruber (white), O. universa, and T. sacculifer (without sac), which mainly inhabit 421 tropical and subtropical waters. G. ruber (white) is the main species in the Atlantic. O. universa is rather 422 ubiquitous, also present in warm transitional Atlantic waters (Bé and Tolderlund, 1971). The spinose and 423 symbiont-barren species G. bulloides tolerates a wide temperature range and is typical of subpolar and 424 transitional regions as well as upwelling areas, it is also found in subtropical and tropical waters at lower 425 abundances (Thunell, 1978; Bé and Tolderlund, 1971). The non-spinose species G. inflata is typical of the 426 temperate Atlantic Ocean (Bé and Tolderlund, 1971).

427 5. 2. 1. *Globigerinoides ruber* (white)

428 In our study and the one by Cifelli (1974), G. ruber (white) occurs with higher abundances in the eastern 429 compared to the western Mediterranean Basin, being the most abundant species in the Levantine Basin 430 and the South Ionian Sea. Also like Cifelli (1974), in our study, G. ruber (white) from the Atlantic station 431 is found with slightly higher relative abundances than in the western Mediterranean Basin. Temperature-432 related factors may be the main cause, i.e.: warmer Atlantic waters (16.1 °C) compared to the western 433 Mediterranean (14.3 °C in the SW, 14.0 °C in the NW; Fig. 1a). In the South Ionian Sea and the Levantine 434 Basinit seems that G. ruber (white) occurs independent of seasons, winter included, which is also true for 435 the pink variety (see also Thunell, 1978; Pujol and Vergnaud-Grazzini, 1995). The increasing dominance 436 of G. ruber (white) from the western to the eastern Mediterranean Basin coincides with eastward 437 increasing salinity and temperature (Fig. 3d; Table 2). Its higher relative abundance in the eastern basin 438 results from the ability of G. ruber to thrive in food-depleted conditions (Hemleben et al., 1989).

439 G. ruber (white) remains scarce (St. 9, 14, 15) or absent (St. 16-18) in the Ionian Sea stations (Fig. 4), 440 increasing its abundance towards the Tyrrhenian Sea. On the other hand, in the Ionian Sea, it exhibits 441 relative abundances around 40 % to more than 60 % in the surface sediments (Thunell, 1978), and 442 decreases towards the Tyrrhenian Sea. This situation could be due to higher food availability in the 443 Tyrrhenian Sea in comparison to the Ionian Sea observed during May 2013 (Fig. 1c; Fig. 3d) plus a small 444 difference in temperature between both seas (Fig. 1a; Fig. 3d). Also, we note that in May 1979, a scarce 445 presence of G. ruber was reported in the Bay of Naples (de Castro Coppa et al., 1980), whereas in our 446 study G. ruber is present at 47 % in the Tyrrhenian Sea, being the dominant species.

The dominance of *G. ruber* (white) and abundance peaks in May in the eastern Mediterranean (this
study), coincides with the positive temperature gradient between Station 9 and Station 13 (16.2–17.3 °C;
Fig. 1). In late summer, *G. ruber* experiences its highest abundanceat warmer temperatures and more

450 oligotrophic conditions, clearly being the main species from the north of Algeria to the Levantine Basin 451 (Pujol and Vergnaud-Grazzini, 1995). G. ruber (pink) is the dominant species at the Strait of Sicily and 452 eastwards (Pujol and Vergnaud-Grazzini, 1995), whereas in May 2013 it was rare at some locations, 453 especially around Crete. In February, at low sea surface tempreatures, G. ruber (pink) almost disappears 454 from the Mediterranean (Pujol and Vergnaud-Grazzini, 1995; Rigual-Hernández et al., 2012). 455 Presumably, G. ruber (white) is better adapted to lower temperatures than the pink variety. To conclude, 456 food availability seems to be the limiting factor for the abundance of G. ruber once it has reached its 457 optimum temperature range (Table 2).

458 5. 2. 2. Globorotalia inflata

459 The presence of G. inflata is related to cold waters and high food availability (Pujol and Vergnaud-460 Grazzini, 1995; Rigual-Hernández et al., 2012), following high nutrient concentrations (Ottens, 1992). 461 This explains its higher abundance in the cooler nutrient-rich western basin, and its progressive scarcity 462 toward the warmer oligotrophic eastern Mediterranean (Fig. 1; Cifelli, 1974; Thunell, 1978). The same 463 pattern is observed in late summer. From spring to late summer, G. inflata shows a displacement from the 464 eastern Alboran Sea to the northwestern Mediterranean, decreasing frequency in the Algero-Provençal 465 Basin and the southwestern Mediterranean Basin, maintaining a residual presence in the eastern basin 466 (Pujol and Vergnaud-Grazzini, 1995). In winter, at lower temperatures, the opposite process happens, and 467 G. inflata becomes the dominant species in the Alboran Sea (Bárcena et al., 2004) and the southwestern 468 basin, with high frequencies in the Strait of Sicily and toward the Ionian Sea. Eastwards its presence is 469 maintained at only residual levels (Pujol and Vergnaud-Grazzini, 1995). Its distribution along the seasons 470 shows that G. inflata is less frequent or absent in warmer, stratified and nutrient-depleted regions of the 471 Mediterranean than in more productive waters.

472 G. inflata is absent in the Tyrrhenian Sea, despite temperature ranges being comparable to those observed 473 in the southwestern Mediterranean, where this species is abundant (this study). In contrast, in May 1979, 474 G. inflata was reported in the Tyrrhenian Sea as the main species, and practically absent in the warmer 475 summer months (de Castro Coppa et al., 1980). G. inflata is reported in sediment trap data in the Gulf of 476 Lion (Rigual-Hernández et al. (2012), close to our northwestern Mediterranean stations (St. 20, 21, 22) at 477 which G. inflata is absent. In addition, the absolute abundances of G. inflata are closely related to the 478 PCA Factor 1, suggesting a certain affinity with food availability inferred from nutrient concentrations 479 and fluorescence data (see sample scores in Fig. 3b; Table 2). Consequently, food depletion may play a 480 more important role in limiting the distribution of G. inflata than temperature.

The distribution of *G. inflata* during spring, with *G. bulloides* as a secondary species in the Alboran Sea confirm the findings of other studies (Pujol and Vergnaud-Grazzini, 1995; van 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 within the temperature range of *G. inflata* (Fig. 1; Fig. 2).

486 5. 2. 3. Globigerina bulloides

487 Following Cifelli (1974), G. bulloides is the dominant species in the Atlanticclose to the Strait of 488 Gibraltar, whereas in our study it shares dominance with other species (Station 1; Fig. 4). The G. 489 bulloides dominance in the Strait of Gibraltar during late spring-early summer confirms the findings of 490 Cifelli (1974). The abundance peak of G. bulloides in the Strait of Gibraltar (this study), coincides with 491 high nutrient concentration and upwelling (Figs. 1, 2, and 4), with station 2 holding highest standing 492 stocks of planktic foraminifera of the whole transect analyzed here. This confirms its association with 493 upwelling, and the production of phytoplankton as the major food source of this opportunistic species 494 (Pujol and Vergnaud-Grazzini, 1995; Sousa et al., 2014; Bárcena et al., 2004; Hernández-Almeida et al., 495 2011; Rigual-Hernández et al., 2012). Consequently, higher standing stocks of G. bulloides are related 496 with higher nutrient concentration(i.e., Mortyn and Charles, 2003; Fig. 1; Fig. 3e; Table 2).

- 497 In April (Pujol and Vergnaud-Grazzini, 1995; van Raden et al., 2011) and May (this study), G. bulloides 498 is the second most abundant species, surpassed by G. inflata, in the westernmost Alboran Sea. High 499 temperature anomalies could provoke an inverse situation, thanks to more suitable environmental 500 conditions for G. bulloides, which profits from more successful reproduction than G. inflata, which 501 instead stays further from its optimum temperature (Bárcena et al., 2004). One month later, G. bulloides 502 is found to be the dominant species replacing G. inflata, which is still dominant in the eastern Alboran 503 Sea (Cifelli, 1974). Its ubiquity and larger abundance in the western basin with respect to the east is 504 supported by previous studies (i.e., Cifelli, 1974; Thunell, 1978), with a higher difference in abundance in 505 February than in September-October (Pujol and Vergnaud-Grazzini, 1995; Rigual-Hernández et al., 506 2012). In late summer, itdecreases in numbers, with abundance peaks only around the Strait of Sicily and 507 south of Sardinia. In winter, G. bulloides occurs at maximum relative but lower absolute abundance peaks 508 in the Gulf of Lion, as well as in the Strait of Sicily and south of Sardinia (Pujol and Vergnaud-Grazzini, 509 1995; Rigual-Hernández et al., 2012).
- 510 G. bulloides decreases in abundance at food depletion in the eastern Mediterranean, where it is always 511 less abundant than in the western basin, at lower conditions due to water column stratification (Rigual-512 Hernández et al., 2012). During spring to late summer in the eastern basin, G. bulloides is less frequent, 513 and is more abundant just east of the Strait of Sicily (Cifelli, 1974; Pujol and Vergnaud-Grazzini, 1995). 514 During winter its abundance increases and it becomes the second most abundant species in the Levantine 515 Basin preceded by G. ruber (white), and it is also one of the main species in the Ionian Sea. Permanent 516 eddies in the Levantine Basin sustain phytoplankton blooms, explaining the presence of G. bulloides in 517 winter (Pujol and Vergnaud-Grazzini, 1995). In the northern Levantine Basin and in the Aegean Sea its 518 abundances are comparable to those in the western basin regarding surface sediment data from Thunell 519 (1978).

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 during the colder months (Ottens, 1992). The coldest station of the first leg of this study (Strait of Gibraltar, 14.2 °C) coincides with an abundance peak of *G. bulloides*, and it is absent from the warmest station (off the Nile Delta, 17.6 °C; Fig. 1a), which is also one of the most depleted stations in foraminiferal prey (Fig. 1c; Fig. 2). . To conclude, the distribution of *G. bulloides* seems to be limited by food availability, caused by stratification

and consequent nutrient depletion of the surface water column, and increased sea surface temperatures(Table 2).

528 5.2.4. Orbulina universa

Orbulina universa was found to be ubiquitous by Pujol and Vergnaud-Grazzini (1995), being present in all the stations and seasons, reaching peak abundances in the southwestern Mediterranean both in latesummer and winter. Regarding our data, it follows the same pattern during spring, being absent from only three stations (St. 6, 9, and 14; Fig. 4; Fig. 3f). No abundance peak occurs in spring (Cifelli, 1974, and this paper) but abundances are slightly higher in the western basin than in the east. These small differences can be caused by more nutrient-rich upwelling areas (cf. Sousa et al., 2014; Morard et al., 2013) in the western basin or by higher salinities in the eastern than western basin.

536 5. 2. 5. *Trilobatus sacculifer* (without sac)

537 In June, T. sacculifer (without sac) has a wide distribution and represents 5 % of the assemblage in the 538 Strait of Gibraltar (Cifelli, 1974). T. sacculifer constituted up to 25 % of the assemblages in May 2013, 539 and was absent from seven stations (St. 5, 7a, 14, 15, 16-18, 20, 22). Low relative abundance occurred in 540 April in the Alboran Sea (Pujol and Vergnaud-Grazzini, 1995). In September-October T. sacculifer 541 shows high abundances and is one of the main species from north of Minorca to the southwestern 542 Mediterranean as far as the Strait of Sicily, where it is rare. In late summer, it progressively decreases in 543 numbers to the east, where G. ruber dominates assemblages (Pujol and Vergnaud-Grazzini, 1995), 544 probably due to slightly higher temperature and salinities (see also Bijma et al., 1990). On the other hand, 545 in February T. sacculifer (without sac) disappears from the north Levantine Basin and its abundance 546 (Pujol Vergnaud-Grazzini, 1995). considerably decreases and

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549 5. 3. Factors controlling planktic foraminiferal test weight

The area density (ρ_A) of tests of both *G. ruber* (white) and *G. bulloides* follow a systematic change from the Atlantic towards the eastern Mediterranean (Fig. 7). Therefore, the ρ_A of these two species is interpreted and discussed for possible environmental effects and biological prerequisites in the following. In contrast, the ρ_A of *O. universa* does not show any change between the western and eastern basins (Fig. 3i), and cannot be interpreted for any particular environmental effects.

555 5.3.1 Unknown control of the ρ_A of *O. universa*

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 ρ_A in the data presented here. Only one out of three genotypes of *O. universa* (i.e. Type III, after Darling and Wade, 2008) occurs in the Mediterranean Sea (Mediterranean species, after de Vargas et al., 1999), 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 (i.e., de Vargas et al., 1999). Whereas the various types of *O. universa* differ in the pore-size (de Vargas et al., 1999; Morard et al., 2009; Marshall et al., 2015), their pore-size is also affected by environmental conditions including water temperature (i.e., 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; Marshall et al., 2015), and is as well affected by environmental conditions and ontogenetic stage of specimens. Adult *O. universa* have been shown to continuously add calcite layers to the proximal surface of the same

- 568 sphere (Spero, 1988; Spero et al., 2015).
- 569 The reason why the ρ_A of *O. universa* is particularly low and highly variable in the Mediterranean despite
- 570 high carbonate ion concentration ($[CO_3^{2-}]$) and pH (Fig. 1) might be sought in factors other than, and in
- 571 addition to, chemical and physical conditions, namely the changing availability of food along the transect
- 572 from the Atlantic Ocean to the Levantine Basin.
- 573 5.3.2 Factors affecting the ρ_A of *G. ruber* (white) and *G. bulloides*
- 574 The ρ_A of G. ruber (white) is only partly controlled by carbonate chemistry, being instead affected by 575 other factors like food availability, similar to O. universa. In contrast to O. universa, the p_A data of G. 576 ruber and G. bulloides follow systematic correlations. High ρ_A of G. ruber in the Atlantic and Tyrrhenian 577 Sea correlates with enhanced primary production (enhanced fluorescence, Fig. 1d; Fig. 3g; Table 2), and 578 presumably enhanced food availability (Fig. 3g; Fig. 7; Fig. 2, also noticeable in Fig. S2d and Fig. S4d). 579 Under more oligotrophic conditions, low ρ_A of G. ruber (white) might be caused by limited food 580 availability. An opposite trend is reported for G. ruber (white) from sediment trap samples in the Madeira 581 Basin, in which, apart from showing a negative significant correlation between calcification intensity and 582 productivity, ρ_A shows positive correlation with temperature (Weinkauf et al., 2016).
- 583 The relationship between food availability and ρ_A in *G. bulloides* is opposite to *G. ruber* (white) (Fig. 3g-584 h; Fig. 7; Table 2). The ρ_A of *G. bulloides* tests increases from the Atlantic toward the eastern 585 Mediterranean. In both species larger IQRs are found toward higher absolute ρ_A (Fig. 7).
- 586 An opposite trend in ρ_A of the two species *G. ruber* (white) and *G. bulloides* had earlier been described 587 from the Arabian Sea, and could neither be assigned to changes in $[CO_3^{2-}]$ of ambient seawater nor
- 588 growth conditions (Beer et al., 2010a). Due to its symbionts, *G. ruber* would rather have an advantage
- 589 over symbiont-barren G. bulloides in oligotrophic waters, and support formation of test calcite through
- 590 CO_2 consumption and increasing $[CO_3^{2-}]$ and pH (see also Köhler-Rink and Kühl, 2005). Those findings
- 591 may still point toward differences in growth conditions: Reproduction of both G. ruber and G. bulloides
- 592 might be hampered under less optimal conditions, and additional calcite layers might be added to the
- 593 proximal test before reproduction, similar to the process described for *O. universa* (see above). Therefore,
- tests may grow heavier under less than optimal food availability, given that carbonate chemistry of
- ambient seawater does not seem to limit the formation of test calcite in our samples.
- 596 Comparing weight-to-long axis relations, *G. ruber* (255–350 μ m size fraction) from plankton tows of the 597 western Arabian Sea have an average weight of 11.5 ±0.69 μ g (de Moel et al., 2009), which is heavier 598 than the individuals from our study (5.9 ±0.31 μ g; Fig. S3a; Appendix A). The difference in weight-to-

599 long axis relation may indicate that *G. ruber* is produced under more suitable conditions for shell calcite 600 formation in the Arabian Sea especially during non-upwelling periods and still higher overall primary 601 productivity and food availability. However, the comparison might be biased by the fact that *G. ruber* 602 (white) and *G. elongatus* were not separately analyzed by de Moel et al. (2009).

603 Data for supra-regional comparison of the weight-to-long axis relation of G. bulloides from the water 604 column possible for the 200–250 µm size fraction: In the north Atlantic (56-63 °N), in June 2009, 605 Aldridge et al. (2012) report a range of $1.75-2.92 \ \mu g$ (r² = 0.52). In the same size fraction, our results (36 606 °N) show heavier tests in the Alboran Sea (3.46 $\pm 0.15 \,\mu$ g), and similar weights at the Strait of Gibraltar 607 $(2.57 \pm 0.00 \ \mu g;$ Fig. S3b). For the same water depth as in our samples, Schiebel et al. (2007) found 608 heavier average weight-to-long axis relations in fall $(5.19 \pm 0.25 \ \mu g)$ than in spring $(4.21 \pm 0.2 \ \mu g)$ in the 609 eastern North Atlantic, and 5.51 ±0.31 µg during the SW monsoon in the Arabian Sea. In general, higher 610 ρ_A occurs at lower latitudes and lower ρ_A at higher latitudes (see also Schmidt et al., 2004). For G. 611 bulloides and G. ruber, increased longevity and ongoing production of additional calcite layers at the 612 proximal side of shells may result in an increased ρ_A , given that seawater carbonate chemistry is only 613 partially affecting the calcite formation in our samples.

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615

616 **6.** Conclusions

617 Absolute and relative abundances of planktic foraminifera were studied from plankton tow samples across 618 the Mediterranean, collected in May 2013. The samples show large differences in species abundance and 619 assemblages between the different basins and sub-basins of the Mediterranean Sea. Absolute abundance 620 and diversity of planktic foraminifer assemblages are low in comparison to other regions of the world 621 ocean. Average standing stocks in the upper 200 m of the water column are 1.42 ± 1.43 ind. 10 m⁻³, 622 including twelve morphospecies in total. Planktic foraminifer assemblages are indicative of changing 623 temperatures and salinities, as well as trophic conditions, between the eastern and the western 624 Mediterranean Sea. Highest standing stocks of total planktic foraminifera occurred in the Strait of 625 Gibraltar and the Alboran Sea. Overall, the largest foraminiferal tests occurred in the western 626 Mediterranean, driven by the assemblage composition, and the presence of large G. inflata.

627 Globigerinoides ruber was the most abundant species; its dominance in the east compared to the west is 628 likely caused by stratification of the surface water column, enhanced SST, and trophic conditions. G. 629 ruber is a symbiont-bearing species, which might be an advantage over symbiont-barren species like G. 630 bulloides under oligotrophic and food-limited conditions as in the Levantine Basin. G. bulloides was 631 more abundant in upwelled waters in the Strait of Gibraltar, in the Alboran Sea, and in the western 632 Mediterranean. O. universa was present at balanced standing stocks along the entire transect from the 633 west to the east. In general, distribution patterns of the main planktic foraminiferal species in the 634 Mediterranean seem to be mainly related to a combination of food availability, controlled by sea surface 635 temperature and stratification.

- 636 In the Mediterranean surface waters are supersaturated with respect to calcite and aragonite (Schneider et
- 638 G. ruber (white) and G. bulloides, are largely affected by food availability. G. ruber is more affine to
- 639 oligotrophic conditions, and grows heaviest tests in less food-limited waters in the western basin near
- 640 Gibraltar and in the Tyrrhenian Sea. In contrast, G. bulloides grows heaviest tests under more food-
- 641 limited conditions in the eastern Mediterranean Sea. We speculate that reproduction is hindered when the
- 642 species-specific food sources are limited, while individuals continue adding calcite to the outer shell, and
- 643 grow heavier tests than individuals that reproduced earlier in ontogeny.
- 644 These observations highlight the need for more interdisciplinary studies on the causes of changing
- 645 for a marginal for a semblage 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.

647 Appendices

Appendix A. Planktic foraminifera data from BONGO nets: relative and absolute abundances, and weight and size parameters. The nomenclature *G. bulloides* represents the *G. bulloides/G. falconensis* plexus, and *G. siphonifera* represents the *G. siphonifera/G. calida/G. radians plexus*.

Location Station	Atlantic 1	Gibraltar 2	Alboran Sea 3	South- Central Western Med. 5	Strait of Sardinia 6	Strait of Sicily 7a	South of Ionian Sea 9	Off Southern Crete 10	Eastern Basin 11	Off Nile Delta 12	Off Lebanon 13	Antikythera Strait 14	Eastern Ionian Sea 15	Adriatic Sea 17	Otranto Strait 16	Northern Ionian Sea 16-18	Tyrrhenian Sea 19	North- Central Western Med. 20	Central Western Med. 21	Catalano-Balear 22
Absolute abundance																				
(individuals*10 m ³)																				
Total numbers																				
G. ruber (white)	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. elongatus	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
T. sacculifer (without sac	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. inflato	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
T. quadrilobatus	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
T. sacculifer (with sac	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. menardi	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
Tota	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
$150\text{-}350\mu\text{m}$ size fraction																				
G. ruber (white)	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. elongatus	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
T. sacculifer (without sac	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. siphoniferd	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
T. quadrilobatus	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
Tota	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
$350\text{-}500\mu\text{m}$ size fraction																				
G. ruber (white	0.049	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.051	0	0	0
G. elongatus	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
T. sacculifer (without sac	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. siphoniferd	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
T. quadrilobatus	. 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
T. sacculifer (with sac	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.026	0	0	0
G. menardi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.029
Tota	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

652 (Appendix A, cont.).

			Alboran	South- Central Western	Strait of	Strait of	South of	Off Southern	Eastern	Off Nile	Off	Antikythera	Eastern	Adriatic	Otranto	Northern	Tyrrhenian	North- Central Western	Central Western	6.1 P.
Location	Atlantic	Gibraltar	Sea	Med.	Sardinia	Sicily	Ionian Sea	Crete	Basin	Delta	Lebanon	Strait	Ionian Sea	Sea	Strait	Ionian Sea	Sea	Med.	Med.	Catalano-Balear
Station	1	2	3	3	0	/a	9	10	11	12	15	14	15	17	16	10-18	19	20	21	22
>500 µm size fraction	0.010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G. ruber s.i.	0.010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1. succurier (without sac)	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
1. quaarnobanis	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 (white)	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. elongatus	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
1. sacculifer (without sac)	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
1. quadrilobatus	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
1. sacculifer (with sac)	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 (white)																				
size fraction (µm)	250-300							200-250	200-250		200-250	250-300			250-300		200-250			
nº 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			
nº 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			
	100 150							200 250	250 100		200.250						200 250			
size fraction (µm)	400-450							300-350	350-400		300-350						500-550			
n° or individuals	1							3	1		2						2			
average size (µm)	412							313.333	300		323.5						343.4			
average weight (µg)	14.00/							1.444	5.06/		11						9.86/			
SD (µg)	1.155							0.385	1.155		U						0.231			
size function (250 400									250 400			
n ^o of individuala								350-400									350-400			
n or murviduals								2									366			
average weight (8 833									9.083			
SD (ma)								0.764									0.144			
ъл (µg)								0.704									0.144			

654 (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	Antikyther Strait	a 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
size fraction (μm) n° of individuals average size (μm) average weight (μg)																	400-450 2 413 16.167 1.258			
5D (µg)																	1.250			
G. bulloides size fraction (µm) n° of individuals	300-350	200-250	200-250	350-400	300-350														400-450	300-350
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) n° of individuals		250-300 12	250-300 2																	400-450 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) n° of individuals		300-350 2	350-400 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																	
SD (ug)		0.289	0																	
		100.150	450 500																	
size fraction (µm)		400-450	450-500																	
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 17.667	280	20.667	445		31		342	6.333	47	43		24.167	452	5.333	444 18.667	24.333	22.667	4/9.5	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
nº 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 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 (um)	550-600					650-700		450-500							450-500	650-700			750-800	500-550
nº 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 48.667					720 34									527.333 21.778					
SD (µg)	0.577					0									0.192					

657 (Appendix A, cont.).

			Alboran	South- Central Western	Strait of	Strait of	South of	Off Southern	Eastern	Off Nile	Off	Antikythera	Eastern	Adriatic	Otranto	Northern	Fvrrhenian	North- Central Western	Central Western	Catalano-
Location	Atlantic	Gibraltar	Sea	Med.	Sardinia	Sicily	Ionian Sea	Crete	Basin	Delta	Lebanon	Strait	Ionian Sea	Sea	Strait	Ionian Sea	Sea	Med.	Med.	Balear
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)	550-700					750-800									550-600					
nº 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					
nº of individuals															1					
average size (µm)															625					
average weight (µg)															23					
SD (µg)															0					
size fraction (µm)															650-700					
nº of individuals															2					
average size (µm)															654.5					
average weight (µg)															31.167					
SD (µg)															0.289					

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865 Tables

- **Table 1.** Date, time, location, volume filtered and environmental parameters of the sampled stations. Sea
- 867 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.
- **Table 2.** Loadings of the environmental parameters in the PCA (left column) and additional Pearson
- 870 correlation coefficients (r) for relationships between stations scores on factor 1 and 2 and the abundances
- 871 / density area of selected species (upper middle / right columns) and between the environmental
- parameters and the abundances / density area of selected species (lower middle / right columns). r-values
 in bold are significant at p<0.05, *p<0.1.

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Leg	Station Code	Station Name	Day (DD/MM/YYYY)	Time	Latitude	Longitude	Volume (m ³)	Temperature (°C)	SST (°C)	Salinity (PSU)	SSS (PSU)	Fluorescense (µg/l)	рН	[CO ₃ ⁻²] (mmol/kg)
1	1	Atlantic	03/05/2013	0:03	36°03'	-6°65'	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	35°94'	-5°56'	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	36°12'	-4°19'	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	38°54'	5°56'	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	38°27'	8°69'	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	37°04'	13°18'	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	35°12'	18°29'	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	33°81'	24°27'	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	33°50'	28°00'	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	33°22'	32°00'	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	34°23'	33°23'	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	36°70'	23°42'	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	36°40'	20°81'	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	41°84'	17°25'	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	40°23'	18°84'	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	39°07'	18°70'	426	no data	no data	no data	no data	no data	no data	no data
	19	Tyrrhenian Sea	27/05/2013	12:40	39°83'	12°52'	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	41°32'	5°66'	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	40°07'	5°95'	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	40°95'	3°32'	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)

876 Table 2.

	PCA r	esults			Abund		Density area				
	Factor 1	Factor 2	<i>G.ruber</i> (white)	<i>T.</i> Sacculifer (without sac)	G. bulloides	G. inflata	O. universa	TOTAL	G. bulloides	<i>G.ruber</i> (white)	O. universa
Factor 1	1		-0.297	0.353	0.511	0.242	0.009	0.309	-0.369	0.324	-0.449
Factor 2	0	1	0.121	-0.549	-0.470	-0.209	-0.127	-0.406	0.279	-0.296	0.133
Environmental	factor loadir	igs:			*					*	
Temperature	-0.825	-0.030	0.346*	-0.158	-0.333*	-0.154	-0.198	-0.154	0.294	-0.324*	0.464
Salinity	-0.777	0.532	0.296	-0.353*	-0.425*	-0.479	-0.005	-0.393*	0.346*	-0.721	0.355*
Oxygen	-0.084	0.602	-0.149	-0.675	-0.684	-0.241	0.042	-0.682	0.050	0.072	0.509
Fluorescence	0.721	-0.185	-0.378*	-0.101	-0.020	0.459	-0.063	0.028	-0.275	0.738	-0.246
[NO3]	0.912	-0.113	-0.344*	0.460	0.567	0.166	-0.063	0.290	-0.295	0.156	-0.548
[PO4]	0.893	-0.272	-0.361*	0.461	0.579	0.293	-0.168	0.340*	-0.264	0.252	-0.538
рН	-0.189	0.969	0.215	-0.559	-0.563	-0.351*	0.117	-0.448	0.263	-0.381*	0.236
pCO ₂	0.086	-0.941	-0.170	0.589*	0.554	0.196	-0.160	0.378*	-0.167	0.154	-0.177
[CO ₃ ²⁻]	-0.594	0.729	0.352*	-0.451	-0.566	-0.452	-0.016	-0.447	0.406*	-0.614	0.434
	N = 20	N = 20	N=13	N=13	N=16	N=10	N=17	N=20	N=16	N=13	N=17

877 **Figures**

Fig. 1. (a) Temperature (°C), **(b)** salinity, **(c)** fluorescence (μ g·l⁻¹), **(d)** pH, and **(e)** [CO₃²⁻] (μ mol·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 are shown on the map (f). For station code names see Table 1. Note reversed color scale at (d) and

- (e). Software used: Ocean Data View (Schlitzer, 2016).
- Fig. 2. Sampled stations with BONGO nets (dots). The numbers in the picture represent the station codes:
 First transect: 1 to 13, second transect: 14 to 22. For station code names see Table 1. Color scale at right
 represents the values of surface chlorophyll concentration (in µg/l), retrieved from *MODIS Aqua (L2)*,
 from the closest day as possible, specified in the upper part, of the first transect.
- Fig. 3. Sample scores on the two PCA factors with the loadings of the environmental parameters on eachfactor represented by the red axis. The black axis represents the overlay of the absolute abundance values
- 890 (individuals $\cdot 10 \text{ m}^{-3}$) according to every station scores of (**a**) all the foraminifera sample, (**b**) *G. inflata*, (**c**)
- 891 *T. sacculifer* (without sac), (d) *G. ruber* (white), (e) *G. bulloides*, and (f) *O. universa*. Overlay of the Area
- density (ρ_A) values ($\mu g \cdot \mu m^{-2}$) of (g) G. ruber (white), (h) G. bulloides, and (i) O. universa. In blue colour
- western Mediterranean stations (incl. Atlantic and Strait of Gibraltar), in red color the easternMediterranean stations.
- Fig. 4. Absolute abundance of planktic foraminifera from BONGO nets during leg 1 (stations 1 to 13) and
 leg 2 (stations 22 to 14). Category 'Others' is comprised of *G. siphonifera/G. calida/ G. radians* plexus, *T. quadrilobatus*, *H. pelagica*, *G. ruber* (pink), *G. menardii* and *T. sacculifer* (with sac).
- Fig. 5. Percentage of each planktic foraminifera size fraction in each station from leg 1 (stations 1 to 13)and leg 2 (stations 22 to 14). Sample size is indicated in italics at the top of each station bar.
- 900 Fig. 6. Relative abundance of planktic foraminifera (%). Category 'Others' is comprised of G.
 901 siphonifera/G. calida/G. radians plexus, T. quadrilobatus, H. pelagica, G. ruber (pink), G. menardii and
 902 T. sacculifer (with sac). Less than 1% values are not shown. Number in parenthesis indicates the total
 903 individuals of each location.
- **Fig. 7.** Area density of *G. ruber* (white) and *G. bulloides* in box-and-whisker plots representation for the different location groupings in the Mediterranean. Box extends from the lower (Q₁) to upper (Q₃) quartiles values of the data, with a line at the median (Q₂). Whiskers extend from the quartiles to values comprised within a 1.5 interquartile range (IQR = Q₃ - Q₁) distance: Q₁ - 1.5 · IQR; Q₃ + 1.5 · IQR. The
- 908 Coefficient of Variation (CV) of each location grouping is represented as a black dot.



0°

10°E

20°E

30°E



912 Figure 3









 Eastern
 Ionian-Adriatic-Aegean Tyrrhenian Sea

 Mediterranean
 (St. 14, 15, 17, 16, 16-18)
 (St. 19)

 (St. 9, 10, 11, 12, 13)
 (St. 14, 15, 17, 16, 16-18)
 (St. 19)

