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To what extent the size fraction affects an interpretation of planktonic foraminiferal assemblages - case study from Southern Adriatic

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Study of planktonic foraminifera, sampled from two levels of a 26 cm thick core, recovered at 1,200 m water depth, sheds some lights on the composition of foraminiferal assemblages that occur in the Southern Adriatic. Altogether 15 planktonic species (including one referred as undeterminable and two species recorded for the first time in the eastern Adriatic Sea) identified from 0-2 cm and 24-26 cm sediment intervals, were grouped into two assemblages: >63 µm fraction Turborotalita quinqueloba and >125 µm fraction as Globigerina bulloides-Globigerinoides ruber. *The differences in core-top and core-bottom assemblages lie in: a) change in the relative proportion of some species; and b) slight differences in diversity indices. The relative proportions of species are strongly controlled by sieve mesh size, whereas the slight increase in diversity follows the increase in sieve mesh size. The benthic foraminifera, although constituting a negligible quantitative factor, show a slight increase in abundance and diversity of species with age.*

Key words: Adriatic Sea, planktonic foraminifera, size fraction, *Turborotalita quinqueloba*, *Globigerina bulloides*, *Globigerinoides ruber*, diversity indices

INTRODUCTION

Planktonic foraminifera are unicellular zooplankton inhabiting the upper part of the water column in world's oceans and seas. They secrete calcite tests that constantly sink and significantly contribute to sediment load to the deep sea sediment deposits (KENNETT, 1982; HEMLEBEN *et al.*, 1989). Since their calcified tests can be subsequently preserved as fossils, planktonic foraminifera are important sources of data for different paleoceanographic interpretations/reconstructions (from the 80th onward, BOERSMA & PREMOLI SILVA, 1983; BOERSMA *et al.*, 1987; KUCERA, 2007). In sediment deposited in outer neritic to bathyal depths of modern seas and oceans, planktonic foraminifera typically comprise more than 80% of the foraminiferal assemblages (LECKIE & OLSON, 2003). They have attracted great interest in the context of morphological and ecological evolution through geological time. One way of interpreting past paleoceanographic conditions is by studying the distribution of recent foraminifera, because it is governed by the distribution of specific surface water-masses, and hence by specific temperature and salinity ranges (THUNELL, 1978; RUTHERFORD *et al.*, 1999; KUCERA, 2007). It is well known that foraminiferal tests sizes increase with increasing temperature (tests can vary from smaller than 0.1 mm to over 1 mm; KUCERA, 2007) and that assemblages show greater diversity from poles to the tropics (SCHMIDT *et al.,* 2004; FRIEDRICH *et al.*, 2012).

Since the composition of the assemblage changes along size spectrum, choice of the sieve mesh size strongly influences the composition of the assemblage and in turn the paleoceanographic interpretations based on these counts. PEETERS *et al.* (1999) investigated the sieve mesh size effect concluding that, in assemblages washed over sieves with mesh greater than 150 µm, most species have reached the adult stage and proposed to use this mesh size for standard faunal analysis. Studying planktonic foraminiferal assemblages from the Mediterranean Sea CAPOTONDI *et al.* (2004) found that there are no significant compositional changes in >63 and >125 µm size fractions, whereas dissimilarities became evident comparing the >63 and >150 µm size fractions. It is well accepted to study planktonic foraminifera sieved over a mesh of size >150 µm or >125 µm (KUCERA, 2007). However, although processing of larger size fraction is a quicker approach, it may cause significant loss of information on species diversity and dominance (SCHRÖDER *et al.*; 1987, SEN GUPTA *et al.*, 1987; CAPOTONDI *et al.*, 2004).

Data on planktonic foraminiferal distribution from the Croatian part of the Adriatic shelf are scarce, indicating limited research interests about them (ALFIREVIĆ, 1998; ĆOSOVIĆ *et al.*, 2011; references therein). Furthermore, there is a geographical discrepancy in the quantity of published data with most of the data collected in the Northern and Central Adriatic. According to ĆOSOVIĆ *et al.* (2011) 18 species of planktonic foraminifera are registered. Interestingly, occurrence data in the primary literature are strongly biased by sampling and by applied preparation techniques. Aware that planktonic species display a great variety of tests size, application of certain mesh sieves may eliminate some species from mesh-residue and from further study. Thus, distributional patterns of recorded planktonic assemblages may not depict the real situation, or even some species by using different preparation methods are missing. JORISSEN *et al.* (1993), on the basis of studies of planktonic and benthic foraminifera (150-595 µm fraction) from 11 sediment cores from the western Adriatic offshore, distinguished 3 biochronological episodes within late Pleistocene and Holocene. In several papers, planktonic foraminifera from South Adriatic cores were applied for chronological description of the Late Glacial to Holocene sediments (PIVA *et al.,* 2008; SIANI *et al.,* 2010; NARCISO *et al.*, 2012). SIANI *et al.* (2010) even found 25 species of planktonic foraminifera (fraction >150 µm, and 1,010 m water depth of the core) among which were *Globoturborotalita tenella* and *Globigerinita uvula*.

This paper describes the foraminiferal assemblage occurring in two levels of a core recovered from 1,200 m of water depth in the southern Adriatic region. The aim of this study is to produce data on the composition of the planktonic foraminiferal assemblages and to test the role of mesh size in composition of assemblages, because the average test size of planktonic foraminifera is a common proxy used in paleoceanographic studies. As the studied material was obtained from great depth we, also, tested VAN DER ZWAAN *et al.* (1990) paleodepth calculation model in order to see how it works in semi-enclosed seas.

Study area

Adriatic Sea is semi-enclosed, elongated, NW–SE oriented basin. Three distinct parts can be distinguished, northern, middle and southern (ARTEGIANI *et al.,* 1997). The Northern Adriatic is the shallowest with an average depth of about 35 m. Average depth of the Middle Adriatic is 140 m, while the Southern Adriatic is the deepest part with an average depth of about 900 m and a maximal depth of 1,223 m. This depression is separated from the Middle Adriatic by the 170 m Palagruža Sill located in the north. To the south it is bounded with an 800 m deep sill at the Otranto Strait. Eastern and western coasts of the Adriatic Sea are considerably different, eastern being carbonate and sediment starved and western being mainly silicoclastic sands. On the outer shelf there are old relict, transgressive, large scale deposits that are no longer fed outcrop. The sediments from western flank are prevented from spreading over the whole shelf by the general cyclonic circulation of the water masses in Adriatic Sea (COLANTONI & MENCUCCI, 2010). The Adriatic is a temperate warm sea with pronounced seasonal temperature variations. The annual surface temperature ranges are 18 °C in the south and 25 °C in the north. During the winter, the southern part is 8-10 °C warmer than central and northern parts. The thermocline occurs at 10-30 m during the warmer season (GAČIĆ *et al.,* 2001). Mean salinity of the Adriatic is relatively high while precipitation and river runoff prevails over evaporation. The Southern Adriatic has salinity between 38.4 and 38.9, while salinity is lower in the northern part of Adriatic Sea and in coastal zones (GAČIĆ *et al.*, 2001). Open waters in the Southern Adriatic are oligotrophic (VILIČIĆ *et al.,* 1989).

In the Southern Adriatic, bottom is mostly covered with mud deposits. Estimated sediment accumulation rate varies greatly in South Adriatic Pit, one data point to 0.36 mm y^{-1} (JORISSEN *et al.,* 1993) and another to 1.8 ± 0.5 mm y^{-1} (PETRINEC *et al.*, 2012). Both data correspond to time averaging between 100 to 5,000 years within a 1 cm interval in pelagic sediments (MÜLLER & SUESS, 1979).

MATERIAL AND METHODS

Sediment sampling was performed in August 2013 at a single station in the Southern Adriatic (42°16′52″N, 17°42′05″E) at the depth of 1,200 m (Fig. 1). Sediment was acquired by Uwitec gravity corer (Ø 90 mm). Acquired sediment core was 26 cm thick, and divided into samples by cutting it horizontally to get 2 cm thick layers. The sediment was homogenous in texture throughout the core and described as brown yellowish mud. After dividing the core, individual samples were placed in the plastic bags and stored in deep freeze. In laboratory, samples were first soaked overnight in hydrogen peroxide (10% H_2O_2) to remove organic content and then washed on a 63 μm sieve. Dry sediments were split into aliquots of around 300 foraminiferal individuals which were identified and counted under the stereoscope microscope with 180x magnification. Total foraminiferal assemblages were assessed with additional analysis of selected tests with scanning electron microscope (Tescan MIRA3) to detect species or confirm examination under stereoscope microscope. After analyzing >63 μm size fraction analyzed aliquots were stored in micropaleontological slides while remaining amounts of samples were dry sieved on a 125 μm sieve, split and analyzed again. In this paper, the uppermost 0-2 cm (core-top) and the deepest 24-26 cm (core-bottom) sediment samples (referred as samples #1 and #2 in the further text) are studied in detail.

Species were identified following the generic classification of LOEBLICH & TAPPAN (1987) and specific identification of CIMERMAN & LANGER (1991) and SAITO *et al.* (1981). Species were defined upon size (the maximum diameter of the test antipodal from last chamber), wall textures, general chamber and test shape, type of coiling, basic position of primary aperture, apertural features, existence and position of second-

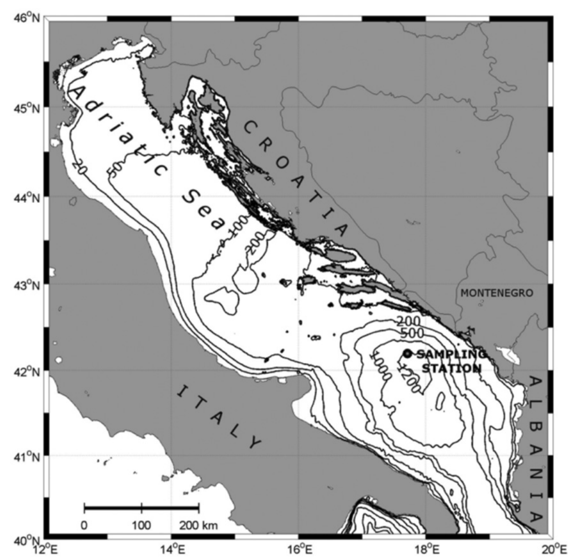

Fig. 1. Map of the Adriatic Sea with isobaths and location of sampling site (redrawn after AMANTE & EAKINS, 2009)

ary aperture(s) and ornamentation (HEMLEBEN *et al.*, 1989; BOUDAGHER-FADEL, 2012).

For quantitative comparison between studied assemblages, some indices were calculated and compared using software package PAST (HAMMER *et al.,* 2001) in order to objectively quantify changes in foraminiferal assemblages. Simpson index ($1 - D$) was used as a measure of "evenness" in the community. It ranges from 0 (one taxon dominates the community completely) to 1 (all taxa are equally present). It is calculated as:

$$1 - D = 1 - \sum \left(\frac{n_i}{n}\right)^2,$$

where n_i is number of individuals of taxon i, and n is total number of individuals. Shannon index (H) also takes into account the number of individuals as well as number of taxa but rare species make little contribution. It varies from 0 for communities with only a single taxon to high values for communities with many taxa, each with few individuals.

$$H = -\sum \frac{n_i}{n} ln\left(\frac{n_i}{n}\right).$$

Evenness index (E) was calculated from Shannon diversity and measures the evenness with which individuals are divided among the taxa present.

$$E = \frac{e^H}{S},$$

where S is number of taxa. Fisher's alpha index (α) is a diversity index calculated from formula:

$$S = \alpha ln\left(1 + \frac{n}{\alpha}\right),$$

and was applied for interpretation of assemblages.

Plankton/benthic ratio was calculated in order to compare the real water depth with the values obtained from formula given by VAN DER ZWAAN *et al.* (1990) which is used to reconstruct paleodepth:

$$\%P = \frac{P}{P+B} * 100,$$
$$Depth = e^{(3.58718+(0.03534\%P))}.$$

Taphonomic conditions were assessed by observing the preservation state of the foraminiferal tests with scanning electron microscope. Most of the individuals were well preserved while some show evidence of bioerosion in their tests (mostly microboring).

RESULTS

Altogether 51 foraminiferal species grouped into 39 genera were identified (Table 2), 15 species were planktonic and 36 benthic. Planktonic specimens outnumber benthic, making 86-91% of the total assemblage. In each sample 24 to 26 different species occur. Total of 37 species were found in the upper 0-2 cm of sediment core sample (sample #1 or core-top sample), and 42 in sub-surface (sample #2, depth 24-26 cm). It is interesting to note that only two planktonic species were available from all size fractions and from both studied samples (Table 2, Fig. 2).

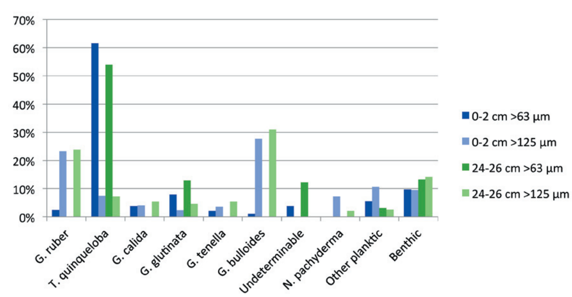

Fig. 2. Relative abundances of planktonic (dominant and associated) and benthic species in each subsample

Planktonic foraminiferal assemblages

In core-top sample #1, in both size fractions, planktonic species account for 90% and 91% of all tests, compared to their relative abundance of 87% and 86% in sample #2 (Table 1). Due to high relative abundance of *T. quinqueloba* (with 62% and 54% shares) in >63 µm fraction together with the subordinate presence of *Globigerinita glutinata* (8% and 13%) and undeterminable planktonic (4% and 12%), the foraminiferal assemblage is named as *Turborotalita quinqueloba* assemblage. Two species have equal proportion in >125 µm fraction, *Gl.*

Table 1. Species richness, number of planktonic species, planktonic/benthic ratio, relative abundance of dominant species, and diversity indices [Simpson index (1 – D), Shannon index (H), Evenness index (E), Fisher's alpha index (α)] in each subsample

	Subsample			
	0-2 cm >63 µm	0-2 cm >125 µm	24-26 cm >63 µm	24-26 cm >125 µm
# taxa (S)	24	25	25	26
# planktonic *S*	9	12	4	11
P/B	0.90	0.91	0.87	0.86
Dominant species (relative abundance)	*T. quinqueloba* (62%)	*Gl. bulloides* (28%)	*T. quinqueloba* (54%)	*Gl. bulloides* (31%)
1-D	0.59	0.83	0.64	0.82
H	1.64	2.29	1.62	2.23
E	0.21	0.40	0.20	0.36
α	6.27	7.02	6.70	7.53

bulloides (contributing with 28 and 31%) and *Gd. ruber* (23% and 24%), thus assemblage is named as *Globigerina bulloides – Globigerinoides ruber* assemblage.

The values of diversity indices showed no differences between samples, but when we compared different size fraction of the same sample (Table 1) some differences occurred. Simpson (*1 – D*) indexes vary from 0.59 to 0.64 in >63 µm fractions, and from 0.82 to 0.83 in >125 µm (Table 1). Shannon – index (*H*) values were lower (1.64 to 1.62) in >63 µm fractions, and greater (2.29 and 2.23) in >125 µm. Evenness index (*E*) had different values in assemblages of the same sample, being between 0.20 and 0.21 in >63 µm, and between 0.36 and 0.40 in >125 µm fraction. Fisher's alpha index (α) was larger than 5 in all subsamples, ranging from 6.27 to 7.53.

The finer fraction of both intervals contains much more tests that are difficult to identify (being representatives of juvenile or being just too small for optical device used in this study). It is also worth mentioning occurrence of tests with aberrant chamber growth or appearance (i.e. bulla like supplements) that are more common in finer fraction than in coarser fraction.

Benthic foraminiferal assemblage

Benthic species account less than 14% of total assemblages in the studied subsamples (their species proportion reaches up to 3%). The representatives of suborder Rotaliina prevail, followed by representatives of Miliolina and Textulariina (Table 2). None of the species found was present in all subsamples. There was slight difference in relative abundances of suborders according to depth of subsample, with finer sediments containing greater diversity of benthic foraminifera. Finer fraction contained little bit more diversified benthic assemblages (15 and 21 species in >63 µm compared to 13 and 15 species in >125 µm fraction; Table 2). Benthic assemblages showed greater diversification of epifaunal foraminifera, although shallow infaunal forms were more abundant.

DISCUSSION

Traditionally, planktonic foraminifera from the Adriatic Sea are assigned to warm temperate group. The most common species *T. quinqueloba*, a symbiotic species, has a wide depth range although its maximum occurrence is within the first 100 m of water column (KUCERA *et al.*, 2005). The second abundant species, *Gl. bulloides*, is a surface (0-50 m) and subsurface (20-75 m) dwelling spinose, symbiont barren form that proliferates in water temperature between 0-27 °C (peak abundance is when temperature varying between 3 and 19 °C). The representatives of this species occur in less abundance in temperate to subpolar water masses and in upwelling areas in lower latitudes (BÉ & TOLDERLUND 1971, LONČARIĆ *et al.*, 2006, JONKERS *et al.*, 2013). *Gd.*

Table 2. Relative abundance of foraminiferal species in each subsample. Relative abundance of < 1% is represented with +

	Subsample			
Species	0-2 cm >63 µm	0-2 cm >125 µm	24-26 cm >63 µm	24-26 cm >125 µm
Textularia agglutinans d'Orbigny				+
Textularia sp.	+		+	
Robertina translucens Cushman & Parker	+	+		+
Ceratobulimina arctica Green			+	
Hoeglundina elegans (d'Orbigny)	+			
Cornuspira involvens (Reuss)		+	+	
Spiroloculina sp.				+
Spirophthalmidium tenuiseptatum (Brady)		+		
Biloculinella globula (Bornemann)	+			
Miliolinella subrotunda (Montagu)	1%	+		
Nummoloculina sp.				3%
Quinqueloculina sp.			+	+
Quinqueloculina stalkeri Loeblich & Tappan			+	
Triloculina sp.		+		
Seabrookia pellucida Brady	+		+	
Fissurina marginata (Montagu)			+	
Fissurina sp.			+	+
Astacolus crepidulus (Fichtel & Moll)			+	
Globulina gibba (Deshayes)				+
Brizalina spathulata (Williamson)	+		+	
Cassidulina laevigata d'Orbigny			+	
Globocassidulina crassa (d'Orbigny)	1%	+		2%
Globocassidulina subglobosa (Brady)	1%	+	2%	
Bulimina marginata d'Orbigny			+	+
Uvigerina mediterranea Hofker		2%		2%
Gavelinopsis praegeri (Heron-Allen & Earland)			+	
Valvulineria bradyana (Fornasini)	+	+		+
Valvulineria minuta (Schubert)	+		1%	
Eilohedra vitrea (Parker)	+		2%	
Planulina ariminensis d'Orbigny			+	2%
Cibicides refulgens de Montfort	+		+	+
Cibicides pachyderma (Rzehak)		+		
Lobatula lobatula (Walker & Jacob)		+		+
Gyroidina neosoldanii Brotzen		+	1%	+
Gyroidina umbonata (Silvestri)	+	+	1%	
Ammonia sp.	+		+	
Globigerina bulloides d'Orbigny	1%	28%		31%

Globigerinella calida (Parker)	4%	4%		5%
*Globigerinoides elongata (*d'Orbigny)		2%		
*Globigerinoides rube*r (d'Orbigny)	2%	23%		24%
Globigerinoides sacculifera (Brady)		4%		+
Globoturborotalita tenella (Parker)	2%	4%		5%
Orbulina universa d'Orbigny		3%		
Undeterminable planktonic	4%		12%	
Globigerinita glutinata (Egger)	8%	2%	13%	5%
Globigerinita uvula (Ehrenberg)	2%			+
*Globorotalia scitul*a (Brady)	3%		3%	+
Globorotalia truncatulinoides (d'Orbigny)		+		
Neogloboquadrina dutertrei (d'Orbigny)		1%		+
Neogloboquadrina pachyderma (Ehrenberg)		7%		2%
Turborotalita quinqueloba (Natland)	62%	8%	54%	7%

ruber, symbiont bearing species, is common in tropical and subtropical mixed layers, known to live throughout the year (HEMLEBEN *et al.,* 1989). Among the cold-water species relevant to this study *G. glutinata* is considered as symbiont-bearing thermocline and sub-thermocline dweller (LONČARIĆ *et al.*, 2006, FRIEDRICH *et al.*, 2012). The comparison of proportions of the shallow (warm-water) and deeper (cold-water) dwelling species points to the size fraction dependence as was concluded by BÉ & HUTSON (1977). In fractions >63 μm a great proportion of planktonic species known as thermocline dwelling occur, while in fractions >125 μm, mixed-layer dwelling planktonic foraminifera prevail. It can be noted that abundances of *T. quinqueloba* is slightly reduced in older interval (Table 2).

Our study shows that composition of assemblage changes as a function of chosen sieve mesh size. Small foraminifera *T. quinqueloba* dominates in finer fraction and reaches moderate abundance in coarser fraction (<10 %). In contrast, some species like *Gl. bulloides* and *Gd. ruber* become dominant in coarser fraction. The selection of sieve mesh size affects the composition in a way that some species could be strongly underestimated or could even be absent. Because of that effect, diversity indices change as a function of used sieve mesh size so indices have to be taken relatively, according to applied sieves. The conditions may cause some false interpretation when we come to study fossil assemblages. For instance, assemblage *T. quinqueloba* implies cold water conditions, while association *Gl. bulloides* and *Gd. ruber* suggests variations between temperate to cold-water and subtropical to tropical conditions (BE & TOLDERLUND, 1971).

The species richness, Shannon and equitability indices, similar in top core and subsurface assemblages, increase with increasing sieve mesh size, contrary to trend found in Arabian Sea (PEETERS *et al.,* 1999). Again, difference occurs when fractions are compared. The coarser subsamples show more evenness, because in finer fraction in both subsamples there is a domination of one species, *T. quinqueloba*.

Planktonic/benthic ratio does not show significant change in relation to size fractions. Calculated water depths were between 750 m and 900 m, 25 % to 38 % shallower than actual depth is. However, we have to consider that calculation model was designed and tested in oceans (VAN DER ZWAAN *et al.*, 1990), and Adriatic Sea is closed, epicontinental sea.

Some of benthic foraminifera (*Ammonia* sp., *Cibicides* sp., *Lobatula lobatula*, *Quinqueloculina* spp.) are known to live in inner to middle shelf environments (JORISSEN, 1987; SGARRELLA & ZEI, 1993; MENDES *et al.*, 2004; MURRAY, 2006). The bottom currents or/and turbiditide currents may transported empty tests from shelf to the great depth. JORRISEN *et al.* (1993) noted that some of sediments recovered from the central part of the southern Adriatic Sea (depths 868-1,234 m) are turbidites. Transportation and reworking of tests may affect plankton/benthic ratio, but in the studied samples overall abundance of benthic tests is very low.

On the other hand, the impact of different life-habitats and life-strategies of planktonic species, rate of production (including predation) and expatriation of tests, also influence the composition of assemblages. Analyzing the assemblages from size fraction >63 μm, KELLOGG (1984) concluded that their composition depends on dissolution potential of the local deep or bottom waters. The reduction in abundances of solution susceptible species *Gl. bulloides* and *Gd. ruber* in *T. quinqueloba* assemblage could be due to postmortem processes (BERGER, 1968; BERGER & PIPER, 1972; RUDDIMAN & HEEZEN, 1967; MARTINEZ & BEDOYA, 2001; KUCERA, 2007).

Two species, *Globoturborotalita tenella* and *Globigerinita uvula* have been identified for the first time in the eastern part of the Adriatic Sea, but both species were reported in the southern Adriatic Sea (SIANI *et al.,* 2010).

CONCLUSIONS

The study of the total planktonic foraminifera assemblages from two levels of a core located on the seafloor at 1,200 m water depth in the Southern Adriatic reveals the following:

- The sieve mesh size plays a great role in composition and consequently in interpretation of foraminiferal assemblages. *T. quinqueloba*, relative small species has the highest proportion in fraction >63 μm while in the >125 μm its proportion dramatically drops. The distributions of larger species, *Gd. ruber* and *Gl. bulloides* showed an opposite trend.
- Species richness and diversity indices are dependent on size fraction; greater values were found in coarser sediments.
- The plankton/benthos ratio was constant for all studied fractions, suggesting no influences of the mesh size in estimation of paleo-water depths. The differences in water depth between calculated values and measured, might be related to depth dissolution of some plankton species in both, coarser and finer fractions.
- Application of mesh size of 63 μm means uncertainty in identification of small and juvenile individuals, which can be time consuming and very hard without help of scanning electron microscope (SEM).
- Two species, *Globoturborotalita tenella* and *Globigerinita uvula* have been recorded the first time in the eastern part of the Adriatic Sea.
- The benthic foraminiferal community that accounts up to 14% of total foraminiferal assemblages, shows a slight increase in diversity and abundance from the core-top down to the bottom, although somewhat more diversified assemblages occur in finer fractions.

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U kojoj mjeri veličina zrna utječe na interpretaciju sastava zajednica planktonskih foraminifera - primjer iz južnog Jadrana

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SAŽETAK

Istraživanje planktonskih foraminifera iz dviju razina 26 cm duge jezgre izvađene sa 1,200 m dubine daje nove podatke o sastavu foraminiferskih zajednica u južnom dijelu Jadranskog mora. Ukupno 15 planktonskih vrsta (uključujući jednu neodredivu i dvije vrste koje su po prvi puta zabilježene u istočnom dijelu Jadranskog mora) određene su iz sedimentnih intervala 0-2 cm i 24-26 cm grupiranih u dvije zajednice: frakcija >63 µm nazvana *Turborotalita quinqueloba*, te frakcija >125 µm *Globigerina bulloides*-*Globigerinoides ruber*. Razlike između zajednica u vršnom i najdubljem dijelu jezge leže u: a) razlici u relativnim zastupljenostima nekih vrsta; b) blagim razlikama u indeksima raznolikosti. Relativna udio vrsta pod snažnim je utjecajem veličine otvora sita, gdje s povećanjem otvora sita lagano raste raznolikost. Bentičke foraminifere, iako čine neznatna kvantitativni faktor, pokazuju blago povećanje udjela i raznolikosti vrsta s dubinom sedimenta (sa starosti).

Ključne riječi: Jadransko more, planktonske foraminifere, veličina zrna, *Turborotalita quinqueloba, Globigerina bulloides*, *Globigerinoides ruber*, indeksi raznolikosti

APPENDIX: PALEONTOLOGICAL NOTES (DESCRIPTION OF FOUND PLANKTONIC FORAMINIFERA)

***Globigerina bulloides* d'Orbigny**

Description: test is low to medium height trochospire with 3-5 globular to slightly ovoid chambers in the final whorl. Chambers are increasing in size slowly as added, and are divided by deep sutures. Aperture is a large, umbilical, interiomarginal, high, symmetrical arch occasionally bordered by a thin rim-like lip. Wall surface bears uniformly and densely distributed pores (as defined in SAITO *et al.* (1981)).

Distribution: this is widely spread species along all oceans, described for the first time from Rimini on the Adriatic Sea. It is a temperate or cold-water form (TODD, 1964), considered as shallow-water species, and predominately lives in 50 to 100 m depth range, (BÉ, 1977).

***Globigerinella calida* (Parker)**

Description: low trochospirally enrolled test is composed of 4-6 subglobular to slightly radially elongate chambers. Chambers rapidly increasing in size as added and are loosely embracing but in studied specimens there were no so mature specimens with the final chamber almost completely detached from the previous whorl (as described in SAITO *et al.* (1981)). Wall is densely perforated. Aperture is an umbilical-extraumbilical, low, asymmetrical arch with a thin lip.

Distribution: shallow-water species, it predominately lives in 50 to 100 m depth range (BÉ, 1977).

***Globigerinoides elongata* (d'Orbigny)**

Description: test is low to medium height trochospiral with 3 subglobular chambers in the final whorl. Chambers are ovoid to rectangular, tightly packed, and slowly increasing in size as added, producing "sub tetrahedroid" shape. Its primary aperture is a large circular opening almost as high as the final chamber. Contrary to description of species in SAITO *et al.* (1981), studied specimens are without noticeable imperforate rim-like lip. Test has secondary apertures on spiral side. Wall is thick and coarsely perforated.

Distribution: the first description of species was from the Adriatic Sea. Species lives in similar conditions as *Gd. ruber* (SAITO *et al.*, 1981).

Remarks: *G. elongata* is very similar to and seems to stand about midway between *Globigerinoides conglobatus* and *Gd. ruber* (TODD, 1964).

***Globigerinoides sacculifera* (Brady)**

Description: low trochospiral test with 3-4 globular chambers in the final whorl. Chambers are rapidly enlarging as added, sutures are distinct. A characteristic incompletely inflated final chamber ("*wine sac*") as noted in SAITO *et al.* (1981) was found in some studied specimens.

Distribution: this symbiont-bearing warm-water form has a wide distribution and great abundance (TODD, 1964).

***Globoturborotalita tenella* (Parker)**

(Plate 1, Fig. 3)

Description: low to medium height trochospiral test with 4 globular chambers in the final whorl. Test size is small to medium (around 150 μm). Its primary aperture is umbilical, an open and high arch with a rim-like lip. Chambers are tightly packed but sutures are distinct.

Remarks: This is the first finding of the species in the eastern Adriatic Sea.

***Globigerinoides ruber* (d'Orbigny)**

(Plate 2, Figs. 1-2)

Description: test is low trochospiral with 3 globular chambers in the final whorl. Sutures are depressed and periphery of the test is broadly rounded. The primary aperture is an interiomarginal arch, whereas on the spiral side there are smaller secondary apertures. Sometimes, tests have characteristic and very distinguishable red pigmentation. Pinky individuals are very scarce in the studied samples.

Distribution: this is widely distributed and usually abundant species. It is regarded as a

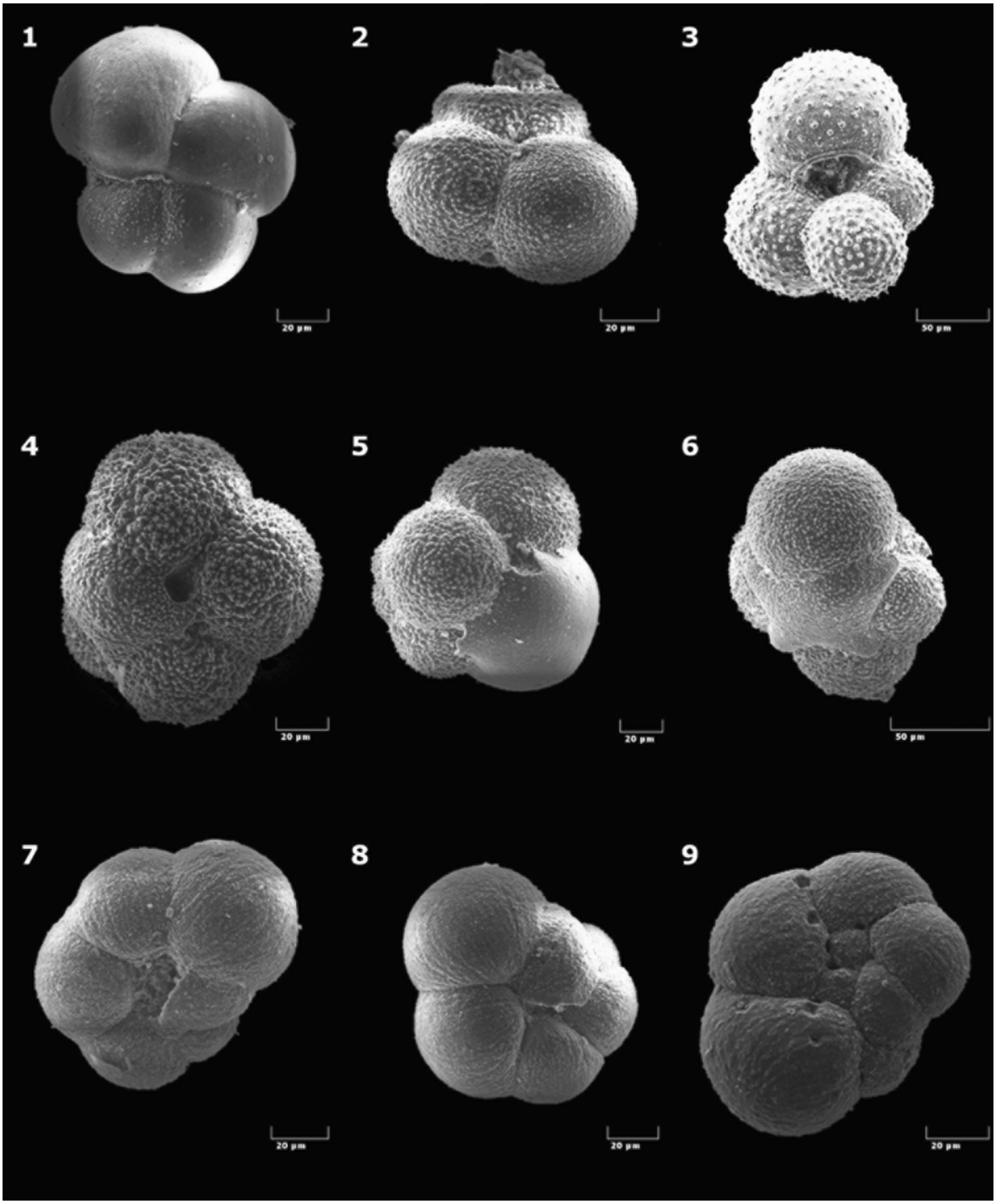

Plate 1. 1. Globorotalia scitula (Brady), umbilical view; 2. Globigerinita uvula (Ehrenberg), umbilical view; 3. Globoturborotalita tenella (Parker), umbilical view; 4-6. Globigerinita glutinata (Egger), 4. umbilical view, 5. side view, 6. umbilical view; 7-9. Undeterminable planktonic, 7. umbilical view, 8. umbilical view, 9. spiral view

warm-water form (TODD, 1964). The representatives of this species show the greatest tolerance range for salinity (22 – 49 ‰) in laboratory experiments (BIJMA *et al.,* 1990). Because of photosymbionts, the species is considered shallowest dwelling one which makes it very suitable for isotopic temperature investigations (HEMLEBEN *et al.*, 1989).

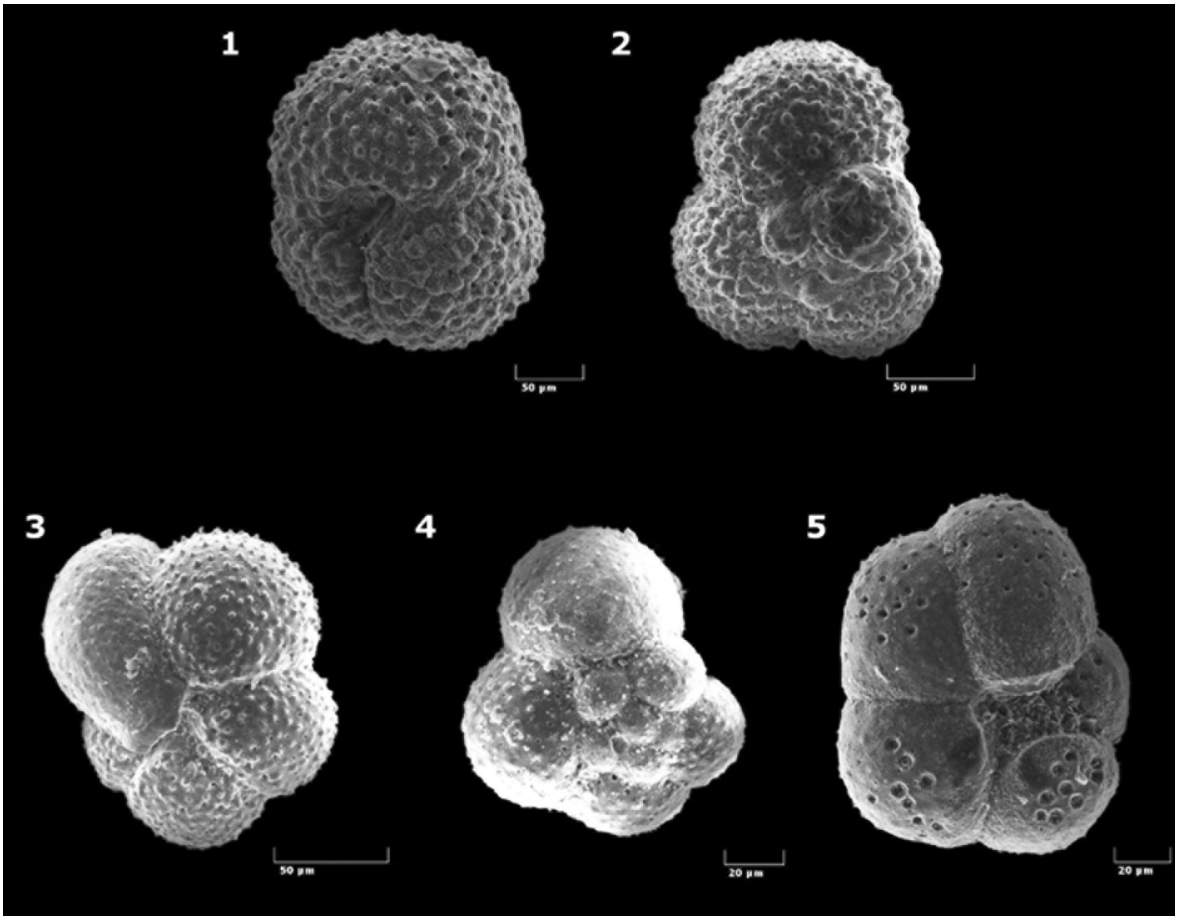

Plate 2. 1-2. Globigerinoides ruber (d'Orbigny), 1. umbilical view, 2. spiral view; 3-5. Turborotalita quinqueloba (Natland), 3. umbilical view, 4. spiral view, 5. umbilical view

Orbulina universa **d'Orbigny**

Description: it is very distinguishable species because of a final enveloping, spherical chamber.

Distribution: this symbiont-bearing species is regarded as an indicator of warm sea-temperature, widely distributed from the tropics to subpolar regions and its size is well correlated with temperature and nutrients (HEMLEBEN *et al.*, 1989). Under laboratory conditions it tolerates high ranges of salinities and temperature (23-46 ‰ and 12-31 °C, respectively) (*ibidem*).

Undeterminable planktonic

(Plate 1, Figs. 7-9)

Based on it's the outer morphology and wall texture studied by SEM and stereoscope microscope, a certain number of individuals haven't fit to any recent known species with certainty, thus stayed undeterminable. *Description*: small in size (around 100 µm), low trochospire test with 6 chambers in the last whorl, altogether 8 chambers arranged in 2 whorls. Chambers are subspherical, slowly enlarging in size as added. Sutures are distinct. Aperture is an umbilical low arch with a thin lip and secondary apertures occur on spiral side seem. Wall texture seems non spinose, but stretch marks are present. Among recent species the most similar to studied ones is *Berggrenia pumilio* (Parker), which is not recognized in samples from the Adriatic Sea so far.

Globigerinita glutinata **(Egger)**

(Plate 1, Figs. 4-6)

Description: medium high trochospiral test with 4 globular chambers in the final whorl. Test size is variable, small to medium (size between

90 µm and 130 µm). Most of the studied individuals have characteristic bulla that covers an umbilical aperture.

Distribution: species is abundant in tropical/subtropical to polar surface waters and is considered as the most widely distributed living species (HEMLEBEN *et al.,* 1989) that tolerates wide range of temperature and salinity variations.

***Globigerinita uvula* (Ehrenberg)**

(Plate 1, Fig. 2)

Description: very small in size (around 100 µm) but representatives of this species are easily distinguished because of their high trochospiral test. Wall is translucent, surface is smooth and very finely perforated, non-spinose texture with fine pustules.

Distribution: species is common in high latitude assemblages (HEMLEBEN *et al.,* 1989).

Remarks: Up to this study, this species wasn't recorded in samples from the eastern Adriatic Sea.

***Globorotalia scitula* (Brady)**

(Plate 1, Figs. 1)

Description: the low trochospire test with 4-6 wedge-shaped chambers in the final whorl. Test is small in size (around 110 µm). Sutures are curved backwards and depressed. Chambers sizes increase slowly as being added. The aperture is an interiomarginal, umbilical-extraumbi-Iical, low, asymmetrical arch with a noticeable lip. Wall is perforated and pustulated near the aperture.

Distribution: the species occurs in temperate regions and sometimes with high frequency. As other species of genus Globorotalia, it is considered as deep water species, mainly found below 100 m (BÉ, 1977).

***Globorotalia truncatulinoides* (d'Orbigny)**

Description: representatives of this species are easily distinguishable because of plano-convex trochospire shape with 5 rhomboid chambers in the final whorl and distinct peripheral keel. From the spiral side, chambers have almost polygonal outline with straight sutures.

Distribution: this is widespread species, indicating warm to temperate waters. As other species of genus Globorotalia, it is considered as deep water species, mainly found below 100 m (BÉ, 1977).

***Neogloboquadrina dutertrei* (d'Orbigny)**

Description: the chambers are subspherical to slightly flattened radially, their sizes slowly increase as added. The number of chambers per whorl varies (5 to 6) and overall shape of test is medium-high trochospire.

Distribution: under laboratory conditions it tolerates high ranges of salinities and temperature (25-46 ‰ and 13-33 °C respectively) (HEMLEBEN *et al.*, 1989).

***Neogloboquadrina pachyderma* (Ehrenberg)**

Description: low trochospiral test with 4-5 globular chambers in the final whorl. Aperture is umbilical, interiomarginal. Wall is thick and chambers are closely packed.

Distribution: cold water species, considered as deep water dwellers, mainly found below 100 m (BÉ, 1977).

Remarks: It is used as coiling direction proxy based on the remarkably strong and consistent relationship between coiling direction and sea-surface temperature where sinistral coiling is associated with cold temperatures (ERICSON, 1959; BANDY, 1960; DARLING *et al.*, 2006).

***Turborotalita quinqueloba* (Natland)**

(Plate 2, Figs. 3-5)

Description: Test size is variable (from small as 60 µm to >200 µm), even though very small species dominate (around 100 µm). The test is low trochospiral with 5 globular chambers in the final whorl. Final chamber partially or completely covers umbilicus producing a bulla-like structure. This structure is better observable in those individuals that contain globular chambers. Wall is thick, finely perforated, hispid and spinose.

Distribution: species is considered as subpolar. It bears photosymbionts and lives mostly in photic zone (HEMLEBEN *et al.*, 1989).