



Foraminiferal assemblages and trophic state in coastal sediments of the Adriatic Sea

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ABSTRACT

The environmental variables that influence the abundance and biodiversity of foraminifera in shallow-water settings are poorly understood. In order to help address this problem, we investigated abundance, biomass and biodiversity of living (as Rose-Bengal stained) benthic foraminifera together with the quantity and biochemical composition (in terms of phytopigment, protein, lipid, carbohydrate and biopolymeric carbon) of the organic matter in coastal sediments of the Central Adriatic Sea. Sediment samples were collected in the Portonovo Bay in May, July and October 2008 and February 2009, and the organic matter quantity and biochemical composition and benthic foraminiferal abundance and assemblage composition were analysed in the top 1 cm. Uni- and multi-variate analyses of variance revealed clear temporal variability of all the investigated variables as well as relationships between the composition of the foraminiferal assemblages and the quantity and quality of the food sources. The foraminiferal abundance and species composition changed significantly between the four sampling periods, reflecting the temporal (seasonal) variability in the quantity and nutritional quality of the food sources. Lipids, among all other organic compounds, explain significant portions of the variance of both foraminiferal abundance and biomass. In winter, a strong phytoplankton bloom led to an increased quantity of nutritionally available organic matter on the sea floor, which in turn was associated with a bloom of *Leptohalysis scottii* and *Psammophaga* sp. 1. These two foraminiferal species thus displayed an opportunistic behaviour in response to the pulse of organic carbon of high nutritional quality. We suggest that these species can be used as indicators of benthic eutrophication in shallow waters.

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1. Introduction

Foraminifera are unicellular eukaryotes that occur ubiquitously in all the world oceans and in all marine habitats, including both aquatic and benthic environments. Benthic foraminifera are one of the main components of marine ecosystems. They are characterised by a short life cycle (when compared to macrofaunal metazoans) and react rather quickly to both short and long-term changes in marine and transitional-marine environments on both a global and a local scale. For these reasons, foraminifera are used increasingly to evaluate the environmental status of marine coastal systems impacted by pollution and eutrophication (see reviews by Frontalini and Coccioni, 2011; Murray and Alve, 2002; and Nigam et al., 2006). Moreover, as they can fossilise, they are also reliable descriptors of environmental change over historical and geological time scales (Gooday et al., 2009).

Several studies have investigated the relationships between spatial and temporal variability of foraminiferal population density (abundance) and assemblage composition in relation to the sediment grain size (e.g., Armynot du Châtelet et al., 2009), the quantity of

sedimentary organic matter (e.g., Armynot du Châtelet et al., 2009; Duros et al., 2011; Fontanier et al., 2002, 2008; Jorissen et al., 1992; Mojtahid et al., 2009; Nardelli et al., 2010; Phipps et al., 2012), downward organic fluxes and oxygen availability (e.g., Corliss and Chen, 1988; Gooday, 2003; Hohenegger et al., 1993; Jorissen et al., 1992, 2007; Rathburn and Corliss, 1994; Rosoff and Corliss, 1992).

In the last decades, our knowledge of the ecology of shallow-water benthic foraminifera has improved considerably (e.g. Gooday, 2003; Jorissen et al., 2007), and several studies have provided evidence of the role of several physical-chemical variables in the spatial and temporal distribution of live (Rose-Bengal stained) foraminiferal assemblages (e.g., Corliss, 1985; Corliss and Emerson, 1990; Eberwein and Mackensen, 2006; Fontanier et al., 2002, 2006; Gooday, 1988; Hess et al., 2005; Jannink et al., 1998; Jorissen et al., 1998; Kitazato et al., 2000; Koho et al., 2007; Langezaal et al., 2006; Licari et al., 2003; Mackensen and Douglas, 1989; Schönfeld, 2002; Schumacher et al., 2007; van der Zwaan et al., 1999). These investigations also revealed that the abundance, assemblage composition and vertical distribution of live foraminiferal faunas in marine sediments are mainly constrained by fluxes of organic particles from: i) the upper water column, ii) near-bottom and pore-water oxygenation, iii) sedimentation rates and near-bottom current velocities (see reviews by Gooday, 2003 and Jorissen et al., 2007). In shallow-water eutrophic systems, the temporal and spatial changes in benthic foraminifera are apparently controlled primarily by the timing and extent of the organic

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matter flux associated with phytoplankton blooms and by the vegetation cover, the inputs of land-derived organic debris and river discharge and the deriving salinity fluctuation. Manipulative experiments confirmed the field studies (e.g., Ernst and van der Zwaan, 2004; Ernst et al., 2005; Geslin et al., 2004; Heinz et al., 2002; Langezaal et al., 2004; Nomaki et al., 2005), but pointed out the presence of differences in the response of different foraminiferal groups to different environmental variables. For instance, some opportunistic calcareous foraminifera are abundant in eutrophic shallow systems (Jorissen et al., 1992) while some agglutinated species are typical of a river-dominated shelf (Goineau et al., 2011; Mojtahid et al., 2009, 2010). Nevertheless, much less information is available about the abundance, biomass and assemblage composition of soft-shelled foraminifera.

Our knowledge of the role of the biochemical composition and the nutritional quality of the sediment organic matter in the ecology of foraminifera is still rather limited. Indeed, the trophic state of marine sediments is not only dependent upon the absolute quantities of organic matter deposited on the sea floor, but it is also a function of its biochemical composition and nutritional quality for consumers (Pusceddu et al., 2009a). Sedimentary organic matter consists of labile and refractory compounds, of which the relative importance is a function of its origin and biochemical composition (Fabiano et al., 1995). The labile (i.e. readily available) fraction of sedimentary organic matter controls benthic communities distribution in lagoons and marine shallow environments (Pusceddu et al., 2007). The quantification of food availability of sedimentary organic matter is a difficult task (Mayer, 1989), and a universally accepted methodology does not exist. However, recent studies have suggested the use of the carbohydrate, lipid and protein sedimentary contents as indicators of the trophic status of sediments in coastal, deep-sea and artificial marine ecosystems (Pusceddu et al., 2007, 2009a, 2010, 2011a, 2011b).

The aims of the present study were to 1) identify the relationships between abundance, biomass and biodiversity of living (Rose Bengal stained) benthic foraminifera and the benthic trophic status (sensu Pusceddu et al., 2009a), and 2) identify the taxa that are potential indicators of the benthic trophic conditions. To address these goals we investigated the abundance, biomass, assemblage composition and species diversity of benthic foraminiferal faunas together with temporal (seasonal) variability in the quantity and biochemical composition of sedimentary organic matter (in terms of phytopigment, protein, lipid, carbohydrate and biopolymeric carbon contents) of sediments at a shallow site (15 m depth) in the Portonovo Bay, Central Adriatic Sea.

2. Materials and methods

2.1. Study site and sampling strategy

The study site is located in the central Adriatic Sea, which, due to the anti-cyclonic surface circulation, is influenced by the Po River plume (Pucci, unpublished PhD thesis). This circulation pattern is more evident in winter and creates a well-defined mud belt along the Italian coast. In summer, when the water column in the northern and central Adriatic is completely stratified, the anti-cyclonic gyre is weaker and part of the northern rivers effluents is transported eastward (Franco et al., 1982; Malanotte and Bergamasco, 1983). In spring–summer, nutrient availability is high following large blooms of phytoplankton (Chiaudani et al., 1983; Degobbis, 1989; Degobbis et al., 1979; Gilmartin and Revelante, 1980; Marchetti et al., 1988; Revelante and Gilmartin, 1976, 1977, 1980). Phytoplankton blooms and the land-derived organic debris represent important sources of food for the benthos, all size classes of which, from prokaryotes to meio- and macrofauna, are very abundant (Balsamo et al., 2010; Danovaro et al., 1999; Frontalini et al., 2011). The highest amounts

of organic matter in the sediment occur in the clay-belt deposited from river discharges (principally the Po River) along the coasts of the Italian sector of the Adriatic Sea (Dell'Anno et al., 2003, 2008; Jorissen et al., 1992). In meso- to eutrophic conditions, a conspicuous fraction of oxygen consumption occurs as the result of organic-matter decomposition. The high algal production rates in late spring and early summer, the high summer temperatures that stimulate organic matter decomposition, and the stratified water column conditions in summer/early autumn, make the northern and central sectors of the Adriatic Sea prone to periodic (late summer and autumn) dysoxic or even anoxic events (Jorissen et al., 1992). Generally, bottom waters become fully re-oxygenated only in late autumn.

Sediment samples were collected in the Portonovo Bay, (43° 36' 12.060" N; 13° 36' 42.300" E, 15 m water depth, Fig. 1) from the *R/V Actea* using a Van Veen grab in May, July and October 2008 and February 2009. Van Veen grabs can show bow-wave effect. For this reason we paid a particular attention to samples retrieval and selected only visibly undisturbed sediments. To analyse the quantity and biochemical composition of sedimentary organic matter and benthic foraminiferal variables, we used the top 1 cm of the sediment cores obtained using Plexiglas corers inserted manually inside separate grab samples (n=3 pseudo-replicates for foraminiferal analyses and n=3 pseudo-replicates for organic matter variables). These surficial sediment samples were stored at –20 °C until analysis in the laboratory. Sediment aliquots for biochemical analyses were stored at –20 °C in Petri dishes and analysed within 4 weeks of collection.

2.2. Quantity and biochemical composition of sedimentary organic matter

Chlorophyll-a and phaeopigment analyses were carried out according to Lorenzen and Jeffrey (1980). Pigments were extracted with 90% acetone (12 h in the dark at 4 °C). After the extraction the pigments were fluorometrically analysed to estimate the quantity of chlorophyll-a and, after acidification with 0.1 N HCl, to estimate the amount of phaeopigments. They were defined as the sum of chlorophyll-a and phaeopigments and, after the concentrations were converted to carbon equivalents by using the conversion factor of 40 µg of C µg⁻¹ (Pusceddu et al., 1999, 2009a) and used to estimate the organic material of algal origin, including the living (chlorophyll-a) and senescent/detrital (phaeopigment) fractions (Pusceddu et al., 2009a). Values of the carbon to chlorophyll-a ratio can vary, depending on the source and ageing of the algal material, from 10 to 100 (Banse, 1977). In the present study, we converted sediment phytopigment concentrations into carbon equivalents using a mean value of 40 µg C µg phytopigment⁻¹, which allowed comparison with previous investigations (Pusceddu et al., 1999, 2000, 2009a). The fraction of biopolymeric carbon (biopolymeric C) represented by relatively fresh algal material was then assessed as the percentage contribution of phytopigment C to biopolymeric C contents and referred to as the algal fraction of biopolymeric C (Pusceddu et al., 2010).

The protein, carbohydrate and lipid contents of the sediments were determined spectrophotometrically (Pusceddu et al., 2009a, 2010). Protein concentration was obtained according to Hartree (1972) as modified by Danovaro (2010). Concentrations are reported as mg albumin equivalents per dry weight g of sediment. Carbohydrate were analysed according to Gerchakov and Hatcher (1972) and expressed as mg glucose equivalents per dry weight g of sediment. Lipids were extracted with methanol and chloroform (2:1 vol/vol) according to Bligh and Dyer (1959) and then analysed according to Marsh and Wenstein (1966). Lipid concentrations are reported as mg tripalmitine equivalents per dry weight g of sediment. Protein, carbohydrate and lipid concentrations were converted into carbon equivalents by using the following conversion factors: 0.49, 0.40 and 0.75 g C g⁻¹, respectively (Fabiano et al., 1995). The sum of protein, carbohydrate and lipid carbon was referred as biopolymeric C (BPC). For each biochemical assay,

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