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Coccolithophore diversity and dynamics at a coastal site in the Gulf of Trieste (northern Adriatic Sea)

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ABSTRACT

Two years-data (May 2011–February 2013) obtained from a monthly sampling carried out at the coastal long term Ecological Research station C1-LTER in the Gulf of Trieste (northern Adriatic Sea) were analysed to describe the seasonal dynamics and diversity of coccolithophore assemblages and to assess their relationship with environmental forcing.

Coccolithophores represented 10.7% of the total Utermöhl phytoplankton that were mainly dominated by small (<10 μm) flagellates and diatoms (62.2% and 24.8% of total abundances, respectively). Coccolithophore abundances obtained by polarized light microscopy analysis ranged from 0.2 to 35.3 $\cdot$ 10^4 coccospheres L^{-1} with a mean value of 5.2 $\cdot$ 10^4 coccospheres L^{-1}. A marked seasonal pattern was observed with a main peak in December–February (2.5–31.5 $\cdot$ 10^4 coccospheres L^{-1}), in correspondence of the winter mixing, mainly due to *Emiliania huxleyi*, and a secondary peak in May–June (0.7–15.0 $\cdot$ 10^4 coccospheres L^{-1}), coinciding with the increase of the light intensity and the beginning of the seasonal stratification, dominated by holococcolithophores and small *Syracosphaera* species. The most abundant taxa were *E. huxleyi* and holococcolithophores, followed by *Acanthoica quattrospina*, *Syracosphaera* species and other minor species. Statistical analyses recognized four distinct groups, corresponding to seasonal variations of environmental conditions. Considering the two years, some species displayed a recurrent seasonal pattern highlighting possible species-specific ecological requirements, while others showed an interannual variability probably due to local factors.

1. Introduction

Coccolithophores are nanoflagellate organisms characterized by external calcite plates (coccoliths) covering their surface in at least one phase of their life cycle. They represent about 10% of the global phytoplankton biomass (Tyrrel and Young, 2009) and are important primary producers at low latitudes, but also responsible for dense and widespread seasonal blooms at high latitudes. Moreover, coccolithophores play key roles in marine biogeochemistry as producers of organic carbon, through photosynthesis, and carbonate, through calcification (Rost and Riebesell, 2004). Finally, they are also involved in the sulphur cycle through their capability to produce dimethyl-sulfoniopropionate, a precursor of dimethyl sulfide (Malin and Steinke, 2004).

In recent years, there has been a growing interest in investigating the ecology and distribution of coccolithophore species since they can provide sensitive indications of environmental changes. They are indeed strongly influenced by different environmental factors such as temperature, salinity, nutrients and light availability as well as by carbonate chemistry as demonstrated more recently (Merico et al., 2006; Beaufort et al., 2008, 2011; Tyrrell et al., 2008; Triantaphyllou et al., 2010; Charalampopoulou et al., 2011; Meier et al., 2014; Oviedo et al., 2015).

Traditional views of coccolithophore ecology are based on the Margalef's paradigm (Margalef, 1978; Balch, 2004) for which they generally prefer moderate turbulence and nutrient conditions typical of open waters. At temperate latitudes, like the

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Mediterranean Sea, coccolithophore assemblages are seasonally controlled (Knappertsbusch, 1993; Triantaphyllou et al., 2004; Dimiza et al., 2008a; Malinverno et al., 2009). Higher abundances of r-strategist taxa occur in winter when vertical mixing makes high nutrient concentrations available in the euphotic zone; lower densities, with dominance of k-strategist taxa such as holococcolithophores, occur in summer, when the presence of a thermocline produces more oligotrophic conditions. However, typical coccolithophore assemblages also dominate in shelf- and river-dominated coastal areas where their cycle can be altered by rapid changes in hydrodynamic regime, freshwater discharges and anthropogenic eutrophication (e.g. Balestra et al., 2008; Silva et al., 2008; Bonomo et al., 2014).

Very few studies on living coccolithophores have been carried out in the Mediterranean Sea, using the suitable method (Bollmann et al., 2002) for their identification (Kleijne, 1991, 1992, 1993; Knappertsbusch, 1993; Cros, 2001; Triantaphyllou et al., 2002; Cros and Fortuño, 2002; Malinverno et al., 2003; Balestra et al., 2008; Dimiza et al., 2008a, 2008b, 2010, 2015; Bonomo et al., 2012, 2014; Oviedo et al., 2015). Many other investigations are based on observations of fixed samples according to the Utermöhl method (1958) and only give a rough and often incomplete estimation of the coccolithophore abundance and diversity.

The northern Adriatic continental shelf region is a shallow semi-enclosed marine area characterized by a large runoff that makes it a highly dynamic environment, strongly influenced by air-land-sea interactions (Malone et al., 1999). The annual runoff has showed significant oscillations on interannual and multidecadal time scale, emerging therefore as one of the most important forcing that can drive the evolution of biogeochemistry of this basin (Cozzi and Giani, 2011). Moreover, the basin is experiencing significant changes of mechanisms and trophic structures (Giani et al., 2012) and for this reason it can provide a good ground to explore the factors controlling coccolithophore distribution in coastal environments.

In the northern Adriatic Sea, phytoplankton communities are generally dominated by diatoms and nanoflagellates during the seasonal blooms in late winter-early spring and autumn (Mozetič et al., 1998; Bernardi Aubry et al., 2012; Cabrini et al., 2012). Coccolithophores are generally more abundant during the winter period (Mozetič et al., 1998; Bernardi Aubry et al., 2004; Viličić et al., 2009; Cabrini et al., 2012; Godrijan et al., 2013), but some species and/or haploid life-cycle phases are reported as more typical of the summer months preferring high temperature and oligotrophic stratified conditions (Bernardi Aubry et al., 2006; Godrijan et al., 2013).

This work investigates, for the first time in the Gulf of Trieste (northern Adriatic Sea), the coccolithophore community structure and diversity throughout a monthly time-series of two years. Our aims are to describe the seasonal dynamics of different species and to assess their relationship with different physical forcing. Some considerations on interannual variations, although based only on two years, will be also addressed to unveil possible temporal modifications that are useful indicators for the definition of good environmental status as required by the Marine Strategy Framework Directive.

2. Materials and methods

2.1. Study area

The Gulf of Trieste is a shallow semi-enclosed basin, with a maximum depth of 25 m, located in the northern part of the Adriatic Sea. It is characterized by an elevated variability in its oceanographic properties with a pronounced seasonal cycle of seawater temperature (from winter minima of 5 °C to summer maxima >26 °C) and strong salinity gradients (25–38), the latter mainly due to freshwater inputs (Malačič and Petelin, 2001). The Gulf of Trieste can indeed be regarded as an example of a coastal region of freshwater influence (ROFI, Simpson, 1997) because it is strongly affected by river inputs (Isonzo and Timavo rivers) in the north-western part and from several submarine freshwater springs along the eastern karstic coast. The river inputs can affect the surface circulation and the vertical structure of the water column (Celio et al., 2006; Cozzi et al., 2012). Circulation is generally cyclonic, determined by the incoming Eastern Adriatic Current (EAC), flowing northwards along the Istrian coast and advecting warmer and saltier waters coming from the Ionian Sea (Poulain and Cushman-Roisin, 2001). However, due to its shallow depth, the general hydrology of the Gulf and the vertical water column structure can be modified in response to intense local atmospheric forcing such as cold winds from the east-north east (Bora) and mild winds from the south (Scirocco) (Querin et al., 2007; Lipizer et al., 2011).

2.2. Sampling and environmental parameters

Sampling was carried out monthly from May 2011 to February 2013 at the Long Term Ecological Research (LTER) C1 station (45°42′2.99″ N and 13°42′36.00″ E, maximum depth 17 m) located in the Gulf of Trieste. The site is located west of the town of Trieste, 270 m from the coast (Fig. 1). For this site, monitored from 1986 and since 2006 part of the LTER network (http://www.lteritalia.it/), a long-term time series of chemical, physical and biological data is available (http://nettuno.ogs.trieste.it/ilter/GoTTs/index.html).

Discrete seawater samples were collected with 5-L Niskin bottles at four depths (0.5, 5, 10, 15 m). CTD profiles of temperature and salinity were obtained with an Idronaut 316 and a SBE 19 Plus Seacat probe.

The dissolved oxygen concentration (DO; μM) was determined following the Winkler method (Hansen, 1999) using an automated titration system (Mettler Toledo G20) with potentiometric end-point detection (Oudot et al., 1988).

The PAR scalar irradiance profiles at surface and underwater were recorded by a Profiling Natural Fluorometer PNF-300A

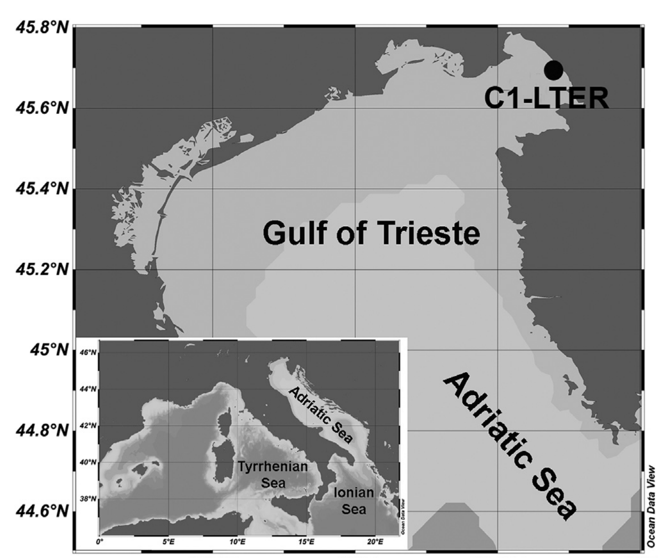

Fig. 1. Map of the study area in the northern Adriatic Sea (Mediterranean Sea) showing the location of the sampling station.