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Phytoplankton temporal changes in a coastal northern Adriatic site during the last 25 years

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ABSTRACT

There is an increasing awareness of the relationships among key phytoplankton groups and their role in biogeochemical cycles; however, less is known about the temporal scales of variability in biodiversity of the phytoplankton community. In the present study a long-term data set (1986–2010) of phytoplankton abundance is used to investigate the temporal variability of the phytoplankton community at a coastal site in the Gulf of Trieste (northern Adriatic Sea). The interannual variability of the phytoplankton community shows two major periods in terms of abundance and community composition. The first one, 1986–1994, was characterized by the highest abundances of microalgae and the dominance of phytoflagellates. The second period (1995–2007) showed lower abundances and a collapse of phytoflagellates. Lastly, an apparent new increase in abundances has been recorded during recent years (2008–2010). On a seasonal scale, a classical cycle with two maxima (spring and autumn) and a summer minimum is evident. Diatoms are the most abundant group of the late winter–early spring bloom whereas phytoflagellates, the most abundant group throughout the year, dominate the late spring blooms. Dinoflagellates and coccolithophores have low abundances and show their maxima in summer and autumn, respectively. The species composition has been analysed according to the Indicator Value Index, highlighting the more frequent and abundant taxa for each month. Results show that the winter months are characterized by coccolithophores, in spring small diatoms are dominant, dinoflagellates and larger diatoms are typical in summer, and coccolithophores and diatom colonies characterise the autumn.

1. Introduction

Microalgae play a key role in regulating atmospheric carbon dioxide concentrations and in fuelling marine and freshwater food webs, and may be a useful index for recognising the consequences of climate change in coastal areas. The phytoplankton community can change even within a few weeks and therefore only long-term studies at coastal sites provide fundamental insights into the phytoplankton cycle (Smetacek and Cloern, 2008). The first study on the phytoplankton community in the Gulf of Trieste (northern Adriatic Sea) dates back more than a century (Steuer, 1903); subsequently, many taxa were described for the first time in this area (Schiller, 1933, 1937) and these early studies are still fundamental to the taxonomic knowledge of phytoplankton diversity. Regular observations on plankton dynamics and environmental conditions began in the early 1970s; the results obtained indicated a high temporal variability in the ecosystem (Specchi et al., 1979; Fonda Umani et al., 1992), while information on the seasonal evolution of phytoplankton community structure was still lacking. More recently, in order to explain the mechanism controlling the phytoplankton variability, constant and consistent observations were started in the western (Cabrini et al., 1994, 2000) and eastern (Malej and Malačič, 1995; Mozetič et al., 1998, 2010) parts of the Gulf of Trieste. The analyses have shown a large spatial, seasonal and interannual variability in the phytoplanktonic community (Cabrini et al., 2000; Mozetič et al., 2002; Comisso et al., 2003) due to the influence of multiple drivers. In particular, the phytoplankton dynamics are influenced by physiological responses, by modifications in hydrological properties and by grazing pressures (Cataletto et al., 1993; Fonda Umani et al., 2005, 2007, 2012; Zingone et al., 2010a). Furthermore, since community composition and its temporal modification are the result of the synergy of multiple environmental conditions, they represent useful indicators for the definition of good environmental status (GES) as required by the European Marine Strategy Framework Directive (MSFD). The aim of

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this study is to identify the typical phytoplankton seasonal evolution and community structure of the Gulf of Trieste, using a 25-year data set (March 1986–September 2010) collected in a Long Term Ecological Research (LTER) coastal site.

2. Material and methods

2.1. Study area

The Gulf of Trieste is a shallow semi-enclosed basin, situated in the northern part of the Adriatic Sea, with a maximum depth of 25 m in the southern part. The surface area of the Gulf is about 600 km^2 with a volume of 9.5 km^3 (Malej and Malačič, 1995). The main freshwater input is through the Isonzo River from the north-west coast (Comici and Bussani, 2007). The river inputs show a high temporal variability that affects salinity (Malačič and Petelin, 2001). The highest river discharges are generally observed in late spring and autumn and the lowest during winter and summer.

2.2. Sampling and analytical protocol

The sampling site (st. C1-LTER, 45°42′03″N,13°42′36″E) is located in the Gulf of Trieste (North Adriatic Sea) 200 m from the coastline (bottom depth 18 m) (Fig. 1). Sampling by a research vessel has been ongoing since March 1986 with a monthly frequency (biweekly frequency from March 1986 to February 1987, from January to December 1990 and from August 2002 to September 2005). To determine phytoplankton, water samples were collected with 5-l Niskin bottles at four depths (0.5, 5, 10 and 15 m) and fixed with $Ca(HCO_3)_2$-buffered formaldehyde (0.8% final concentration; Throndsen, 1978). Here we present results focused on the surface layer for the period from March 1986 to September 2010.

Cell abundance and species composition of phytoplankton were estimated on 342 samples according to Utermöhl's method (1958), using an inverted microscope equipped with phase contrast, at 320–400× final magnifications. Variable volumes of seawater (25–50 ml, depending on cell concentrations) were settled for at least 48 h. Counting for dominant taxa was performed in random

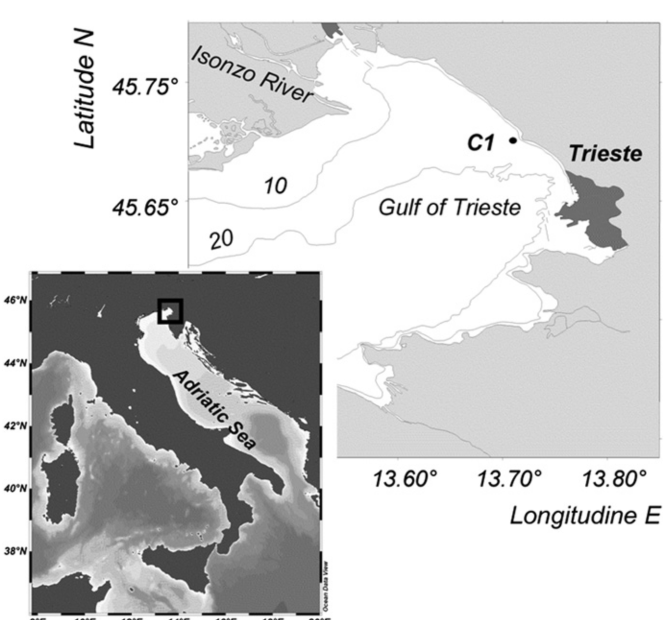

Fig. 1. Position of the sampling station C1-LTER in the Gulf of Trieste.

fields or along transects. In addition, the whole sedimentation chamber was also examined for the less abundant taxa (Zingone et al., 2010b). Identifications were performed referring to Van Heurck (1899), Hustedt (1924, 1930, 1959), Schiller (1933, 1937), Taylor (1976), Dodge (1982), Sournia (1986), Ricard (1987), Balech (1988), Chrétiennot-Dinet (1990), Van den Hoek et al. (1995), Tomas (1997), Bérard-Therriault et al. (1999), Horner (2002), Young et al. (2003) and Malinverno et al. (2008). Phytoplankton taxa were ascribed to the following groups: diatoms, dinoflagellates, chlorophytes, chrysophytes, cryptophytes, dictyochophytes, euglenophytes, prasinophytes, prymnesiophytes both calcareous (coccolithophores) and non-calcareous, and undetermined phytoflagellates.

2.3. Data analysis

The seasonal cycle and interannual variability of total phytoplankton abundance and of the main groups (diatoms, dinoflagellates, coccolithophores and phytoflagellates) were calculated on the basis of monthly (seasonal cycle) and annual (interannual variability) median values from surface data for the period 1986–2010. Interquartile range (IQR) and minimum and maximum intervals of data were also calculated and are shown as box plots. A regime shift analysis (Rodionov and Overland, 2005) was applied to the total annual phytoplankton abundances in order to detect relevant periods. The analysis, which compares the year-by-year changes with the interannual variability, used the freely downloadable Matlab software "Stars" (http://climatelogic.com/stars.html). The following parameters were used to set the analysis: series length-cutoff of 10 years, a significance level of $p = 0.025$ and the Huber weight function value of 1. The phytoplankton community structure was analysed by applying the Indicator Value Index (IndVal) proposed by Dufrêne and Legendre (1997), grouping all samples per month (12 partitions). This indicator consists of the product of two independent parts *A* and *B*: $IndVal_{ij} = A_{ij} \times B_{ij} \times 100$; *A* is the specificity, i.e. the ratio between the mean abundance of the species *i* sampled in month *j* and the sum of the mean abundances of the species over all of the months, and *B* is the fidelity, i.e. the ratio between the number of samples in which the species *i* is recorded and the total number of samples for month *j*. The number of species was selected using the rule of thumb, i.e. retaining up to the last species before the plot flattens, as generally used in principal component analysis (Jolliffe, 2002). In general, the specificity of the species *i* for a given month was high when the species was observed mainly in that month. On the other hand, the fidelity of the species *i* to a given month was high when the species was observed in all the samples of that month throughout the years. The analysis was performed on species observed in at least 0.5% of samples (Appendix 1).

The IndVal analysis was also applied to two distinct periods, identified on the basis of regime shift analysis, to test long-term differences in the structures of phytoplankton communities. Computation of the individual values and their significances was made by using the indval.exe software freely downloadable at http://old.biodiversite.wallonie.be/outils/indval/home.html.

The diversity (species richness, *S*) of diatoms (by far the largest group in the phytoplankton community, and also including the highest number of taxa) was evaluated by counting the number of species in spring (from March to May) and autumn (from September to November) samples and computing the seasonal mean value for each year. Shannon's diversity index H' (ln-based; Shannon, 1948) was calculated in order to represent the specific diversity of diatoms in spring and in autumn. The index takes into account the number of species and the evenness of their abundance; the mean H' for every year was considered. Bloom