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Composition and interannual variability of phytoplankton in a coastal upwelling region (Lisbon Bay, Portugal)

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ABSTRACT

From July 2001 to May 2005, at a fixed station located in Lisbon Bay (Cascais: 38° 41′ N, 09° 24′ W), surface seawater samples were collected on a weekly basis. We aimed to describe at different temporal scales, short-term to interannual, the phytoplankton community in relation to hydrographic conditions.

Maxima of the main phytoplankton groups varied according to the seasonality of upwelling/downwelling cycles and nutrient availability and were associated with particular hydrological mesoscale structures highlighted by satellite images. Short succession cycles were identified dependent on coastal upwelling events. Intermittent and weak pulses allowed the coexistence of species from different succession stages and groups, although having consecutive maxima. The interannual differences observed in the phytoplankton community, in Lisbon Bay, varied according to both the duration and strength of the upwelling events and to precipitation and Tagus river flow regimes.

Diatoms developed and were dominant, during spring–summer under prevailing upwelling conditions and silicon availability. Short upwelling pulses appeared to be unfavourable for diatoms maintenance. When upwelling weakened and SST increased due to onshore advection of warmer waters, coccolithophores dominated. This assemblage was the second most abundant during the study, in particular during the short transition period from upwelling (summer) to downwelling seasons (autumn) distributing in the largest range of hydrographical conditions between diatoms (maximum turbulence) during early spring and dinoflagellates (maximum stratification) during summer to further dominate during autumn and winter. Nitrites and nitrates seemed to favour greater developments of this group. Dinoflagellates peaked mainly during summer and were the less abundant through the four years due to the decrease of lasting convergence periods. Like coccolithophores, a preference for warmer waters emerged but this group seemed to have a narrow tolerance to turbulence and temperature changes.

1. Introduction

At the west coast of Portugal upwelling generally occurs seasonally, from April to September, under northerlies, while onshore advection of oceanic waters is observed during autumn and winter, when southerly winds begin to dominate and there is an intensification of waters flowing poleward (Fiúza et al., 1982; Haynes and Barton, 1990; Peliz et al., 2005). Episodes of reverse winds can occur during both seasons. Lisbon Bay is either influenced by the subtropical branch of the Eastern North Atlantic Central Water (ENACWst) as by Tagus river discharges, an import nutrient source especially during winter. North of the bay, an upwelling filament rooted at cape Roca (Fig. 1) recurrently occurs during the northerly wind periods (upwelling favourable), typically extending to the south and westward direction. However, at Lisbon Bay the structure of upwelling is complex since it represents an important coastline discontinuity. This region is considered an upwelling shadow area where phytoplankton species can be accumulated through different retention mechanisms (Graham and Largier, 1997; Moita et al., 2003; Oliveira et al., 2009). Moita (2001), for this coast, identified upwelling as the major source of seasonal and spatial variability of phytoplankton. Primary production depends on incoming solar irradiance, temperature, nutrients and oligoelements and in upwelling systems is defined practically by the external energy made available (Margalef, 1978a). In shelf waters, phytoplankton production is primarily controlled by the interaction of water masses supplying different levels of nutrients to the euphotic zone (Ciotti et al., 1995) and by the alterations of the water column stability (Laubscher et al., 1993; Brandini et al., 2000). Thus, the development of a certain size structure of the phytoplankton community depends on the physical–chemical characteristics of the environment (Kiørboe, 1993).

The sampling site, Cascais (Fig. 1), is located at the northern side of Lisbon Bay and south of cape Roca. Here, phytoplankton is either influenced by upwelled waters of the Roca filament or by warmer and mature surrounding waters. The prevailing condition depends on the intensity and persistence of upwelling favourable winds and on the

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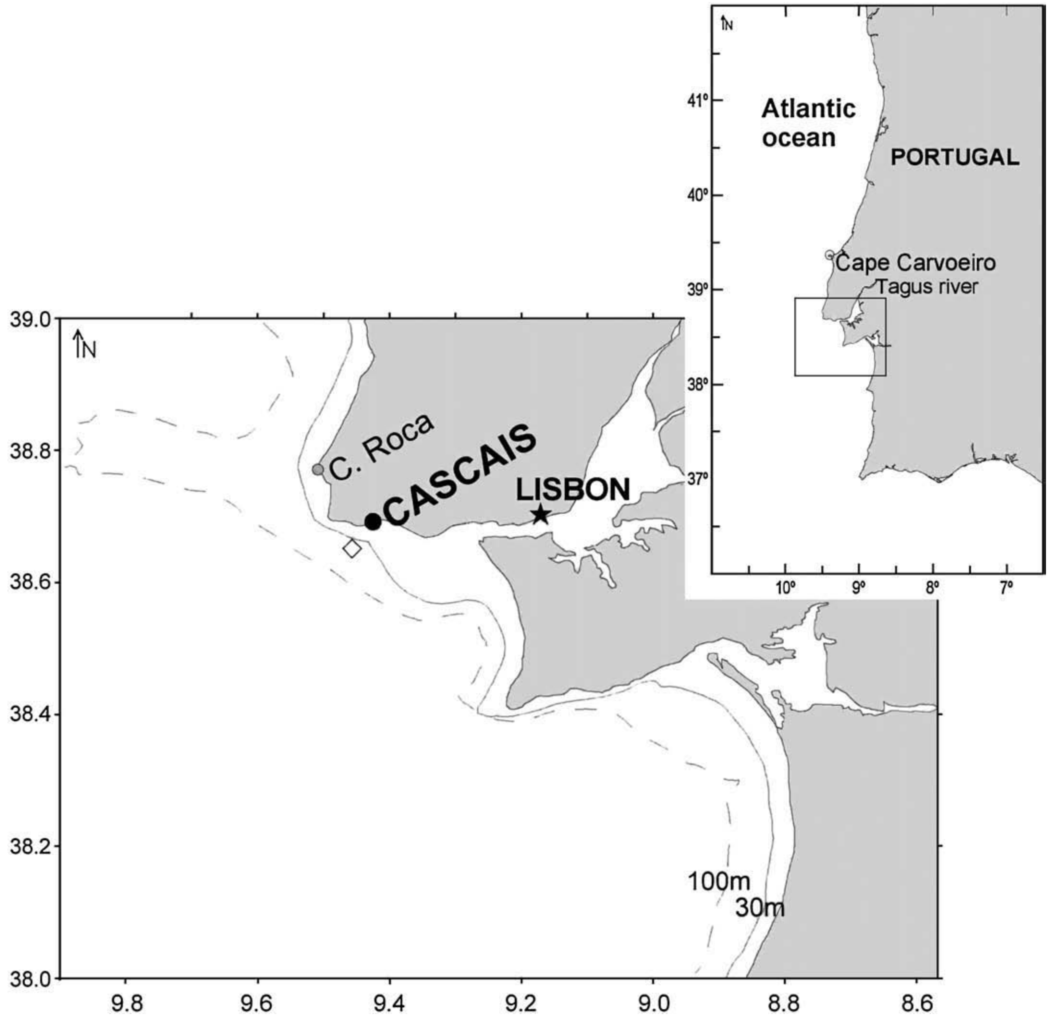

Fig. 1. Location of the sampling site — Lisbon Bay/Cascais (●) and validation station (◊), 4 km offshore.

offshelf mesoscale structures controlling the offshore extension and position of the upwelling filament. Weak upwelling conditions allow a larger influence of warmer and stratified waters into the bay.

The aim of this study, based on four years of weekly sampling, was the characterization of the dominant phytoplankton community (diatoms, dinoflagellates and coccolithophores) in relation to hydrological conditions from short-term to interannual scales of variability. Such data set will allow comprehensive observations on phytoplankton species succession and is original since rarely on Portuguese coastal waters, the three phytoplankton groups are studied simultaneously with sampling and observation methods focus on coccolithophores.

2. Materials and methods

2.1. Surveyed area and sampling strategy

From July 2001 to May 2005, at a fixed coastal station located in Lisbon Bay (Cascais: 38° 41′ N, 09° 24′ W) (Fig. 1), seawater samples were collected on a weekly basis, from surface, 1 h before high tide to minimize the direct influence of Tagus estuarine waters on the area. The surface samples were used for chlorophyll *a*, the fraction of chlorophyll *a* less than 20 µm, phytoplankton composition and nutrient determination. Temperature, salinity and depth were determined *in situ* with a Quanta CTD.

Daily wind data were obtained from the meteorological station of Cape Carvoeiro, located 50 km north of Cascais (Fig. 1).

2.2. Chlorophyll a and nutrient analyses

To evaluate the chlorophyll *a* concentration, 250 ml seawater samples were filtered and for chlorophyll *a* <20 µm, the same volume was filtered through a 20 µm net placed on top of the filter (Whatman, 47 mm nitrate cellulose membrane with a 0.45 µm nominal pore size). Pigments were extracted with 90% acetone and determined on the Perkin-Elmer spectrofluorometer (Holm-Hansen et al., 1965).

The water for nutrient determination was filtered through a Millipore filter of 0.45 µm and stored at −4 °C for subsequent analysis. Nitrites and nitrates ($NO_2^- + NO_3^-$), phosphates (HPO_4^{3-}) and silicon ($SiO_4{}^{4-}$) were determined using an autoanalyser "SKALAR" according to the methods of *Technicon Industrial Systems* (Grasshoff, 1983). The detection limit is 0.2 µM for silicon and 0.05 µM for nitrites + nitrates and phosphates.

2.3. Phytoplankton analyses

Phytoplankton samples were preserved with hexamethylenetetramine buffered formalin to a final concentration of 2% (Throndsen, 1978). Phytoplankton species were identified and enumerated in subsamples of 50 ml by the Utermöhl technique (Hasle, 1978), using a Zeiss IM35 inverted microscope with phase contrast and bright field illumination. A magnification of 160× and 400× was used to analyse the phytoplankton assemblage with a detection limit of 40 cells l^{-1} and 2000 cells l^{-1}, respectively. When possible, the cells were identified to species level according to Hasle and Syvertsen (1996),