Phytoplankton variability modulation by the hydrodynamic regime in Alfacs Bay (NW Mediterranean). A combined experimental and modelling study

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Abstract

Understanding the spatio-temporal variability of phytoplankton in aquaculture areas is necessary for the appropriate management of natural resources and the prevention of toxic outbreaks. With this objective, we combined synoptic cruises, time series of physical parameters, and modeling, to study the ecosystem of Alfacs Bay, an important shellfish and fish production area commonly affected by toxic outbreaks.
Synoptic cruises performed during relevant harmful species proliferations, such as a *Karlodinium* spp. outbreak in 2007, showed the existence of a preferential phytoplankton accumulation area in the inner NE side of the Bay. We explored the role of nutrient supply (which takes place mainly through the irrigation channels discharging into the northern coast) and the hydrodynamic regime in explaining the observed phytoplankton distribution patterns. Based on a 3D hydrodynamic model combined with a particle-tracking module, we suggest that the phytoplankton confinement in that area could be fostered by the estuarine circulation dynamics taking place in the bay.

Keywords: Alfacs bay, NW Mediterranean, phytoplankton dynamics, estuarine circulation

Introduction

Alfacs Bay is a shallow microtidal estuary located in the Ebre Delta (NW Mediterranean), which receives freshwater inputs coming mainly from the runoff of rice field irrigation channels discharging from its northern coast, and from groundwater seepage (e.g. Camp and Delgado 1987). Its high productivity (in contrast to the adjacent oligotrophic Mediterranean waters) has allowed the development of valuable aquaculture activities. Unfortunately, recurrent harmful phytoplankton outbreaks (caused mainly by *Alexandrium minutum*, *Dinophysis* spp., *Pseudo-nitzschia* spp. and *Karlodinium* spp.) threaten this industry (Fernández-Tejedor *et al.* 2008). In this context, the appropriate management of natural resources and the prevention of toxic outbreaks require a good understanding of the phytoplankton dynamics in the bay and in particular of harmful algal blooms.
With this objective in mind, we investigated the spatio-temporal variability of the phytoplankton biomass distribution in relation to the major physico-chemical forcings: nutrients, general circulation, light availability, and degree of stratification (Llebot *et al.* 2010 and references therein). The motivation for this study derived from our observation of maximum abundances of the ichthyotoxic *Karlodinium* spp. on the NE side of the Bay and near and below the pycnocline during an outbreak in June-July 2007. In subsequent field cruises and by combining both *in situ* sampling and modeling tools, we explored the underlying mechanisms which could lead to these preferential phytoplankton accumulation area in the bay.

Materials and Methods

Synoptic cruises (1- to 2-day duration) were performed to obtain *in situ* data to characterize the variability of both the phytoplankton biomass (chlorophyll, cell numbers) and the physico-chemical parameters (water temperature and salinity from CTD casts and organic and inorganic nutrients from water samples) at basin scale. The cruises were conducted between April 2007 and July 2011, at different times of the year covering the three main periods regarding the magnitude of freshwater inputs (open, semi-open, and closed irrigation channels). Some cruises coincided with the occurrence of harmful outbreaks. Modeling experiments were performed to test hypotheses regarding the observed basin-scale phytoplankton distributions and variability. A semi-implicit 3D hydrodynamic model of water circulation (Smith 2006) previously implemented in Alfacs Bay (see detailed description in Llebot *et al.* accepted) was coupled to a Lagrangian particle-tracking model (Ross and Sharples 2004, Ross et al *in preparation*). The models had been previously validated using continuous time series data of water temperature, salinity, water velocities, and fluorescence obtained with instruments moored at a central station near the mussel rafts, combined with concurrent meteorological information. The simulations were performed with 2 clouds of 4000 passive tracers. One cloud was released in a vertically homogeneous distribution near the mouth of the bay and the second cloud in the bay's interior. Simulations were performed for relevant periods for which we had cruise data, in order to compare the observed chlorophyll distributions with the modeled tracer concentrations.

Results and Discussion

At a basin scale, horizontal salinity and density gradients were often observed in Alfacs Bay as reported in previous studies (not shown, but see e.g. Camp and Delgado 1987, Llebot et al. 2014).

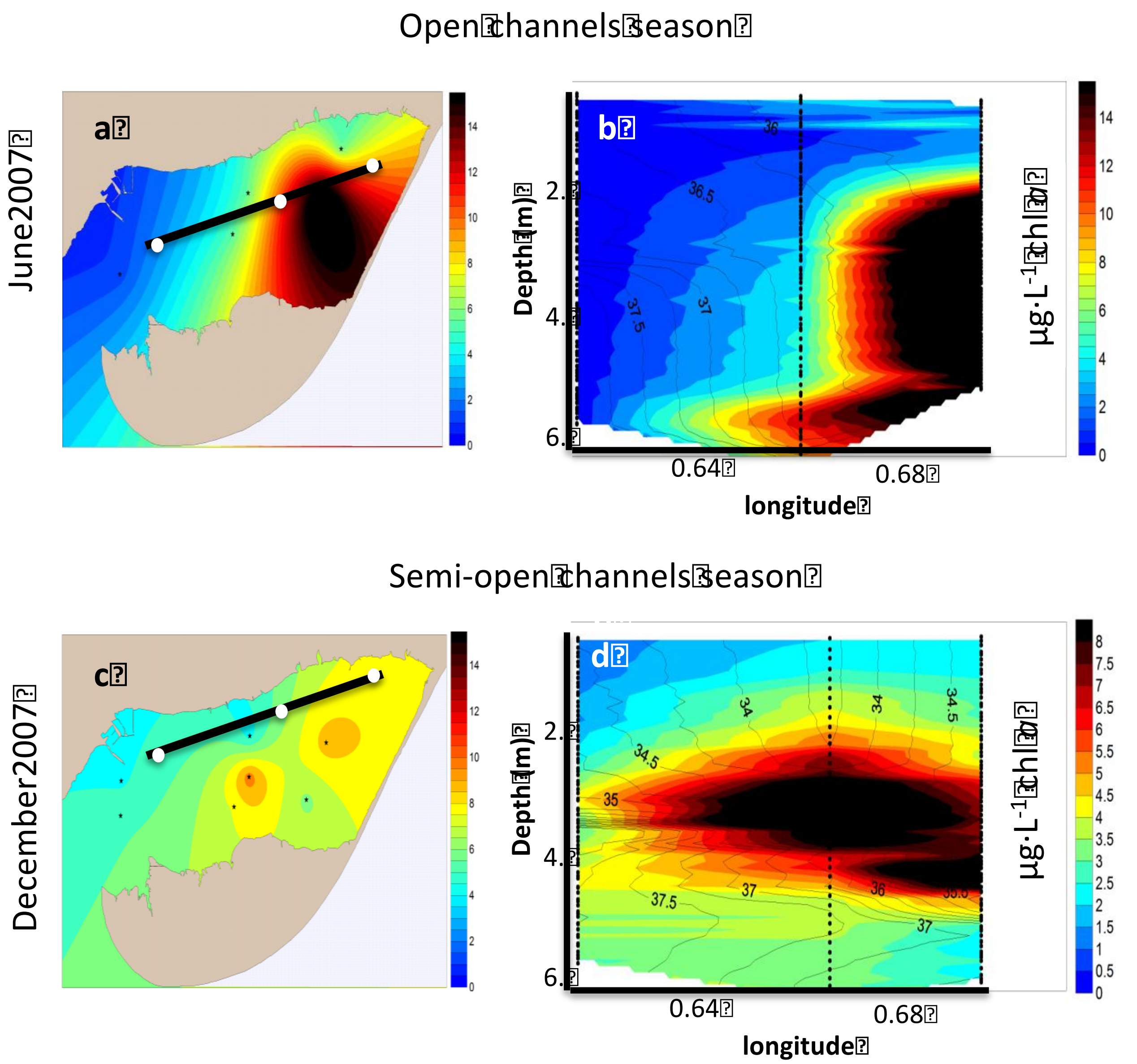

Fig. 1: (a, c) Distribution of depth averaged profiles of chlorophyll a in Alfacs Bay in representative cruises. Dots indicate the sampling points. (b, d) Vertical distribution of chlorophyll a along the longitudinal transect of the bay (black bar in a and c). In these graphs chlorophyll is plotted in colour contours with overlays of salinity contours.

Less dense, brackish waters (salinity <35) were typically found in the northern interior of the bay, while dense, saltier (salinity range 36-37.8) marine waters would be observed to enter from the Mediterranean Sea. Along the year, the water density varied as a result of temperature and salinity fluctuations. The highest density values (26.5 – 27.7) were measured during the coldest winter months (December to March) with a reduced freshwater inflow from the channels (semi-open and closed channels periods). In turn, the lowest densities (22-26) were typically recorded during the warmer summer months of June and July (open channels period).

The phytoplankton distributions in the bay exhibited a rather heterogeneous pattern. For instance, in June-July 2007 the highest chlorophyll concentrations occurred towards the NE, in the interior part of the bay (Fig. 1a). In the vertical, chlorophyll maxima were mainly found just above the pycnocline or near the bottom (Figs. 1b). *Karlodinium* spp. reached maximum concentrations of ca. $1.5x10^{-6}$ cell·L^{-1}, while chlorophyll increased up to 30 µg· L^{-1}. During a subsequent survey in December 2007 (Figs. 1c and 1d), a similar horizontal pattern was observed. In that case, the only toxicogenic organism, *Dinophysis* spp., was present below the warning threshold. In general, the highest phytoplankton biomass was associated with brackish rather than with marine waters.

Measurements of nutrient concentrations confirmed that the main supply enters through the irrigation channels (Camp and Delgado 1987) with comparatively low levels during the closed channel period (Llebot et al. 2010). The highest concentrations were typically observed near the N (Sant Carles port) and NE interior of the bay. However, areas with high nutrient levels did not always coincide with high chlorophyll concentrations, suggesting that other factors may modulate the phytoplankton patches in the bay.

In particular, we tested whether the hydrodynamic flow regime could facilitate the existence of a retention area that favours biomass accumulation. The particle tracking simulations showed how the estuarine circulation and tracer distributions responded to changes in buoyancy, wind and tidal forcing. The estuarine circulation was particularly active when the water column was stratified and wind mixing was weak (Fig. 2a). In this situation, the circulation drives the bottom particles towards the bay's interior, while flushing the particles in the surface layer out into the open Mediterranean. When wind-induced mixing is strong, the density stratification and associated estuarine circulation break down (Fig. 2b) and particles accumulate in the bay's interior (Fig. 2c). These model results are in good agreement with observed distributions of chlorophyll (Fig. 1), supporting the hypothesis that the inner bay retention area is largely controlled by the physical forcing. The degree of tracer retention is lower when the channels are open (e.g. July 2007, figs. 1a and 1b) compared to the closed (not shown) and semi-open periods (e.g. December 2007, figs. 1c and 1d). When the freshwater inflow from irrigation channels is reduced (semi-open or closed channel periods) and/or wind-induced mixing is high, water column stratification decreases resulting in a weakening of the estuarine circulation. The residence time (defined as the time for which at least 50% of the particles remain in the bay) in such situations is of the order of 3-4 weeks which is a period long enough to facilitate bloom development. This often coincides with *Alexandrium minutum* and *Dinophysis* spp. outbreaks (Fernández et al., 2008). In addition, nutrient levels can also be relatively high in this period. A direct link between nutrients and circulation cannot be established at this stage, as concentrations result from the balance between sources (including recycling) and consumption by the organisms. When the estuarine circulation is well developed (often coinciding with the open channel period), nutrient levels are high but the residence time can drop to less than 1 week.

Some other studies to characterize in more detail the seasonal and small-scale variability of phytoplankton patchiness, including harmful species, are in progress (Artigas et al. in press). Future research is aimed to accurately calculate the residence times under different circulation scenarios. Besides improved understanding of Alfacs Bay, the results highlight the importance of physical/hydrographic factors in determining HABs.

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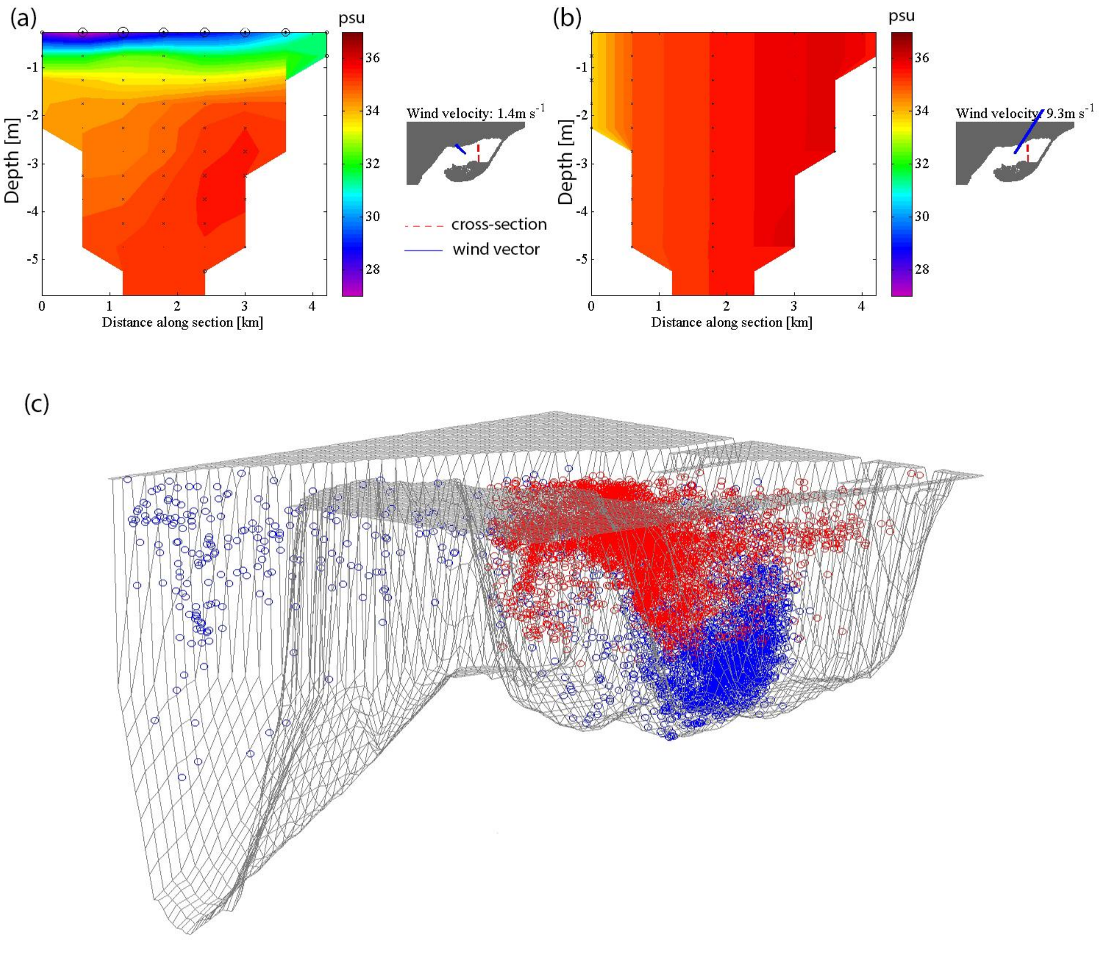

Fig. 2: Simulation of a semi-open channel scenario showing (a) the vertical salinity stratification during low wind intensities (the crosses and circles with dots inside them, represent the flow into and out of the bay respectively), (b) higher wind leading to weakened salinity stratification and a breakdown of the flow, (c) a snapshot of the coupled 3D hydrodynamic-particle tracking model including the bottom topography showing the retention of two clouds of particles (blue and red circles) in the NE interior.