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Coastal Mediterranean plankton stimulation dynamics through a dust storm event: An experimental simulation

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ABSTRACT

An enhancement of aeolian inputs to the ocean due to a future increase in aridity in certain parts of the world is predicted from global change. We conducted an experimental simulation to assess the biological response of NW Mediterranean coastal surface waters to an episodic dust addition. On the assumption that planktonic growth was limited by phosphorus, dust effects were compared to those induced by equivalent enrichments of phosphate. The experiment analyzed the dynamics of several parameters during one week: inorganic nutrients, total and fractioned chlorophyll *a*, bacterial abundance, phytoplankton species composition, abundance of autotrophic and heterotrophic flagellates, particulate organic carbon and particulate organic nitrogen. The maximum addition of dust (0.5 g dust L^{-1}) initiated an increase in bacterial abundance. After 48 h, bacterial numbers decreased due to a peak in heterotrophic flagellates and a significant growth of autotrophic organisms, mainly nanoflagellates but also diatoms, was observed. Conversely, lower inputs of dust (0.05 g dust L^{-1}) and phosphate enrichments (0.5 μmol PO_4^{3-} L^{-1}) only produced increases in phototrophic nanoflagellates. In our experiment, dust triggered bacterial growth, changed phytoplankton dynamics and affected the ratio of autotrophic to heterotrophic biomass, adding to the variability in the sources that affect system dynamics, energy and carbon budgets and ultimately higher trophic levels of the coastal marine food web.

1. Introduction

The dynamics of plankton in temperate and subtropical oceanic waters has a strong seasonality driven mainly by the winter mixing that brings new nutrients to the upper euphotic layer. In coastal areas this seasonality tends to be smoothed without a clear pattern (Cloern and Jassby, 2008). Higher nutrient availability, multiple nutrient sources with their own dynamics and nutrient imbalances with respect to the Redfield ratio may increase the variability. As an example, the dynamics in Blanes Bay (NW Mediterranean) seems to be largely driven by specific events (Guadayol et al., 2009) on top of a seasonal background. Inorganic nutrients of terrestrial origin are supplied to the coastal system through runoff, driven in part by episodic meteorological phenomena. Nutrients are also resuspended into the water column through storm and wave action. Another potential event-driven source of nutrients is atmospheric deposition, with a highly variable component of dust from Saharan origin.

The Saharan and Sahel regions are two of the most active ones in terms of dust export (Prospero et al., 1996; Lee et al., 2006; Maher et al., 2010). Pérez et al. (2007) estimate that these two areas are responsible for more than half of the world's mineral dust emissions. A large part of this dust travels across the Mediterranean Sea and is deposited within its coastal area (Loÿe-Pilot and Martin, 1996; Guerzoni et al., 1999). Saharan dust is known to contain a variable amount of inorganic nutrients (Duce and Tindale, 1991; Bergametti et al., 1992; Jickells, 1995; Prospero et al., 1996). Several studies have been conducted to test aerosol effects in the Atlantic Ocean (Blain et al., 2004; Mills et al., 2004; Duarte et al., 2006; Marañón et al., 2010), in the eastern Mediterranean basin (Herut et al., 2005; Eker-Develi et al., 2006), and in the western Mediterranean Sea (Klein et al., 1997; Bonnet et al., 2005; Pulido-Villena et al., 2008, 2010). These studies, conducted within an open sea scenario, have shown variable results. A positive impact on autotrophic communities has been experimentally shown (Mills

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et al., 2004; Bonnet et al., 2005), and increases in bacterial activity and abundance following dust enrichments have also been reported, both in experiments and with direct measurements at sea (Herut et al., 2005; Pulido-Villena et al., 2008). Whether such biological responses are mutually exclusive, part of a seasonal and common ecological succession, or particular for certain locations or environmental conditions (Marañón et al., 2010) requires further study.

Stimulation of plankton components with dust is usually related to the alleviation of macro- or micro-nutrient limitation. The Mediterranean is an oligotrophic sea thought to be globally limited by phosphorus (Berland et al., 1980; Krom et al., 1991; Thingstad et al., 1998; Moutin et al., 2002), albeit inorganic nutrient concentrations are very low and the system is often found to switch between different limiting nutrients (Marty et al., 2002; Sala et al., 2002; Lucea et al., 2005; Pinhassi et al., 2006). The input of phosphorus is 82% of terrestrial origin, including atmospheric sources, compared to 2% for the global ocean (Bethoux and Migon, 2009). Terrestrial sources of nutrients have an N:P composition higher than the Redfield ratio of 16 for plankton thus exacerbating P-limitation in the long-term. Hence, phosphorus in atmospheric dust, even if present in relatively low amounts (Markaki et al., 2008), is a candidate for plankton stimulation events (Pulido-Villena et al., 2010). The importance of atmospheric dust loads may become even larger as desertification in the North African and Mediterranean regions increases in future climate scenarios (Gao and Giorgi, 2008).

The present study describes the response of a natural coastal planktonic community to large dust additions and hypothesises that the changes induced by dust are comparable to the effects of equivalent phosphate enrichments. Further results with particular focus on bacterial activity and composition are the subject of a companion paper published elsewhere (Lekunberri et al., 2010). The present experiment includes small-scale turbulence as a secondary environmental variable to test whether turbulent conditions, often accompanying dust storms, lessen or enhance the effects of dust on the planktonic community. The study further examines whether dust inputs can drive changes in biomass and structure within the microbial community of a particular NW Mediterranean coastal site, and if such changes may shift the balance between autotrophy and heterotrophy.

2. Materials and methods

2.1. Aerosol collection

Aerosols used in the experiment were gathered during an intense Saharan dust wet deposition event associated with a cold front in Nice, France (43°42′10″ N, 7°16′9″ E) on February 21, 2004. The Dust REgional Atmospheric Model (DREAM, www.bsc.es/projects/earthscience/DREAM) wet deposition forecast for this day shows a large area of Southern France, Northern Italy and the Northwest Mediterranean above 41°N with a deposition above 1 g m^{-2}. The mass flux was measured at the nearby meteorological station of Cap Ferrat during the event was 22 g m^{-2} (pers. comm. Christophe Migon [CNRS-UMPC Paris 06, UMR 7093, LOV, Observatoire océanographique, Villefranche/Mer, France]). We collected the dust in a plastic tray (ca. 0.28 m^2) exposed during the storm event (>1 day), with a locally estimated mass flux of 64 g m^{-2}. The dust was dried (60 °C, 48 h) and stored in an acid-washed polypropylene bottle. Before use, the dust was ground to homogenize the sample.

2.2. Water sampling and experimental setup

Water for the experiment was collected at the Blanes Bay Microbial Observatory (41°40′0″ N, 2°48′0″ E) on May 16th, 2006. Table 1 shows the N:P ratio for Blanes Bay. The mean molar N:P is 23 and shows no clear seasonal pattern (no significant seasonal autocorrelation), although the average summer value of 18 is slightly lower than for the rest of the year (24 in winter, 27 in spring and 22 in autumn). Inorganic phosphorus ranges from <0.02 (undetectable) to 0.94 μmol L^{-1} with an annual mean and standard deviation of 0.16 ± 0.10 μmol L^{-1}. Dissolved inorganic nitrogen ranges from 0.22 to 8.60 μmol L^{-1} with an annual mean and standard deviation of 2.60 ± 1.80 μmol L^{-1}. After screening the water through a 150 μm Nylon mesh, we filled 20 L plastic carboys that had previously been washed with a dilute solution of sodium hypochloride and thoroughly rinsed with tap water, milli-Q water and sample water. The water was taken to the laboratory, where 15 L cylindrical metacrylate containers were used for the experiment. Each of these containers was filled with 7.5 L of water, and they were subjected to experimental conditions in a light and temperature controlled environmental chamber during 7 days. We had eight experimental conditions (see Lekunberri et al., 2010) determined by three variables: levels of dust addition (DL, DH), phosphate enrichment (P) and absence/presence of turbulence (S, T). Controls (C) were not enriched with either phosphate or dust. We could not replicate all treatment combinations due to logistical constraints hence the compromise between the desired multifactor design and the number of feasible units was solved in favor of duplicating some of the combinations, namely CS, CT, DLS and DLT.

Small-scale turbulence was generated by means of vertically-oscillating grids with a mechanical device described in Peters et al. (2002). We used a turbulent kinetic energy dissipation rate of 10^{-2} cm^2 s^{-3}, estimated from the equations in Peters and Gross (1994). This value is within the range of turbulence intensities in coastal areas (Kiørboe and Saiz, 1995). Turbulence was only applied during the first three days of the experiment, a typical duration for turbulence events of the applied mean intensity in the Blanes area (Guadayol and Peters, 2006). Thereby, containers corresponding to T treatments underwent turbulent conditions for three days and remained still until the end of the experiment, whereas S treatments were kept still.

Both dust and phosphate were added as a unique dose at the beginning of the experiment. Ridame and Guieu (2002) suggest that 60% of 'Saharan rains' carry between 0.005 and 8 g of dust per liter. We did a preliminary nutrient release test for different dust concentrations in the water (Fig. 1) and found that a 0.05 g L^{-1} dust concentration released 0.38 ± 0.08 μmol PO_4^{3-} L^{-1}. We decided to use a dust addition of 0.05 g L^{-1} as our low addition level (DL) and 0.5 g L^{-1} as our high addition level (DH). To check whether a similar

Table 1
Nutrient data for Blanes Bay summarized from March 2001 to January 2008 (Blanes Bay Microbial Observatory). Data are means with standard errors in parenthesis.

Season	Day range (m/d)	*n*	NO_3+NO_2 (μmol L^{-1})	NH_4 (μmol L^{-1})	Si (μmol L^{-1})	P (μmol L^{-1})	N:P
All	1/1–12/31	108	1.52 (0.15)	1.08 (0.08)	1.64 (0.14)	0.16 (0.01)	22.6 (2.48)
Winter	12/21–3/20	26	2.34 (0.37)	1.21 (0.23)	1.96 (0.32)	0.17 (0.01)	24.5 (3.64)
Spring	3/21–6/20	25	1.86 (0.26)	1.07 (0.15)	1.97 (0.30)	0.19 (0.03)	26.7 (8.18)
Summer	6/21–9/20	25	0.54 (0.10)	1.00 (0.10)	0.92 (0.12)	0.13 (0.01)	17.7 (4.17)
Autumn	9/21–12/20	32	1.36 (0.25)	1.04 (0.12)	1.69 (0.30)	0.14 (0.01)	21.5 (3.26)