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Atmospheric input of dissolved inorganic phosphorus and silicon to the coastal northwestern Mediterranean Sea: Fluxes, variability and possible impact on phytoplankton dynamics

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Abstract

One hundred twelve rainwater samples collected from 1986 to 2003 at the signal station of Cap Ferrat (France, NW Mediterranean coast) were analysed for phosphate and silicate contents. This sampling site is affected by a European urban-dominated background material, with episodic Saharan dust inputs. The input of dissolved inorganic phosphorus (DIP) and dissolved inorganic silicon (DISi) was calculated. The most significant loadings of DIP and DISi were selected in order to assess their potential impact on phytoplankton dynamics, particularly in oligotrophic conditions, when surface waters are nutrient-depleted. The theoretical new production triggered by DIP and DISi inputs (NP_{atmo}) was estimated through Redfield calculations. The maximum theoretical DIP-triggered NP_{atmo} was up to 670 mg C m^{-2} in October, at the end of the oligotrophic period (135 mg C m^{-3} in the 5 m-thick surface layer). During the same period, the daily integrated primary production measured at the DYFAMED site (NW Mediterranean Sea) was on average 219 mg C m^{-2} d^{-1} within the 0–100 m depth water column, while the mean daily primary production in the 5 m-thick surface layer was 1.6 mg C m^{-3} d^{-1}. However, high NP_{atmo} due to high DIP inputs might be episodically limited by lower DISi inputs, which may consequently lead to episodic preferential growth of non-siliceous phytoplanktonic species.

Keywords: Rainwater; Phosphorus; Silicon; Fertilisation; Oligotrophy; Phytoplankton; Northwestern Mediterranean Sea

1. Introduction

The chemical factors that control primary production (PP) and their temporal variability are major questions in oceanography. Apart from

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internal sources of nutrients (vertical mixing and recycling), the atmosphere may constitute an important pathway for nutrients to the photic zone of the open sea where there is little riverine input (Migon et al., 1989; Bergametti et al., 1992; Prospero et al., 1996; Benitez-Nelson, 2000). This particularly applies to the Mediterranean Sea, because of its reduced dimensions and because surrounding continental emission sources of nutrients are intense and continuously increasing (Béthoux, 1989; Guerzoni et al., 1999; Béthoux et al., 2002).

What is the significance of wet and dry atmospheric inputs in terms of primary productivity? Some studies have shown evidence that the atmospheric input of phosphate is likely to affect biological productivity in Mediterranean oligotrophic waters (Herut et al., 1999; Migon and Sandroni, 1999; Ridame and Guieu, 2002; Markaki et al., 2003). The impact of nutrient-enriched atmospheric inputs is enhanced under oligotrophic conditions. During summer and autumn, the seasonal stratification of the water column is well developed in the Mediterranean Sea, and depleted surface waters are isolated from underlying waters. Under such conditions, the atmospheric spreading of nutrients over offshore waters is expected to generate a phytoplanktonic biomass increase (Migon et al., 1989; Bergametti et al., 1992; Migon and Sandroni, 1999; Ridame and Guieu, 2002).

The dry deposition mode is a significant source of nutrients to surface waters at the yearly scale (Migon et al., 2001; Herut et al., 2002). However, when nutrient concentrations in surface water are low, nutrients do not accumulate and are immediately consumed by biota (Migon et al., 1989), and new production triggered by the atmospheric input (NP_{atmo}) may not be clearly observable. The rapid exhaustion of atmospheric suspended matter during atmospheric washout causes high pulses of nutrients associated with washout events (Buat-Ménard and Duce, 1986).

The present work evaluates the potential impact of rain events on biological activity, based on a large phosphorus (P) data set. An attempt is also made to consider the role of the silicon (Si) wet input, which, to our knowledge, is not documented in the Mediterranean Sea.

2. Study area and methods

Rainwater was collected at the signal station of Cap Ferrat, situated on the southeastern coast of France (43°41′ N, 7°19′ 30″ E, altitude 130 m; Fig. 1). Because of its peninsular characteristics and mountainous environment, this site is sheltered from local sea spray as well as from direct continental sources, although it exhibits a marked marine influence. The average rainfall is approximately 10% lower than that observed at the neighbouring Nice airport situated on the shoreline. More detailed discussion on the site (meteorological characteristics, surrounding anthropogenic influences, occurrence of Saharan events, etc.) can be found elsewhere (Migon et al., 1991; Chester et al., 1997). The Cap Ferrat site is overall affected by a European urban-dominated background material, with episodic Saharan dust inputs. Anthropogenic inputs, originating generally from the north and the northeast, prevail in winter, whereas Saharan episodes are observed mainly in spring and in summer. These seasonal signatures have been recently observed for the case of aerosol P (Migon et al., 2001).

Rainwater samples were collected with an automatic rain collector that opens only when it rains and not under the influence of fog or dew. In order to limit the bacterial consumption of nutrients, samples were poisoned in situ: 4 mg $HgCl_2$ (Suprapur quality) were added to 20 ml of Milli-Q water in the polycarbonate sampling bottle. As the amount of rainfall cannot be predicted, it is impossible to reproduce the same poison concentration in each sample. Our aim was to be within the order of magnitude of ~20 mg $HgCl_2$ L^{-1}, as recommended by Kirkwood (1992).

Thirty-two samples were collected in 2000, 2001 and 2003. Additional unpublished data from 80 samples formerly collected at the same site are also presented in this study: 21 samples collected in 1986, 36 in 1987 and 23 in 1997. These additional samples were collected under the same conditions, but were not poisoned, as they were analysed immediately after the rain event. The 1997 data have been previously published (Migon and Sandroni, 1999), but are combined here with data from other years to provide a wider data set, in