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Impact of contaminated sediment elutriate on coastal phytoplankton community (Thau lagoon, Mediterranean Sea, France)

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ABSTRACT

Effects of sediment-released contaminants and nitrogen were assessed on phytoplankton communities sampled from Thau lagoon (France, Mediterranean Sea) and one close offshore marine station. Phytoplankton was exposed to sediment elutriate (seawater containing a mix of metals, organic chemicals, and nutrients) or to ammonium enrichment for four days using immersed microcosms exposed to natural conditions of light and temperature. Functional (production - respiration balance) and structural (taxonomy and cell densities) responses of the phytoplankton community were assessed. In the lagoon, both treatments stimulated phytoplankton growth, compare to controls. Conversely in the offshore station, the phytoplankton growth was stimulated only with the sediment elutriate addition. In offshore and lagoon stations, both treatments caused a shift in the taxonomic composition of the phytoplankton. Proliferation of potentially toxic diatoms and dinoflagellates resulted from the addition of elutriate. Correspondence analysis determined that phytoplankton from the offshore station was more sensitive to both treatments compared to the lagoon community. According to daily production and respiration balance, lagoon community metabolism remained heterotrophic ($P < R$) for all treatments, whereas only transient shifts to net autotrophy ($P > R$) were observed in the offshore community. Direct toxicity of contaminants released from sediment, if any, was therefore masked by nutrient enrichment effects, whereas indirect evidence of contaminant pressure was highlighted by changes in community composition and metabolism.

1. Introduction

Anthropogenic contaminants in marine ecosystems are often eventually trapped by sediments, which act as a sink for pollutants. Resulting contaminated sediments affect mainly the benthic organisms but can also impede pelagic compartments when chemicals are released to the water column (Birch and O'Hea, 2007; Jonas and Millward, 2010; Roberts, 2012). Disturbance of contaminated sediments by anthropogenic (dredging and disposal of dredged materials, trawling, ship movements and propeller wash) and natural processes (tides, storms and bioturbation) may affect a wide range of species, eventually being incorporated into food webs (Burton and Johnston, 2010). Resuspension of contaminated sediments (RCS) has been shown to be an important source of dissolved chemicals in historically contaminated estuaries (Kalnejais et al., 2010; Roberts, 2012). Dissolved polycyclic aromatic hydrocarbon (PAH) and polychlorinated biphenyl (PCB) concentrations have been shown to increase due to dredged material disposal, even though the levels did not exceed water quality criteria (Cornelissen et al., 2008). For example, in conditions of turbulent mixing in oxygenated seawater, organic (PAH and PCB) and inorganic (trace metals) contaminants were desorbed from sediments (Josefsson et al., 2010; Voie et al., 2002). In anthropized coastal areas, such mixing events also cause nutrients release, with consequent enrichment of the water column (Cantwell et al., 2002; Kalnejais et al., 2010), and ammonia may be released in greater amounts (Jones-Lee and Lee, 2005). A few studies have reported that nutrients and contaminants may have opposite results, with the beneficial effect of the nutrients overcompensating for the detrimental impact of the contaminants (Crain et al., 2008). The effects of RCS on pelagic organisms are still being studied and have not yet been fully incorporated into ecological risk assessment for management of coastal ecosystems (Roberts, 2012). Several studies have shown that marine organisms (such as fish, bivalves, algae and polychaetes) are sensitive to RCS by many pathways (Edge et al., 2015; Edge et al., 2016; Hill et al., 2009; Tolhurst et al., 2007; Voie et al., 2002).

Phytoplankton feeds pelagic food webs and determines aquatic ecosystem primary production and functioning at higher trophic levels (Field et al., 1998). Any change in its community structure and metabolism may, therefore, trigger a cascade of indirect effects throughout the plankton ecosystem (De Hoop et al., 2013). Understanding how

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phytoplankton responds to contaminants is of primary importance for forecasting the ecological consequences of chemical contamination and for targeting priority management and restoration policies for aquatic systems. There is however no general consensus about the responses of primary producers, in direction and extent, to the simultaneous load of pollutants and nutrients. For example, Riedel et al. (2003) reported that phytoplankton growth was inhibited after exposure to a combination of contaminants (mix of trace metals) and nutrients, whereas Lafabrie et al. (2013a, b) showed that RCS can stimulate growth and modify phytoplankton community structure, suggesting that the toxic effect of chemicals if any could be offset by nutrients.

Within the marine environment, coastal ecosystems such as lagoons have become particularly impacted by chemical pollutants from anthropogenic inputs (agricultural, urban, and industrial) (Lafabrie et al., 2013a; Levin et al., 2001). This increased chemical contamination can cause a drastic alteration of the lagoon environment and eventually a threat to the services associated with lagoon environments (fisheries, aquaculture, tourism).This is the case for example of Thau lagoon (France), located on the northern shores of the Western Mediterranean Sea. The Thau lagoon is one of the largest French Mediterranean Lagoons and is one the most important shellfish farming areas in Europe (Castro-Jiménez et al., 2008). It sustains a large population of exploited fish (gilthead seabream *Sparus aurata* and European seabass *Dicentrarchus labrax*) and reared shellfish (mussels, clams and oysters) (Fouilland et al., 2012). This lagoon appears to be under intense anthropogenic pressure characterized by an increase in industrial, agricultural and urban activities. Recent studies in the Thau lagoon have revealed moderate to high chemical contamination in the sediment (Rigollet et al., 2004), and high nutrient enrichment of the water (Anschutz et al., 2007; Fouilland et al., 2012) whereas the combined effects of pollutants and nutrients on the planktonic organisms of the lagoon have retained lesser attention. The Thau lagoon like all shallow marine ecosystems is subject to sediment resuspension that may have important consequences for the ecosystem functioning, and impact aquaculture activities (changes in the structure and contribution of potentially toxic phytoplankton for example). Among factors that can trigger resuspension (reviewed in Roberts, 2012) in the area, flash floods and windstorms are documented (Fouilland et al., 2012), together with dredging activities in the nearby waterways and harbor. This study aimed to assess the effects of elutriates prepared from RCS on the structure and the functioning of the Thau lagoon phytoplankton community incubated under natural outdoor conditions of temperature and irradiance, compared to near coastal community, as well as on the dynamics and metabolism of autotrophic and heterotrophic compartments. The present work focused on the soluble fraction resulting from sediment resuspension considered as directly bioavailable for plankton communities, taking in mind that suspended sediment itself is prone to have different effects even trough physical damage (Edge et al., 2015; Edge et al., 2016). The two stations were chosen to compare the responses of a pre-exposed community from a closed lagoon, subjected to local inputs of contaminants to an *a priori* unexposed community from offshore station, considered as a reference.

2. Materials and methods

2.1. Study area

The Thau lagoon, one of the largest French Mediterranean Lagoons (43°24′N-3°36′E; Fig. 1) with an area of 70 km^2, is an important shellfishing area. Climate is characterized by autumnal storm events, and a single flood can contribute a quarter of the annual nitrogen supply from watershed (Tournoud et al., 2006). Consequently, dissolved ammonium, especially in the oyster farming areas, can reach a significant concentration (Fouilland et al., 2012; Gilbert et al., 1997). Thau lagoon has also been strongly affected by industrial activities and an intense urbanization since the mid-20th century, which have resulted in a

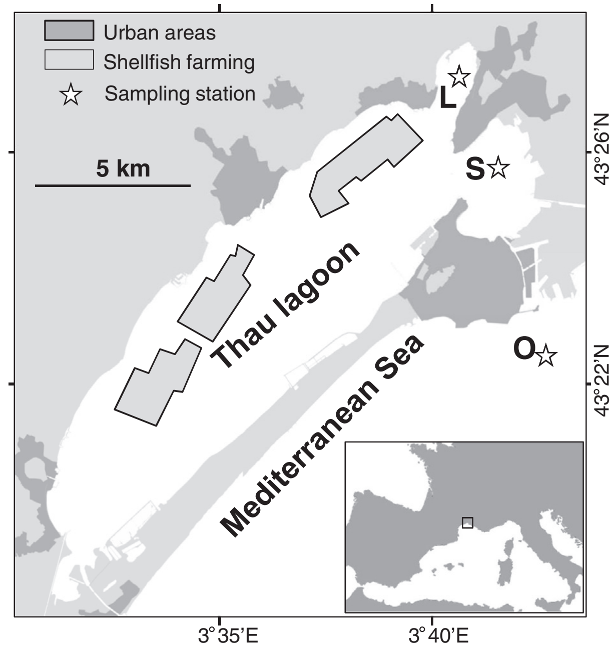

Fig. 1. Situation of the Thau lagoon in Southern France, and location of sampling stations: sediment and water for elutriate preparation (S), lagoon (L) and offshore (O) water inoculum.

significant concentration of contaminants in sediments including polycyclic aromatic hydrocarbons PAH (440–7700 μg kg^{-1}), polychlorobyphenyls PCB (600–30,000 ng kg^{-1}), trace metals (8.9–6098 ng g^{-1}) and pesticides (2921 ng kg^{-1}) as reported in several studies (Kawakami et al., 2008; Léaute, 2008; Rigollet et al., 2004).

2.2. Sediment elutriate preparation and chemical analyses

Water and sediment were sampled in June 2011 in the "*Eaux Blanches*" bay (Station S, Fig. 1). The sediments in this area have previously been characterized as highly contaminated by trace metals, PAH and PCB (Kawakami et al., 2008; Léaute, 2008). The sediment was sampled using a Van Veen grab and screened directly through a 2 mm mesh stainless steel sieve to remove stones, macrofauna and plant fragments. Water for elutriate preparation was collected from the surface in a bucket and immediately filtered through a 80 μm mesh to remove the largest organisms and debris. The sediment elutriate was prepared as described by Bonnet et al. (2000). Sediment was stirred in water (ratio 1:4 v:v) for 8 h to mimic resuspension. After settling for 8 h, the supernatant was collected and then filtered through 1 and 0.2 μm membranes to remove any native microorganisms and leave only dissolved chemical contaminants. The elutriate was used as contaminated water (CW) for the microcosm experiment.

Ammonium concentration in the elutriate was measured spectrophotometrically using indophenol blue complexation in basic medium (Koroleff, 1969), with a detection limit of 0.04 μM.

Sub-samples of sediment and elutriates were preserved for further determination of 16 PAHs (naphthalene, acenaphthylene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenzo(a,h)anthracene, benzo(ghi)perylene, indeno(1,2,3-cd)pyrene and acenaphthylene) and 7 PCB congeners (180, 28, 52, 101, 118, 138, and 153) by GC–MS method after liquid-liquid extraction for the CW and soxhlet extraction for the sediment. Trace metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn, U, V, Mn, Fe, Co and Mo) concentrations in elutriate were measured by ICP-MS, and the NH_4^+ concentration in the CW was determined using fluorometry (Holmes et al., 1999). Analytical methods involved the use of spiked deuterated standards and Canadian National Research