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Spatial and temporal variability of CO_2 fluxes at the sediment–air interface in a tidal flat of a temperate lagoon (Arcachon Bay, France)

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ABSTRACT

This study aimed to explore the spatial and temporal variability of benthic metabolism in a temperate mesotidal lagoon. This was achieved by measuring fluxes of CO_2 in static chambers during emersion, both under light and dark conditions. Three sample sites were selected according to their tidal level (upper or mid), their sediment type (sand or mud) and the presence/absence of the seagrass *Zostera noltei*. The three sites were investigated at three seasons (end of winter, spring and beginning of autumn). At each site and each season, three benthic chambers were used simultaneously in successive incubations over the emersion period. The sediment chlorophyll-*a* content varied seasonally in the upper sands (reaching 283 mg.m^{-2} in spring) but not in the mid muds (averaging 142 mg m^{-2} in bare muds and 186 mg m^{-2} in muds covered by seagrass). The maximum sediment CO_2-uptake under light was 9.89 mmol m^{-2} h^{-1} in the mid-bare muds, in early autumn. The maximum sediment CO_2-release under darkness was 6.97 mmol m^{-2} h^{-1} in the mid muds covered by seagrass, in spring. Both CO_2-fluxes measured in the light and in the dark increased over periods of emersion. This increase, not related to light nor temperature variations, could be explained by changes in the amount and chemistry of pore water during the air exposure of sediments. The benthic trophic state index, based on the maximum light CO_2-flux versus maximum dark CO_2-flux ratio, assigned to each site at each season indicated that the sediments were net autotrophic in spring in upper sands and in mid muds covered by seagrass and highly autotrophic in other cases. The most autotrophic sediments were the mid-level bare muds whatever the season. The relevance of this index is discussed compared to carbon annual budget.

1. Introduction

The metabolic balance of the coastal ocean appears to be a key part of the global carbon budget (Muller-Karger et al., 2005). Within coastal areas, intertidal sediments inhabited by microalgae and seagrasses play an important role in both the production and the remineralization of organic matter (Cahoon, 1999; Duarte et al., 2005). The definition of the status of these intertidal ecosystems as source or sink of CO_2 for the atmosphere requires evaluating the balance between primary production and respiration at relevant spatial and temporal scales.

Factors affecting the biomass of primary producers in intertidal sediments, and thereafter the associated metabolic processes, are numerous. Exposure to hydrodynamic energy (as indicated by sediment type) and tidal level have been recognized as significant factors affecting spatial variations of microphytobenthic biomass in intertidal flats. The biomass of microalgae is considered to be lower in sandy sediments than in muddy sediments (Mac Intyre et al., 1996), to peak between mid-tide level and mean high water neap tide level (Underwood and Kromkamp, 1999) and to show a high degree of heterogeneity at small spatial scale with a patchy distribution (Spilmont et al., 2011 and references therein). Seagrasses, such as *Zostera*, occur from the mid-intertidal to the immediate sublittoral on various sediments, and primary production has long been shown to be higher in sediment covered by seagrass than in unvegetated sediment (e.g. Asmus and Asmus, 1985). Seasonality in light availability and temperature is well recognized as exerting an important influence on primary production in temperate areas (e.g. Migné et al., 2004). Temporal variability of microphytobenthic biomass is however also dependent on local environmental changes at other temporal scales such as erosion and deposit events in muddy shores (Underwood and Kromkamp, 1999). In microalgae community (e.g. Migné et al., 2004) and seagrass meadows

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(e.g. Ouisse et al., 2011), gross primary production has been shown to vary over the emersion period, in response to natural light variations. Variation in community gross primary production is also expected to occur during the course of emersion due to vertical migrations of the microphytobenthos in the surface sediment (e.g. Spilmont et al., 2007).

Factors controlling intertidal sediment respiration have been less studied than the ones controlling primary production and no general relationship with the sediment type has been evidenced (Middelburg et al., 2005). Bacterial respiration is however suspected to be the highest contributor to benthic community respiration and granulometry could control the distribution of benthic compartments and thus the benthic respiration at an intertidal bay scale (Hubas et al., 2006). Sediment respiration is also known to be enhanced in seagrass meadows due to the stimulation of the bacterial activity around roots (Middelburg et al., 2005). Temporal variations in sediment respiration are expected to be mainly controlled by temperature both at seasonal and daily scales (van Es, 1982; Hancke and Glud, 2004).

The aim of this study was to explore the spatial and temporal variability of benthic primary production and benthic respiration in a temperate mesotidal lagoon. Sample sites varied according to their tidal level, their sediment type and the presence/absence of the seagrass *Zostera noltei*. Primary production and respiration were measured in situ as CO_2-exchange rates between the sediment and the atmosphere at low tide, using static benthic chambers under both light and dark conditions. Small spatial scale variability was considered at each site using three benthic chambers simultaneously. Measurements were performed at three seasons and the small temporal scale variability was considered performing successive incubations over the emersion period.

2. Materials and methods

2.1. Study site

The Arcachon Bay is a mesotidal shallow lagoon on the French Atlantic coast with a semidiurnal tide. The studied tidal flat is located in the eastern part of the lagoon, near Cassy harbour (44°43′ N, 1°03′ W, Fig. 1). Three sites were investigated; site S1 was in the upper beach sandy area (covered with water 1 to 2 h per tide, grain size ≈ 250 μm, porosity ≈ 0.4) and sites S2 and S3 were in the mid-muddy area (covered with water 3 to 4 h per tide, grain size ≈ 15–40 μm, porosity ≈ 0.8). Sites S1 and S2 were free of macrophytes while S3 was covered by the seagrass *Zostera noltei*, which biomass varied seasonally, from 23 to 377 g_{DW} m^{-2} in March and September 2006 respectively (Deborde et al., 2008a).

2.2. CO_2 flux measurements

Fluxes of CO_2 were measured at the sediment-air interface at low tide using the closed-chamber method described in Migné et al. (2002). A sediment area of 0.071 m^2 was enclosed down to a 10-cm depth. Changes in air CO_2 concentration (ppm) in the benthic chamber (10.5 L) were measured with an infrared gas analyser (LiCor Li-800) for 10–20 min. CO_2 concentrations were recorded in a data logger (LiCor Li-1400) with a 15 s frequency. CO_2 flux was calculated as the slope of the linear regression of CO_2 concentration (μmol mol^{-1}) against time (min) and expressed in mmol C m^{-2} h^{-1} assuming a molar volume of 22.4 L at standard temperature and pressure.

Transparent chambers were used to estimate the net benthic community production (NCP, the balance between the community gross

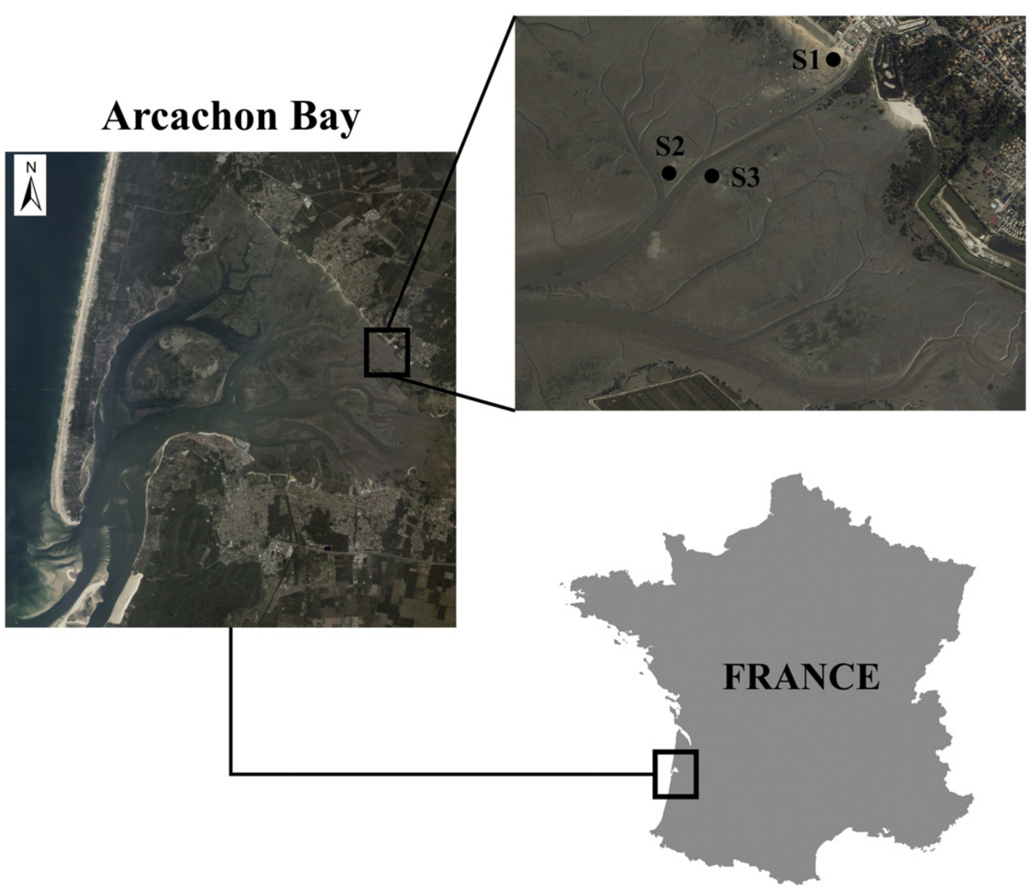

Fig. 1. Detailed map of the study site and sampling stations in the Arcachon Bay (SW France). S1: upper tidal level, sand; S2: mid-tidal level, bare mud; S3: mid-tidal level, mud + *Z. noltei*. © Ortho littorale 2008.