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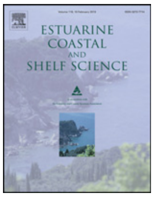

Modelling benthic oxygen consumption and benthic-pelagic coupling at a shallow station in the southern North Sea

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ABSTRACT

A time-series of benthic oxygen consumption, water-column and sediment chlorophyll concentrations, and temperature in the southern North Sea was subjected to inverse modelling in order to study benthic-pelagic coupling in this coastal marine system. The application of a Markov Chain Monte Carlo (MCMC) on a simple box model allowed deriving deposition rates and temperature-dependent remineralization rates of both phytopigments and bulk carbon, as well as estimates of uncertainty for each of these processes. Together with organic matter availability, temperature had an important effect on benthic respiration rates thus delaying remineralization of spring bloom material until the late summer when temperatures were at their highest. The sediment at our station clearly acts as a buffer, removing large quantities of nutrients from the pelagic system during the spring bloom and only slowly releasing them back into the water column as temperatures increase later during summer.

1. Introduction

The coastal zone accounts for less than 10% of the global ocean in terms of surface area, but has a disproportionally high contribution to some biogeochemical fluxes and budgets. For instance, benthic mineralization on the shelf represents over 80% of global benthic remineralization (Wollast, 1998) as up to 50% of the pelagic primary production is deposited on the bottom and mixed into the sediment by bioturbation (Jørgensen, 1983), while primary production in the open ocean is mainly respired in the water column. Moreover, denitrification in shelf sediments accounts for an estimated third of all nitrogen loss from the global ocean (Middelburg et al., 1996b).

In temperate continental shelf systems, organic matter production and deposition show high seasonality. For instance, in the Southern Bight of the North Sea, the spring phytoplankton bloom is an annual recurrent event. As oligotrophic Atlantic waters enter through the Straits of Dover, they receive input from a series of major rivers and estuaries with catchment areas covering some of the most densely populated areas in the world. Nutrient levels in the North Sea are highest in winter, as remineralization continues to some extent while primary production by phytoplankton is limited by temperature and irradiance. In early March, rising temperatures and irradiance trigger a phytoplankton bloom which, although initiated by an early silicate-controlled diatom bloom (about 200 mgC m^{-3}), is dominated by the colonial haptophyte *Phaeocystis* which reaches peak densities (roughly 1000 mgC m^{-3}) in mid-May (Rousseau et al., 2000, 2002; Gypens et al., 2007). During the *Phaeocystis* bloom diatoms maintain elevated densities, and a second slightly smaller diatom bloom typically occurs in July and August.

A recent model-based estimate, using only water column data, puts annual net primary production in the Belgian coastal waters at 213 gC m^{-2} y^{-1} (Lancelot et al., 2005). Approximately 25% of this production (51 gC m^{-2} y^{-1}) is estimated to end up in the sediment, although the exact fate of *Phaeocystis*, the dominant primary producer, is still debated (Rousseau et al., 2000; Lancelot et al., 2005). Organic matter enters the sediment compartment either through physical transport (deposition and advective injection into coarse-grained sediments) or biologically mediated transport (benthic filter feeders) (Middelburg and Soetaert, 2005). It is clear that a major part of the organic matter supplied during spring is not readily respired or assimilated, but incorporated and mixed into the sediment and degraded on longer timescales (van de Bund et al., 2001; Josefson et al., 2002 and references therein). Once mixed and diluted, the organic material may be less accessible to macrofauna (van Nugteren et al., 2009). With temperature being a prime

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factor in organic matter mineralization (Crill and Martens, 1987; Thamdrup et al., 1998), benthic oxygen consumption is expected to peak several months after the spring bloom, at least in fine-grained sediments as permeable sediments may exhibit much higher organic matter turnover rates due to advective transport of oxygen and degradation products (Huettel and Rusch, 2000; Rauch et al., 2008). This mismatch between remineralization and phytoplankton nutrient demand has implications for the functioning of the pelagic compartment as it limits primary production and ultimately secondary production.

Oxygen demand is an often-used proxy for total mineralization, as it integrates microbial aerobic respiration, oxidation of reduced metabolites, and faunal respiration (Glud, 2008). Several studies have addressed benthic oxygen consumption in the southern North Sea (Fig. 1, Table 1), but few of these have captured the complete seasonal cycle in sufficient detail and in combination with water column variables, which are needed in order to study the coupling of the benthic and pelagic compartments.

This study analyzes a series of oxygen consumption measurements and chlorophyll-a measurements, both in the water column and in the sediment, from a well-studied station in the Belgian coastal zone. We address several questions: what is the extent of the time-lag between the input of organic matter and the inventory of very labile organic matter, as represented by chlorophyll-a, and remineralization of the bulk of the organic matter, as represented by oxygen demand? What is the relative importance of settling bloom material versus temperature in determining the seasonality of sediment oxygen demand? How important is the sediment column in this shallow system for the functioning of the pelagic compartment? To achieve this we use a simple pulse-response model, similar to those used by Sayles et al. (1994) and Soetaert and Herman (2009) to estimate carbon degradation rates in the deep sea, and a set of inverse modelling tools to derive organic carbon fluxes to the sediment, mineralization rates, and their dependency on temperature from the data. A Markov Chain Monte Carlo simulation is used to obtain uncertainty estimates for parameter values as well as model output.

2. Materials and methods

2.1. Sampling

From September 2002 until October 2003, the sediment and near-bottom water at station 115bis on the Belgian continental shelf were sampled monthly. This station is located at 51°09.10′ N 02°37.10′ E in an area known as the Western Coastal Banks, at a depth of approximately 15 m (Fig. 1). The sediment consists of fine sand with a median grain size of 180 μm and a silt content of 14%. The station is well studied in terms of macrofauna (van Oevelen et al., 2009), meiofauna (Franco et al., 2008), bacteria (Franco et al., 2007) and organic matter processing (van Oevelen et al., 2009; Franco et al., 2010). Macrobenthic biomass varies between 5.7 gC m^{-2} in February and 78 gC m^{-2} in October, and is dominated by surface deposit feeders and predators in February and filter feeders in April and October. The relatively high sedimentary chlorophyll concentrations, when compared to another station along the Belgian coast with similar hydrodynamic conditions but low in macrobenthic biomass, suggests that the macrofauna is an important mediator for transport of organic matter into the sediment at station 115bis (van Oevelen et al., 2009).

Sediment was collected with a 180 cm^2 Reineck box corer which in general did not penetrate deeper than 10 cm into the sediment. Three subcores with a diameter of 36 mm were taken from different box core samples, and sliced at 1 cm intervals for pigment analysis. Two 78.54 cm^2 subcores were taken for oxygen consumption measurements. Triplicate water samples were collected with

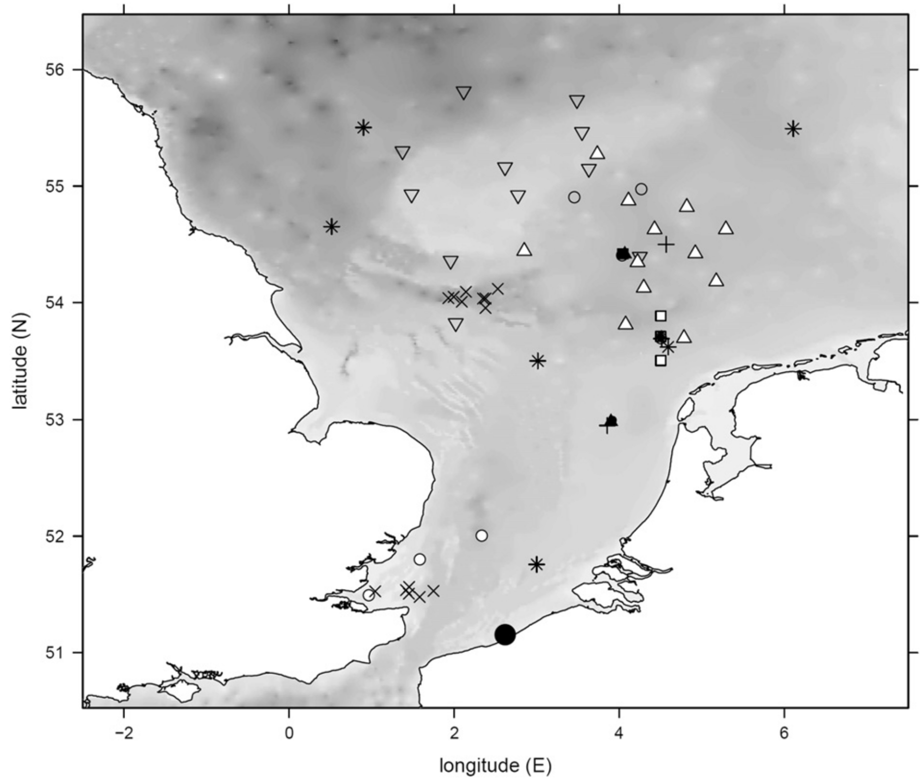

Fig. 1. : Benthic oxygen consumption measurements in the southern North Sea (Δ De Wilde et al., 1984), □ Cramer (1990), Van Raaphorst et al. (1990), ● Van Raaphorst et al. (1992) and van Duyl et al. (1992), * Upton et al. (1993), ■ Lohse et al. (1996), ▲ Osinga et al. (1996), + Boon and Duineveld (1998), white ○ Trimmer et al. (2000), × Trimmer et al. (2005), ○ Weston et al. (2008), ● Franco et al. (2010) and this study.