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Phytoplankton versus macrophyte contribution to primary production and biogeochemical cycles of a coastal mesotidal system. A modelling approach

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ABSTRACT

This study presents an assessment of the contributions of various primary producers to the global annual production and N/P cycles of a coastal system, namely the Arcachon Bay, by means of a numerical model. This 3D model fully couples hydrodynamic with ecological processes and simulates nitrogen, silicon and phosphorus cycles as well as phytoplankton, macroalgae and seagrasses. Total annual production rates for the different components were calculated for different years (2005, 2007 and 2009) during a time period of drastic reduction in seagrass beds since 2005. The total demand of nitrogen and phosphorus was also calculated and discussed with regards to the riverine inputs. Moreover, this study presents the first estimation of particulate organic carbon export to the adjacent open ocean.

The calculated annual net production for the Arcachon Bay (except microphytobenthos, not included in the model) ranges between 22,850 and 35,300 tons of carbon. The main producers are seagrasses in all the years considered with a contribution ranging from 56% to 81% of global production. According to our model, the −30% reduction in seagrass bed surface between 2005 and 2007, led to an approximate 55% reduction in seagrass production, while during the same period of time, macroalgae and phytoplankton enhanced their productions by about +83% and +46% respectively. Nonetheless, the phytoplankton production remains about eightfold higher than the macroalgae production. Our results also highlight the importance of remineralisation inside the Bay, since riverine inputs only fulfill at maximum 73% nitrogen and 13% phosphorus demands during the years 2005, 2007 and 2009. Calculated advection allowed a rough estimate of the organic matter export: about 10% of the total production in the bay was exported, originating mainly from the seagrass compartment, since most of the labile organic matter was remineralised inside the bay.

1. Introduction

The coastal zone, although representing less than 1% of the total oceanic surface, is characterized by high biodiversity and intense productivity (gross primary production ranges from 18 to 232 Mol C m^{-2} y^{-1}, according to Gattuso et al., 1998). In the shallowest areas, the primary producers are microalgae (phytoplankton, microphytobenthos), macroalgae (seaweeds) or marine phanerogams (seagrasses). These three compartments constitute the basis of coastal trophic chains although their growth kinetics, the quality of the organic matter they produce, and their impacts on biogeochemical cycling are very different. For instance, the effects of seagrass beds on early diagenesis in superficial sediments are important (Hemminga et al., 1994; Welsh et al., 2000; Jensen et al., 2005; Deborde et al., 2008) and this has an impact on the nutrient fluxes at the sediment–water interface, and consequently on the water column primary production as well. Moreover, the fate of seagrass detritus is different from that of macroalgae or phytoplankton. In fact, the perennial and slow growing seagrasses produce detritus rich in organic carbon and is of refractory quality. Seagrass detritus is much more inclined to be exported by currents over large distances, washed onshore or buried into the sediment.

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On the contrary, algal detritus is more likely to be decomposed inside the system, participating in internal nutrient regeneration (Enriquez et al., 1993).

The transition zone between land and ocean is firstly affected by variations in terrestrial inputs from natural and anthropogenic origins. Evidence of threats to coastal ecosystems by ongoing habitat degradation has been reported worldwide (Gray, 1997, and references therein). Seagrass meadows are suffering from a global decline (Waycott et al., 2009) that may lower primary productivity as well as net secondary production in the impacted ecosystems (Heck et al., 2008), enhance sediment erosion (Ganthy et al., 2014), cause change in biodiversity and in trophic structure (Duffy et al., 2005), and cause modification in the sediment redox status (Delgard et al., 2013). Thus, it seems worthwhile to study the biogeochemical cycles of a whole coastal system (lagoon, bay, estuary), including all types of primary producers, in order to understand its global functioning and give new insights to the prevailing changes. Nonetheless, as natural systems usually behave non-linearly due to complex interactions between biotic and abiotic processes, it is often arduous to extrapolate the processes recorded at small scales from the global functioning at regional scales. Cloern (2001) stresses the high level of variability of responses to nutrient changes that a coastal ecosystem exhibits. Ecosystem models, although aggregating ecological diversity into a small number of state variables (functional groups), can help in reproducing plausible patterns of biogeochemical cycles and in assessing the ecosystem responses to anthropogenic or natural changes (Lancelot et al., 2002; Zaldívar et al., 2009; Duarte et al., 2008; Azevedo et al., 2014).

The Arcachon Bay is a macro-tidal triangular-shaped lagoon (surface 174 km^2, mean depth 4.6 m, tidal amplitude ranges between 0.8 and 4.6 m), located in the south-east of the Bay of Biscay (Fig. 1). The tidal prism of the bay was estimated to be 384 million cubic meters for a mean tide and the flushing time of the bay ranges between 12.4 and 17.4 days (Plus et al., 2009). Fresh water inputs represent a mean annual volume of about 813 million cubic meters, with the main river – the Eyre – contributing to about 73% of total inflows. The two phanerogam species growing in the Bay – dwarf-grass (*Zostera noltei*) on tidal flats, and eelgrass (*Zostera marina*) on the channel edges – suffered a severe decline between 1988 and 2008 (Plus et al., 2010). According to this study, more than one third of the *Zostera* beds were lost within twenty years with a worsening effect from the year 2005 onwards, and the situation does not seem to have changed since that time (I. Auby, pers. comm.). The causes remain unclear even if several explanations with possible synergy are currently being investigated: heat waves during summers 2003 and 2006, pesticide contamination, direct physical damage due to clam harvesting activities and seagrass decline contributing to mud resuspension and thus reducing, like in a vicious circle, the available light for seagrass growth.

It is likely that an event of such a magnitude has caused changes in the biogeochemical status of the Arcachon Bay. The first indications of changes due to seagrass regression are for example the increase in ammonium concentration in the water column (Plus et al., 2010) as well as the impact on the local flows leading to modifications in sediment erosion and deposition rates (Kombiadou et al., 2014). Furthermore, a net release of ammonium as well as a drop in the reactive P stock in the sediments was found (Delgard et al., 2013). All these changes may consequently have impacted macrophyte, phytoplankton, and seagrass contributions to the total production and biogeochemical cycles of the Bay.

In this study, we propose a mathematical model coupling hydrodynamics with ecological processes, to be used as a tool to investigate the different pathways of organic matter production in the Arcachon Bay (phytoplankton, macroalgae and phanerogams), their impacts on biogeochemical cycles (nitrogen, phosphorus and silicon cycles) and the fate of the produced organic matter, in the context of drastic seagrass reduction. We also hope that the

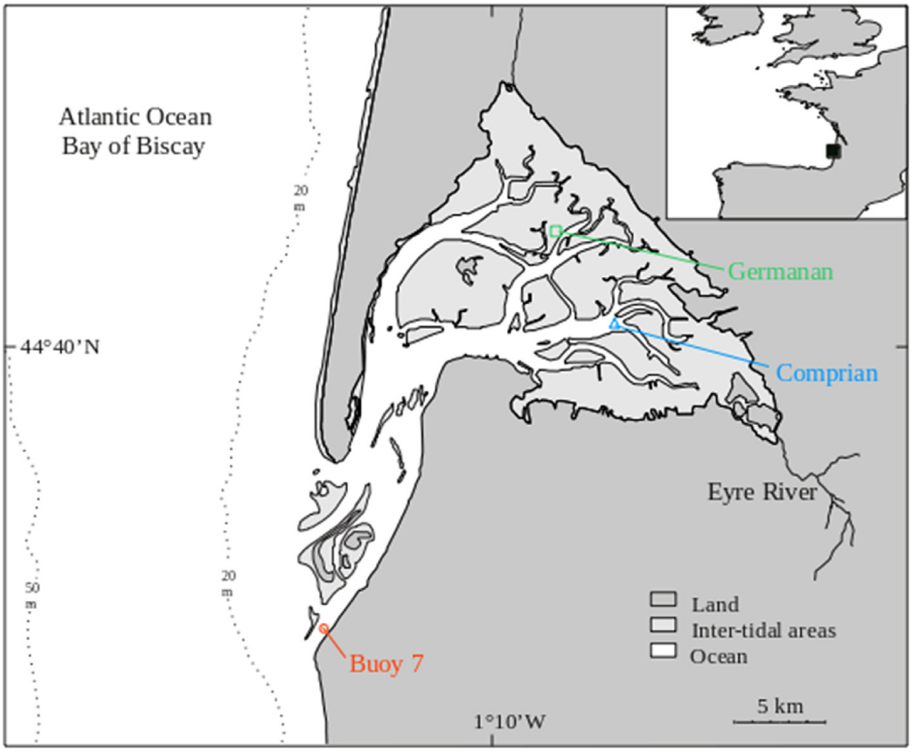

Fig. 1. The Arcachon Bay, general view and location of observation stations.