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A numerical study of the benthic–pelagic coupling in a shallow shelf sea (Gulf of Trieste)

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HIGHLIGHTS

- Benthic–pelagic coupling successfully simulated with BFM–POM 1D.
- Sensitivity experiments revealed best reference parameters.
- Mechanistic experiment highlighted the role of filter feeders in a shallow shelf sea.
- Results recognize BFM–POM 1D potential as a support to ecosystem management.

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ABSTRACT

A coupled physical–biogeochemical 1D model (BFM–POM 1D) with an intermediate complexity benthic formulation was used to carry out sensitivity tests on the coupling parameters (sedimentation and diffusion at the sediment–water interface). Moreover, a mechanistic experiment was designed to investigate the role of filter feeders in regulating the biogeochemical state of the system in a coastal sea. Best reference parameters of sedimentation and diffusion were chosen from the sensitivity experiments carried out based on available observations. The mechanistic experiment revealed the importance of filter feeders' role in trapping pelagic organic matter and regulating benthic–pelagic nutrient fluxes, as well as controlling pelagic primary production. The model demonstrated to be able to qualitatively reproduce the biogeochemical characteristics of the system and adapt to different trophic configurations. The results shown are encouraging and foresee its possible use as a tool to study causal relationships and help in finding solutions for management issues.

1. Introduction

Coastal waters are among the most productive ecosystems in the world (Marcus and Boero, 1998). Their exposure to anthropogenic pressures has led to important system changes and has triggered increasing interest and concern within the scientific community. Hence, a lot of effort is spent in studying and understanding regulating processes and system feedbacks to various conditions and pressures.

The processes connecting the pelagic and benthic realms define the so-called "benthic–pelagic coupling" (hereafter BPC). This term comprises the two-way exchange of matter (particulate and dissolved) physically and biologically mediated, between the bottom sediment and the overlying water column (Marcus and Boero, 1998; Raffaelli et al., 2003; Soetaert et al., 2000). Coastal environmental dynamics of shallow seas are greatly influenced by benthic biogeochemical processes (Burdige, 2011), as the intensity of the BPC mainly depends on water depth (Suess, 1980).

The processes defining the BPC dynamics related to organic matter and nutrients are schematized in Fig. 1. The physically mediated sediment–water exchanges contributing to structure the BPC entirely depend on the sinking and resuspension fluxes of particulate organic matter (POM) and on the diffusive oxygen, carbon dioxide and inorganic nutrients at the sediment–water interface. On the other hand, the biological process consists of the grazing of the "filter feeders" functional group on the sinking organic particles. Such group includes the non-moving benthic organisms feeding directly on the pelagic system by filtering the suspended particles (e.g. bivalve molluscs). The particle feeding complements the transfer of organic matter from the water column to the sediment operated by the sedimentary flux, thereby adding to the BPC processes a highly active component (Gili and Coma, 1998). Such process is sometimes defined as biodeposition (Haven and Morales-Alamo, 1966) and consists of the sequestration of

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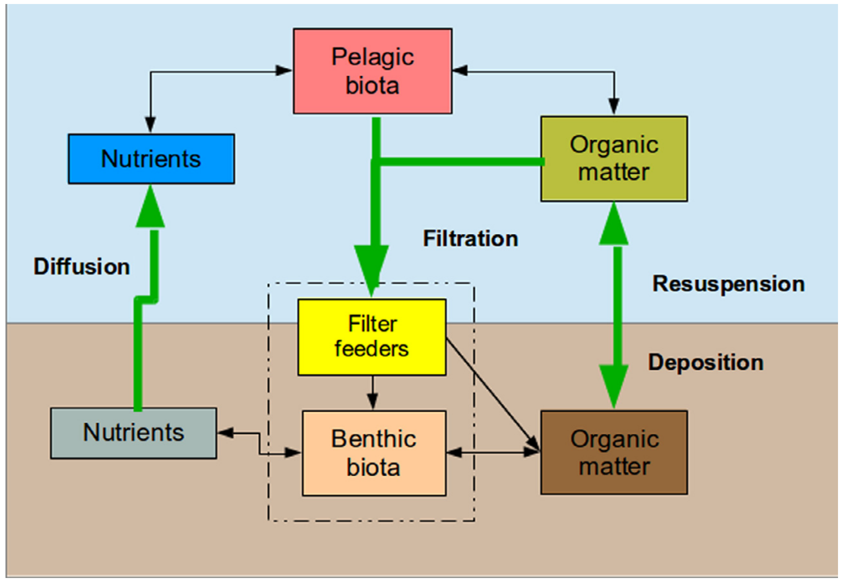

Fig. 1. A scheme representing the organic and inorganic matter related benthic–pelagic coupling. Green double-headed arrows represent the benthic–pelagic processes of diffusion, filtration, deposition and resuspension. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

organic matter from the pelagic system and its deposition into the benthic domain in the form of faeces and pseudo-faeces. Biodeposition has therefore a twofold and opposite impact on the pelagic dynamics: it removes living phytoplankton (Herman et al., 1999) and it contributes to the oxygen and nutrient pool via the bacterial organic matter recycling processes (Dame, 1993; Norkko et al., 2001), modulated by the diffusion at the benthic–pelagic interface. Such impact causes biodeposition to be considered as a possible process controlling eutrophication (Grall and Chauvaud, 2002; Officer et al., 1982) under given environmental conditions. Bacterial activity on the deposited organic matter causes the interstitial waters to be enriched in inorganic nutrients and carbon dioxide, and depleted in oxygen. The difference in concentration between interstitial waters and the overlying water column leads to an effective diffusive exchange back into the water column (Herndl et al., 1989) modulated by biological processes such as bioturbation, bioirrigation and particle reworking (Aller, 1988, 1994; Bertuzzi et al., 1997).

The strong interactions between pelagic primary production, benthic communities and detritus are thus crucial in defining the trophic conditions in coastal regions. Being relatively fixed in place and long lived, the benthos integrates environmental influences at a particular site over a relatively long timespan (Herman et al., 1999). This is important because the presence, spatial distribution and trophic structure of the fauna significantly influences the physical and chemical characteristics of the sediments and sediment–water exchange (Heip, 1995).

It is therefore essential to study the role of the benthos in coastal areas, especially those affected by problems such as eutrophication and bottom oxygen depletion (hypoxia/anoxia).

Numerical modelling allows to test specific hypotheses and to investigate the integrated effects of various factors under given assumptions (Henderson et al., 2001). Moreover, it can inform on the behaviour of the ecosystem as a whole (De Mora et al., 2016). With an appropriate validation against field data, this method may have a key role in developing a strategy for environmental management and sustainability. However, modelling the benthic system has always been a challenge within the scientific community due to the scarcity of information available (Capet et al., 2016). The reason for this is related to the difficulty of sampling the benthos, which is problematic and time consuming (Cardoso et al., 2010; Ebenhöh et al., 1995). Most biogeochemical models for water column processes either neglect the sediments or apply a rather crude approximation for the benthic response (Soetaert et al., 2000). In fact, models of pelagic and benthic biogeochemistry are typically not coupled or connected (Capet et al., 2016; Mussap et al., 2016).

As a continuation of a previous work with the pelagic model BFM–POM 1D implemented in the Gulf of Trieste (northern Adriatic Sea, Mussap et al., 2016), the implementation has been extended to include the benthic realm and the BPC, by coupling the pelagic model with a benthic model of intermediate complexity.

The aim of this paper is to establish and test the structure of the benthic compartment and its interactions with the water column. We aim to provide an understanding of the extent to which the benthic "biogeochemical machinery" determines the sediment–water fluxes. We start by investigating the sensitivity of the system with respect to deposition and diffusive fluxes, and subsequently we carry out a mechanistic experiment involving the removal of the filter feeders functional group in order to understand their role in the BPC.

2. Materials and methods

2.1. The model

The coupled numerical model used in its pelagic component is the Biogeochemical Flux Model (BFM, Vichi et al., 2007). In the model, the trophic and chemical interactions are represented through the concepts of chemical functional families (CFFs) and living functional groups (LFGs Vichi et al., 2007). With respect to the previous implementation form (Mussap et al., 2016), an additional phytoplankton LFG was added (the "large" phytoplankton, i.e. dinoflagellates). Such functional group is characterized by a low growth rate and low grazing pressure, and is known to develop in the Gulf of Trieste (Mozetic et al., 1998). The pelagic BFM is coupled "on-line" to the one-dimensional version of the Princeton Ocean Model (POM 1D, Blumberg and Mellor, 1987). A full description of the coupling between the two models can be found in Mussap et al. (2016). As in Mussap et al. (2016), the implementation of the hydrodynamical model is diagnostic, with prescribed climatological, time dependent (monthly varying) temperature and salinity vertical profiles (obtained from *in situ* data).