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Modelling ecosystem functions and properties at different time and spatial scales in shallow coastal lagoons: An application of the LOICZ biogeochemical model

Gianmarco Giordani [a,*], Martina Austoni [a], José M. Zaldívar [b], Dennis P. Swaney [c], Pierluigi Viaroli [a]

[a] Department of Environmental Sciences, University of Parma, Viale G.P. Usberti 33/A, I-43100 Parma, Italy
[b] Joint Research Centre, European Commission, Via Enrico Fermi 1, I-21020 Ispra, Varese, Italy
[c] Department of Ecology and Evolutionary Biology, Cornell University, Tower Road, Ithaca, NY 14853, USA

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Abstract

The Land-Ocean Interactions in the Coastal Zone (LOICZ) biogeochemical model (LBM) was applied at different temporal and spatial scales in 17 Italian lagoons of the LaguNet network (http://www.dsa.unipr.it/lagunet). A series of alternative assumptions taking into account benthic vegetation and sedimentary fluxes were introduced and compared with the classical LBM approach at various time scales. The reliability of the LBM application to the seventeen Italian lagoons was tested by comparison to a pool of shallow coastal systems from the global LOICZ database with comparable depths and sizes. The nutrient loads of the Italian sites can be considered relatively low, particularly for dissolved inorganic phosphorus (DIP). Although the median values of estimated internal transformations (source-sink) of both dissolved inorganic phosphorous and nitrogen at the LaguNet sites were comparable with the selected LOICZ sites, the positive and negative extreme values were one order of magnitude lower. Overall, the LBM applications to the Italian sites gave good quality budgets for shallow systems subjected to relatively low nutrient inputs and with a wide range of primary producer communities, including seagrass, macroalgae and phytoplankton. Furthermore, stoichiometry of Carbon:Nitrogen:Phosphorous for the different primary producer groups allowed the integration of previous studies by identifying a series of relationships between nutrient loads and ecosystem functions.

To some extent, the LBM application at monthly and seasonal time scales, as shown for the Sacca di Goro lagoon, can simulate the internal variability affected by the life cycle of the dominant primary producers. Therefore, the LBM not only allows the assessment of net ecological metabolism but seems, also, capable of representing the wide range of trophic conditions associated with shallow coastal systems. Overall, the application of alternative assumptions supports the robustness of the classical LBM, although some of the simplifications that enable the LBM to function in a wide range of systems and with incomplete data sets must be considered with caution for shallow environments.
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1. Introduction

In the last thirty years, anthropogenic inputs of nutrients to coastal zones have increased exponentially, up to three times (Smith et al., 2003). In parallel, eutrophication and hypoxia/anoxia events have occurred frequently in many coastal aquatic ecosystems and adjacent seas (EEA, 2001). The trophic status is affected not only by increased primary production and organic matter enrichment, but also by morphology, hydrodynamics and multiple stressors (Nixon, 1995; Cloern, 2001). Overall, it accounts for the net ecosystem metabolism (NEM), which results from the difference between primary

* Corresponding author.
E-mail address: giordani@nemo.unipr.it (G. Giordani).

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production and community respiration. Aquatic ecosystems, that consume organic matter derived from exogenous sources, can consume oxygen in excess of *in situ* production and thereby become heterotrophic (Duarte and Cebrian, 1996). Recent studies demonstrate that heterotrophy prevails in aquatic ecosystems, with an increasing impact also on gas emission to the atmosphere (Smith and Hollibaugh, 1993; Duarte and Prairie, 2005). The debate on whether coastal aquatic ecosystems are heterotrophic or autotrophic has often focused on the accumulated organic matter budget (Nixon, 1995) and Carbon:Nitrogen:Phosphorus (C:N:P) stoichiometry (Smith, 1993). Among the wealth of studies on this subject, the Land-Ocean Interactions in the Coastal Zone (LOICZ) project has developed a simple and effective modelling approach for estimating the NEM and biogeochemical functions of coastal aquatic systems (Gordon et al., 1996). More than 200 systems of the global coastal zone have been assessed so far (Buddemeier et al., 2002). A wider approach has recently been presented by Gazeau et al. (2004) and Crossland et al. (2005) relating the most relevant geomorphological, oceanographical and ecological attributes to the human dimension in the coastal zone.

This zone is a heterogeneous complex of systems which reacts in different ways to the delivery of material from watersheds, as well as to global changes (Crossland et al., 2005; Eisenreich, 2005). Among these, coastal lagoons are subjected to strong anthropogenic pressures, as they receive organic and mineral nutrients as well as being heavily exploited for aquaculture and tourism. The general availability of inorganic and organic nutrients and light supports primary production from species adapted to a wide range of geomorphological, physical and chemical conditions. A general model has been proposed considering pristine coastal lagoons as dominated by extensive meadows of seagrass species, which are assumed to take advantage of nutrient supply from sediment (Borum, 1996; Hemminga, 1998; De Wit et al., 2001). An increasing nutrient input is thought to favor, initially, phytoplankton and epiphytic microalgae, and later floating ephemeral macroalgae, cyanobacteria and/or picoplankton species. Moreover, macroalgal blooms have been recognised as one of the most catastrophic symptoms of community degeneration (Valiela et al., 1997). These changes have been particularly severe in the Mediterranean coastal lagoons, with summer events of anoxia and frequent dystrophy (Castel et al., 1996; Schramm and Nienhuis, 1996 and references therein).

Mediterranean coastal lagoons are generally shallow, microtidal or non-tidal. Due to the high sediment surface area to water volume ratios, processes occurring within the sediment and at the water-sediment interface strongly influence ecosystem metabolism and nutrient budgets (Castel et al., 1996). Hence, sediments play important regulatory function for the whole ecosystem, through their storage and transformation capacity for organic matter and nutrients.

The LOICZ biogeochemical model (LBM) is based on the mass balance of water and materials (Gordon et al., 1996; Smith et al., 2005). Water and salt are assumed not to undergo significant biogeochemical transformations within the system, whilst nutrients behave as non-conservative compounds due to biogeochemical processing within the system. Hence, salt budgets and known water inputs and outputs are used to estimate water exchange between the system and the adjacent sea. The mass balance of essential non-conservative nutrients, namely dissolved inorganic phosphorus (DIP) and nitrogen (DIN), allows estimates of rates of biological transformations and ecosystem processes, such as NEM – i.e., the difference between primary production and community respiration – and the net nitrogen budget, which is assumed to depend upon the difference in the nitrogen fixation and denitrification rates.

The water budget can be easily estimated with data of runoff (V_R), precipitation (V_P), groundwater (V_G), sewage or other inputs (V_O) and evaporative outflow (V_E). The compensating outflow or inflow that balances the water volume in the system is called residual flow (V_R). The seawater volume necessary to maintain salinity in the lagoon (mixing flow, V_X) can be estimated using the conservative salt budget. The salt budget is calculated by using the salinity difference between the lagoon and the adjacent sea.

DIP and DIN budgets are calculated from water budgets and concentration data. Deviations of budgets/concentrations (ΔDIP and ΔDIN) from predicted values are assumed to depend upon non-conservative processes or internal transformations, and basically represent the net difference between nutrient sources and sinks.

In the LBM, both NEM and the net nitrogen budget are calculated from ΔDIP and the molar C:N:P ratio of the reacting organic matter – generally that of the dominant primary producers, but other material (e.g. sewage) may be considered if judged to be significant. This assumes that ΔDIP depends only on biological transformations. The molar C:N:P ratios can be considered as the link among the cycles of these elements in the production and respiration processes, and deviations from the expectations based on these ratios can be quantitatively assigned to other processes. The net nitrogen budget is the difference between ΔDIN and ΔDIN expected from ΔDIP and C:N:P ratio and is considered as the difference between nitrogen fixation and denitrification (nfix-denit). Care is required in the interpretation of ΔDIP because it is affected by benthic fluxes and sorptive processes with suspended materials as well as biotic processes in the water column; these effects may be especially important in shallow water bodies. Moreover, the C:N:P stoichiometry and its effects on ecosystem processes varies greatly among primary producers (Hessen et al., 2004).

In this paper, the application and the reliability of the LBM are analyzed at different temporal and spatial scales. Firstly, the LBM is applied to the Sacca di Goro and other Italian lagoons following the standard procedure. Then, alternative assumptions, that account for benthic vegetation and sedimentary fluxes, are considered where enough information is available. In this way, the sensitivity of the basic LBM assumptions are evaluated and compared with alternative estimations. Finally, the LBM application is discussed thorough the inter-comparison of this set of Italian shallow coastal lagoons and within the context of the global LOICZ dataset.

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