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3D modeling of phytoplankton seasonal variation and nutrient budget in a southern Mediterranean Lagoon

Béchir Béjaoui [a], Cosimo Solidoro [b], Ali Harzallah [a], Cristèle Chevalier [c,d], Annie Chapelle [e], Noureddine Zaaboub [a], Lotfi Aleya [f,*]

[a] Institut National des Sciences et Technologie de la Mer - 28, rue 2 mars 1934 - Salammbô 2025. Laboratoire Milieu Marin, Tunisie
[b] Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – OGS, Borgo Grotta Gigante 42/c Sgonico, Italy
[c] Aix-Marseille Université, CNRS/INSU, IRD, Mediterranean Institute of Oceanography (MIO), UM 110, 13288 Marseille, France
[d] Université de Toulon, CNRS/INSU, IRD, Mediterranean Institute of Oceanography (MIO), UM 110, 83957 La Garde, France
[e] IFREMER DYneco/Pelagos Brest, BP 70, 29280 Plouzané, France
[f] Université de Bourgogne Franche-Comté, Laboratoire de Chrono-Environnement, UMR CNRS 6249, La Bouloie, F-25030 Besançon Cedex, France

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ABSTRACT

A 3D coupled physical-biogeochemical model is developed and applied to Bizerte Lagoon (Tunisia), in order to understand and quantitatively assess its hydrobiological functioning and nutrients budget. The biogeochemical module accounts for nitrogen and phosphorus and includes the water column and upper sediment layer. The simulations showed that water circulation and the seasonal patterns of nutrients, phytoplankton and dissolved oxygen were satisfactorily reproduced. Model results indicate that water circulation in the lagoon is driven mainly by tide and wind. Plankton primary production is co-limited by phosphorus and nitrogen, and is highest in the inner part of the lagoon, due to the combined effects of high water residence time and high nutrient inputs from the boundary. However, a sensitivity analysis highlights the importance of exchanges with the Mediterranean Sea in maintaining a high level of productivity. Intensive use of fertilizers in the catchment area has a significant effect on phytoplankton biomass increase.

1. Introduction

Coastal lagoons are complex systems, strongly influenced by continental and marine inputs which regulate the trophic network and biogeochemical cycles (e.g. Solidoro et al., 2005; Tett et al., 2013; Zaaboub et al., 2015). Located on the southern coast of the Mediterranean Sea, Bizerte Lagoon (Tunisia) is 1) a transitional environment as confirmed by studies on foraminiferal assemblages (Martins et al., 2015) 2), has been well known for decades throughout the country for its shellfish farming (mussels, oysters and clams) yielding an annual production > 100 tons for the developing Tunisian economy (Turki et al., 2014; Fertouna-Bellakhal et al., 2014) and, unfortunately, 3) subject to sporadic heat waves and eutrophication, which negatively impact bivalve production (Sahraoui et al., 2012; Béjaoui-Omri et al., 2014). The lagoon has been the subject of several studies addressing different biological compartments (Sakka Hlaili et al., 2006, 2008; Fertouna-Bellakhal et al., 2015, Zaaboub et al., 2014), sediment characterization (Zaaboub et al., 2015) and hydrodynamics (Harzallah, 2003; Béjaoui et al., 2008) which suggest that primary production in the lagoon results from highly dynamic exchanges between marine and continental inputs and the fluctuations of environmental factors. There also are a few data analysis studies, including those of Béjaoui et al. (2008), which focused on hydrobiological functioning of the lagoon using a multivariable approach and Grami et al. (2008), which used an inverse modeling technique to characterize the structure and functioning of the plankton food web in this lagoon. However, there still is a lack of, and a need for, dynamic modeling efforts able to produce reliable information on the coupling of hydrodynamic and biogeochemical properties of the lagoon. Such a model might help to reach a quantitative understanding of the functioning of the lagoon's ecosystem and to predict the effect of climatic conditions and anthropogenic intervention over time.

Biogeochemical models have been used to describe eutrophication since the seventies (Jorgensen et al., 1978) and have now evolved into spatially explicit, multi-nutrient, 3D coupled transport biogeochecmical models, able to describe multi-nutrient interaction and to support the identification and implementation of management policies (Melaku Canu et al., 2011), particularly in reference to eutrophication (Menesguen, 1992), nutrient load regulations, bivalve exploitation (Pastres et al., 2001) and more, also considering the expected climate change (Melaku Canu et al., 2010).

* Corresponding author.
E-mail address: lotfi.aleya@univ-fcomte.fr (L. Aleya).

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The aim of this study is to explore the space and time variability of major biogeochemical properties, to quantify the annual fluxes of matter among different ecosystem components and to compute a nutrient budget for the lagoon. Additional simulations were performed to assess the relative importance of river input versus exchanges with the Mediterranean Sea in defining the lagoon's trophodynamics.

2. Materials and methods

2.1. Study area

Bizerte Lagoon is a semi-enclosed body of water located on the northern coast of Tunisia, connected to the Mediterranean Sea through a 6-km long inlet. It covers an area of 128 km^2, has a mean depth of 7 m, and is also connected to Ichkeul Lake through the Tinja Channel which is approximately 5-km long and only a few meters in depth (Fig. 1). Several towns in the surrounding area are undergoing rapid population growth and industrial expansion. The ecosystem of this shallow lagoon is affected by various anthropogenic activities, including domestic effluents, industrial waste, atmospheric pollution and bivalve aquaculture (Béjaoui-Omri et al., 2014), as well as from important agricultural activities within its catchment area (480 km^2).

Water temperature in the lagoon follows a seasonal cycle, ranging from 10 °C in winter to 28 °C in summer (Harzallah, 2003). Salinity ranges from 30 in winter to 38 in summer (ANPE, 1990; Béjaoui et al., 2005). Nutrient concentrations and the phytoplankton biomass are relatively higher than in other Mediterranean Lagoons (Chapelle et al., 2000; Solidoro et al., 2005; Trabelsi et al., 2013), with chlorophyll peaks up to 8.0 mg m^{-3}. The residence time is remarkably high (Béjaoui and Sammari, 2012) with a water renewal time of about 250 days, triggering high microalgae blooms (Sahraoui et al., 2012; Turki et al., 2014; Zaaboub et al., 2014).

Few studies have addressed water mass circulation within the lagoon. Based on a visual depiction, Frisoni et al. (1986) reported a cyclonic circulation with convergence towards the lagoon center. A more recent study of water circulation, based on observations and numerical modeling, was undertaken by Béjaoui and Sammari (2012).

Important changes have occurred since the construction of dams in the catchment area of Ichkeul Lake and locks on the Tinja Channel. Reservoirs now discharge into Ichkeul Lake and exchanges between the lake and the lagoon are now controlled (MAERH, 2003), thus water input into the lagoon has decreased and salinity has risen.

2.2. Experimental data

Sampling campaigns were carried out in Bizerte Lagoon in 2012 (Béjaoui et al., 2016), with samples collected twice a week from a single sampling station (Fig. 1). The surface water samples were collected about 10–20 cm below the water surface using pre-cleaned sample bottles and then stored in sample containers in the dark.

The samples were laboratory analyzed for ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{3-}), Chlorophyll *a* (Chl *a*) and dissolved oxygen (O_2). Mineral elements were analyzed using an Auto-analyser (Tréguer and LeCorre, 1975). Chlorophyll *a* (Chl *a*) was determined using the spectrophotometric method of Lorenzen (1967) and following the procedure of Parsons et al. (1984) after 24 h, with extractions in 90% acetone carried out at −5 °C in the dark.

All nitrogenous and phosphorous fractions in sediment pore waters were analyzed after extraction into centrifugation tubes under N_2 atmosphere. Samples were centrifuged for 30 rpm at 3000 rpm; the supernatant pore water was filtered using Whatman membrane filters (pore size: 0.45 mm) and then analyzed by spectrophotometer (Zaaboub et al., 2014).

Two current meters were deployed inside the lagoon, a Mechanical Current Meter (MCM, 1500 kHz) and an Acoustic Doppler Current Profiler (ADCP, 500 kHz), as part of the Horizon 2020 study (Horizon 2020;, 2013). Technical characteristics of the current meters deployments are given in Table 1.

2.3. Model conception

The coupled hydrodynamic-biogeochemical model of Bizerte Lagoon (*MOHYB*) was developed for use in lagoon monitoring efforts. The code is written in Fortran 90 and describes biogeochemical dynamics in both the water column and the upper sediment layer. The

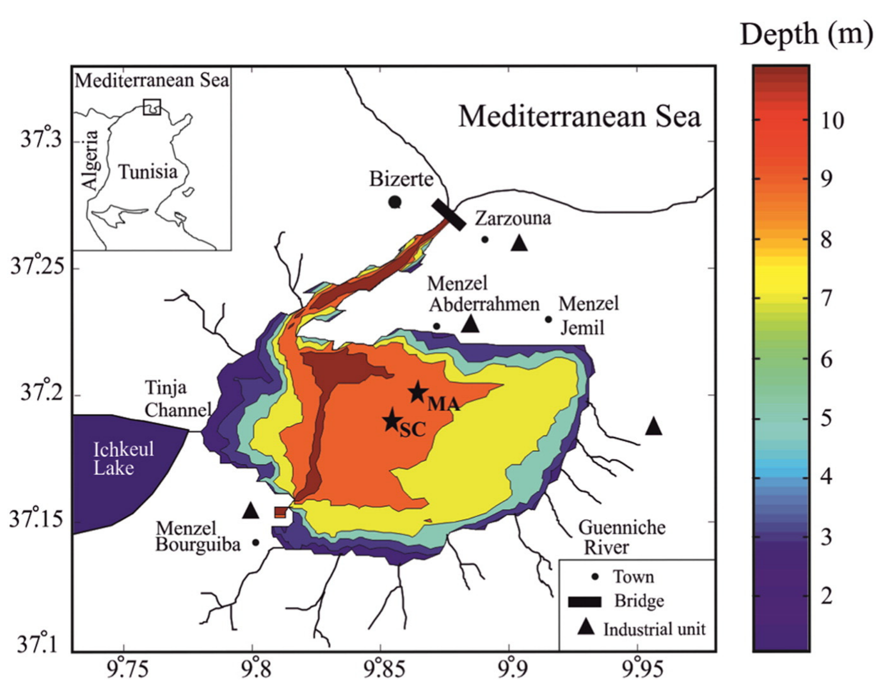

Fig. 1. Geographical location of Bizerte Lagoon. The main industrial units, rivers surrounding the lagoon and sampling stations are also shown. The MA sampling station, devoted to chemical and chlorophyll *a* measurements, is located facing Menzel Abderrahman town, whereas the SC sampling station, located in the lagoon center, is devoted to chemical analysis in sediment interstitial waters.