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Impact of the river nutrient load variability on the North Aegean ecosystem functioning over the last decades

K.P. Tsiaras [a,*], G. Petihakis [b], V.H. Kourafalou [c], G. Triantafyllou [a]

[a] Hellenic Centre for Marine Research, An avyssos, Greece
[b] Hellenic Centre for Marine Research, Heraklion, Greece
[c] Rosenstiel School of Marine and Atmospheric Science, Univ. of Miami, Miami, FL, USA

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ABSTRACT

The impact of river load variability on the North Aegean ecosystem functioning over the last decades (1980–2000) was investigated by means of a coupled hydrodynamic/biogeochemical model simulation. Model results were validated against available SeaWiFS Chl-a and in situ data. The simulated food web was found dominated by small cells, in agreement with observations, with most of the carbon channelled through the microbial loop. Diatoms and dinoflagellates presented a higher relative abundance in the more productive coastal areas. The increased phosphate river loads in the early 80s resulted in nitrogen and silicate deficiency in coastal, river-influenced regions. Primary production presented a decreasing trend for most areas. During periods of increased phosphate/nitrate inputs, silicate deficiency resulted in a relative decrease of diatoms, triggering an increase of dinoflagellates. Such an increase was simulated in the late 90s in the Thermaikos Gulf, in agreement with the observed increased occurrence of Harmful Algal Blooms. Microzooplankton was found to closely follow the relative increase of dinoflagellates under higher nutrient availability, showing a faster response than mesozooplankton. Sensitivity simulations with varying nutrient river inputs revealed a linear response of net primary production and plankton biomass. A stronger effect of river inputs was simulated in the enclosed Thermaikos Gulf, in terms of productivity and plankton composition, showing a significant increase of dinoflagellates relative abundance under increased nutrient loads.

1. Introduction

The North (N.) Aegean is a marginal Sea that connects the Eastern Mediterranean and Black Sea basins through the water exchange at the Dardanelles Strait. It receives a significant amount of low-salinity waters of Black Sea origin (BSW) that are enriched in particulate and dissolved organic matter (Polat and Tugrul, 1996; Sempere et al., 2002), triggering an increased primary and secondary production (Frangoulis et al., 2010; Siokou-Frangou et al., 2002). In terms of dissolved inorganic nutrients, BSW inputs are less important (Krom et al., 2004; Polat and Tugrul, 1996), while inputs from N. Aegean rivers (Tsiaras et al., 2012), which spread along its northern coast (Fig. 1), are particularly significant. To put the N. Aegean riverine nutrients in perspective, they amount to about half of those in the neighbouring Adriatic Sea, a much larger basin (see Table 8 in Ludwig et al., 2009). Therefore, although the Aegean Sea is characterised as an overall oligotrophic environment, the BSW and riverine inputs contribute to an increased biotic productivity of the N. Aegean, sustaining one of the most important fish stocks in the Eastern Mediterranean.

River inputs of nitrogen and phosphorus have shown a 3-fold increase in their global delivery to the ocean between 1970 and 1990 (Smith et al., 2003), due to anthropogenic activities, such as fertiliser use in the agriculture, urban and industrial waste waters. Ludwig et al. (2009) estimated a 5-fold increase in the nitrogen and phosphorus river inputs for the Mediterranean basin since 1960. Phosphorous (P) loads declined in the 90s, due to the upgrade of urban waste treatment and the banishment of P-containing detergents. Eutrophication problems in river-influenced coastal systems are often related to increased river loads of nitrogen and phosphorus, in excess over dissolved silica (Billen and Garnier, 2007; Cloern, 2001), as compared to the requirements of diatoms. In silicate limiting conditions, coastal ecosystems may be progressively dominated by non-siliceous phytoplankton taxa, such as flagellates/dinoflagellates, which are often associated with Harmful Algal Blooms (HABs). Such shifts in the phytoplankton community composition have been documented in several coastal areas, such as in the German Bight (Radach, 1992) and the North-western Black Sea (Moncheva and Krastev, 1997). The Thermaikos Gulf (Fig. 1) has also been known to suffer from the occurrence of HABs (Moncheva et al., 2001; SoHelME, 2005). Therefore, although the Aegean is probably not susceptible to severe eutrophication problems, given its oligotrophic status, increased river inputs may have a significant impact on the ecosystem functioning of the coastal areas.

* Corresponding author.
E-mail address: ktsiaras@hcmr.gr (K.P. Tsiaras).

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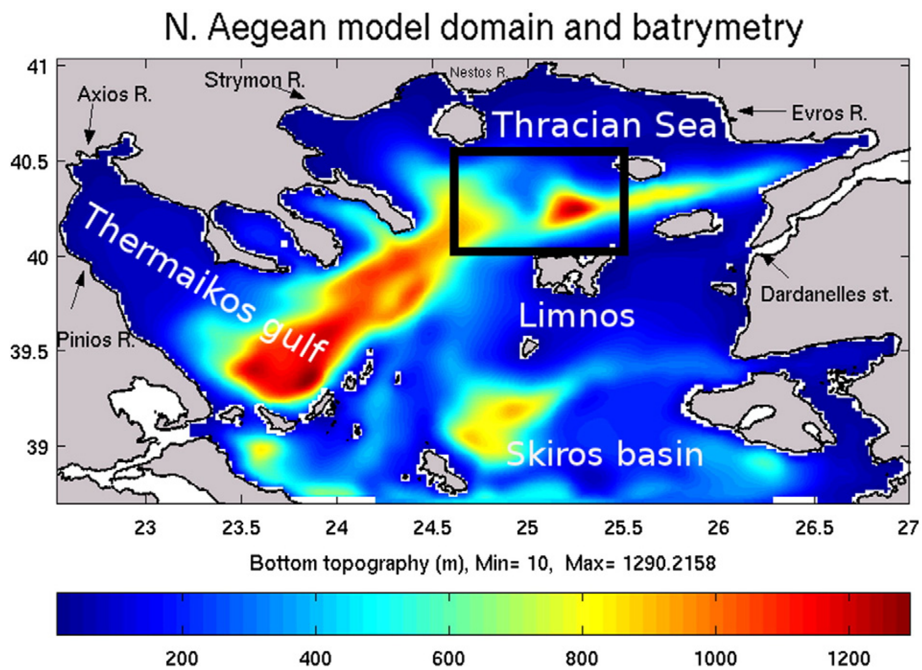

Fig. 1. Map of the study area. N. Aegean model domain and bathymetry. Major N. Aegean Rivers and the Dardanelles Strait are indicated. The area where model results are compared with in situ data of MATER project (Siokou-Frangou et al., 2002) is indicated by the black box.

The increase of productivity in coastal waters due to eutrophication has also been considered as a factor contributing to the significant increase of the fish catches in Hellenic waters in the 80s and early 90s. Another factor is the modernisation of the fishing fleet (SoHelME, 2005). In particular, small pelagics, such as anchovy and sardine that represent more than 60% of the total catch in the Aegean, strongly depend on plankton productivity (Palomera et al., 2007).

Tsiaras et al. (2012) employed a comprehensive, coupled hydrodynamic/biogeochemical model to investigate the impact of air–sea interaction and thermohaline circulation changes on the N. Aegean productivity, with emphasis on open-sea processes. They found that river inputs are a significant component of the N. Aegean nutrient budget, playing a major role in its productivity. Data supporting the long-term variability of N. Aegean river nutrient inputs were not available until recently, in the absence of river water discharge regular monitoring. Ludwig et al. (2009) reconstructed the variability of river inputs in the Mediterranean, based on existing data and hydrological modelling. These reconstructed time series on river discharges for major N. Aegean rivers, in tandem with available nutrients concentrations (Skoulikidis, 2009), allowed us to perform the long-term simulation described in Section 2. In Section 3, the model results are discussed, with emphasis on the impact of river load variability on the N. Aegean ecosystem functioning over the last decades.

2. Methods

A long-term simulation over the 1980–2000 period was performed using the coupled hydrodynamic/biogeochemical model by Tsiaras et al. (2012). The hydrodynamic model is based on the Princeton Ocean Model (Blumberg and Mellor, 1983), a widely spread community model that has been previously implemented in the N. Aegean area (Kourafalou and Barbopoulos, 2003; Kourafalou and Tsiaras, 2007; Tzali et al., 2010). The biogeochemical model is based on the European Regional Seas Ecosystem Model (ERSEM, Baretta et al., 1995), a generic comprehensive model that has been successfully implemented across a wide range of coastal and open ocean ecosystems, such as the North Sea continental shelf (Pätsch and Radach, 1997), the oligotrophic Mediterranean (Allen et al., 2002; Petihakis et al., 2002) and the Arabian Sea (Blackford and Burkill, 2002), among others. The present configuration of the biogeochemical component has been adopted from Petihakis et al. (2002), where a detailed model description is given. Important attributes are as follows.

ERSEM uses a “functional” group approach to describe the ecosystem, where the biota are grouped according to their trophic level (subdivided according to size classes or feeding methods). The pelagic model food web that has been slightly modified from the standard configuration in order to represent the Eastern Mediterranean system, consists of 4 phytoplankton groups: diatoms (20–200 μm, silicate consumers), nanoplankton (2–20 μm), picoplankton(<2 μm) and dinoflagellates (20–200 μm), bacteria and 3 zooplankton groups: heterotrophic nanoflagellates (feeding on bacteria, picophytoplankton and nanophytoplankton), microzooplankton (feeding on nanophytoplankton, heterotrophic nanoflagellates, diatoms and dinoflagellates) and mesozooplankton (feeding on diatoms, dinoflagellates, microzooplankton and heterotrophic nanoflagellates). The pelagic model variables also include particulate and dissolved organic matter (produced by the mortality, excretion and lysis of primary and secondary producers and utilised by bacteria), along with dissolved inorganic nutrients (nitrate, ammonia, phosphate, silicate). Carbon dynamics are coupled to chemical dynamics of nitrogen, phosphate and silicate, as each group has dynamically varying C/N/P ratios. The uptake of dissolved inorganic nitrogen and phosphorus by phytoplankton is regulated based on the difference between internal and external nutrient pools, following a Droop kinetics formulation (Droop, 1974) to describe nutrient limitation, allowing for luxury uptake. Since there is no internal storage of silicate, the growth of diatoms is further regulated by a Michaelis–Menten function of the external availability of dissolved silica. The most important changes in the parameter set, adopted from Petihakis et al. (2002) are shown in Table 1. These include an update of the food web matrix that describes the relative preferences for each consumer, based on the current expert knowledge of the N. Aegean ecosystem (Frangoulis et al., 2010; Isari et al., 2007; Siokou-Frangou et al., 2002).

The atmospheric forcing for the long-term simulation is based on the ECMWF ERA40 reanalysis dataset, downscaled to 0.5° resolution (Herrmann and Somot, 2008). The Dardanelles water exchange is parameterized through a two-layer open boundary condition (Nittis et al., 2006) with prescribed water inflow/outflow and salinity, adopting climatological biogeochemical (inorganic nutrients and non-living