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Ecosystem modelling: Towards the development of a management tool for a marine coastal system part-II, ecosystem processes and biogeochemical fluxes

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ABSTRACT

Pagasitikos gulf is a semi-enclosed basin highly influenced both by anthropogenic activities (inflow of nutrients at the north and west parts) as well as by water exchange between the gulf and the Aegean Sea at its south part (Trikeri channel) resulting in the development of functional sub-areas within the gulf. Thus the inner part is characterised by eutrophic conditions with sporadic formation of harmful algal blooms whilst the central part acts as a buffer with mesotrophic characteristics influenced by the outer area. In a companion paper, the circulation fields and the development of water masses in the Pagasitikos gulf were explored. The aim of this study is to investigate the interactions between the physical and biogeochemical systems in the Pagasitikos gulf by coupling advanced hydrodynamic and ecological models. The simulation system comprises two on-line coupled sub-models: a three-dimensional hydrodynamic model based on the Princeton Ocean Model (POM) and an ecological model adapted from the European Regional Seas Ecosystem Model (ERSEM) for this specific ecosystem. After a model spin up period of 10 years, the results from an annual simulation are presented. Emphasis is given to the description of the spatial and temporal variability of the ecosystem parameters as well as to the relationship between physical forcing and the evolution of the ecosystem along with other factors affecting the nutrient cycling and primary production. A cost function is used for the validation of model results with field data. Simulation results are in good agreement with in-situ data illustrating the role of the physical processes in determining the evolution and variability of the ecosystem, as well as highlighting the potential usefulness of the model as an operational tool to support environmental management decisions.

1. Introduction

Pagasitikos is a rather sensitive ecosystem due to its semi-enclosed nature and shallow depths (Fig. 1). Human activity in the coastal areas is more or less confined to traditional agricultural farming, the major occupation. However over the last years there has been a shift towards intensive production of cereal and cotton with the use of large quantities of fertilisers rich in nitrogen, phosphate and sulphur. A significant proportion of these chemicals find their way into the marine ecosystem carried by rain waters through a network of periodic small torrents. The only major city, Volos, at the north part of the gulf, has a population of 120,000 inhabitants and a well-developed industrial sector. The first heavy industries, built during the 60's, attracted workers from the surrounding areas, which gradually led to a population explosion. The fast growth of the area in conjunction with a lack of the necessary infrastructure was the source of critical problems in the gulf, which became the main recipient of rural and industrial effluents. Although a domestic sewage treatment plant for domestic effluents had been planned as early as 1964, it took 23 years to become operational.

An extreme perturbation event occurred in the early 60's during the draining of Lake Karla when large quantities of nutrient-enriched waters were channelled into Pagasitikos via a duct at the north of the gulf. Thus after a couple of years when most of the previous lake had dried up, the area was given over to an intensive cultivation programme. However the Pagasitikos system continued to be affected particularly during winter, when rainwater flushes out soils rich in fertilisers, pesticides and particulate material. Significant proportions of these runoff waters flow into the gulf.

During 1982 dense mucilage composed of phytoplankton cells, bacteria, zooplankton excretions and detritus covered large areas in the north part of the gulf causing serious problems both to the fishing community and to tourism. This phenomenon was greatly reduced both in scale and duration in the following years, but returned with greater severity in 1987, the worst year ever recorded. Although the exact causes remain unknown, it has been suggested that the nutrient inputs in conjunction with the shallow depths of the north part of the gulf and the high summer water temperatures are the responsible

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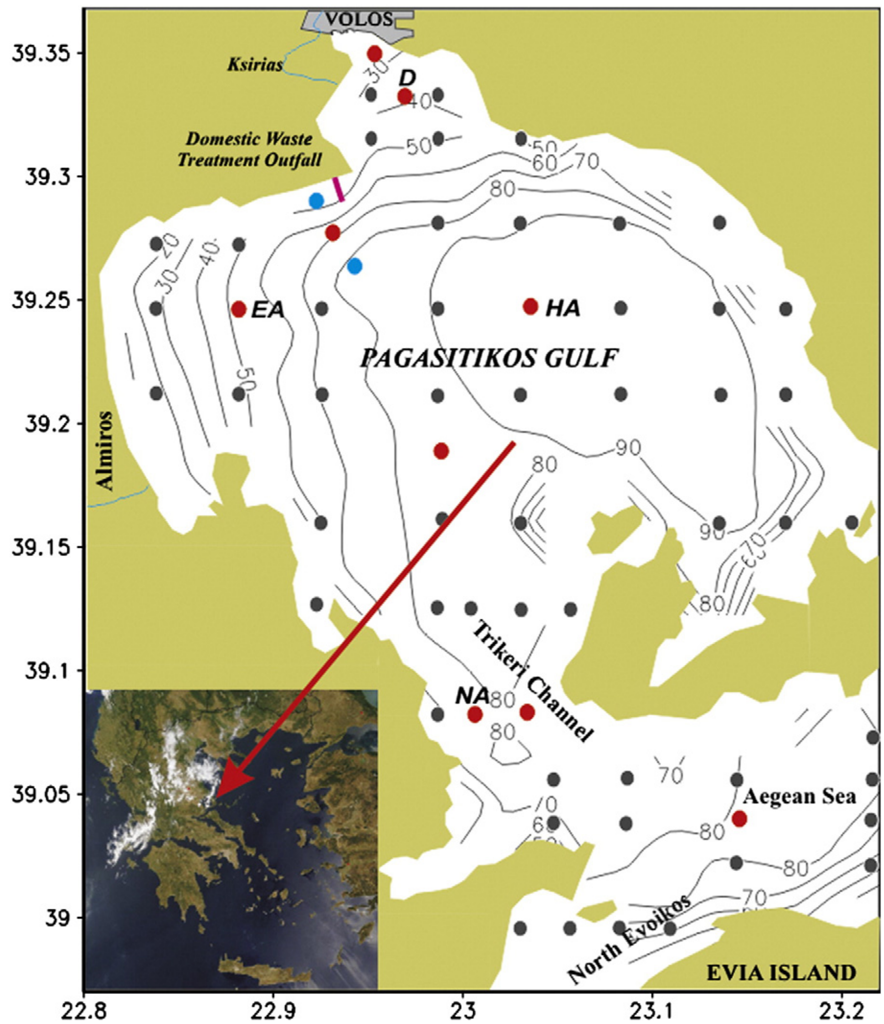

Fig. 1. Map of Pagasitikos gulf with bathymetry (m), sampling stations (● physical parameters, ● plus water nutrients, ● plus water nutrients and biotic parameters) and stations used in cost-function (D, EA, HA, NA).

factors (Friligos, 1987). Although natural systems seem able to withstand certain nutrient inputs, for a given food web structure there is a certain critical level of nutrient supply where the likelihood of uncontrolled blooms increases abruptly and in a non-linear way (Ingrid et al., 1996). Scientific efforts to learn about and explore the underlying mechanisms and find possible solutions to this phenomenon have now been set up. Thus during 1998–1999 an interdisciplinary project took place under the supervision of the Magnisia Prefecture aiming towards the *Development of an Integrated Policy for the Sustainable Management of Pagasitikos Gulf* (Theodorou and Petihakis, 2000).

Having identified this particular need, and taking the opportunity of the collected dataset, an ecosystem model was developed, parameterised, tuned and validated for Pagasitikos gulf. Coupled physical–biological models have quite a long history in oceanography, starting as early as 1942 with the model of Riley (1942)). Since then aquatic ecological models have shown rapid growth dictated mainly by the need for environmental management of lakes and rivers (Jorgensen, 1997). As in-depth knowledge on the system was acquired, models became increasingly complex taking advantage of the rapid development of computers, and gradually replacing simple models which were limited to specific scientific questions. The complexity of ecology is its most interesting aspect since a large number of species interact with biotic and abiotic factors, with spatial and temporal variation, often in an unpredictable manner. The complete food web along with associated physical, chemical and biological processes cannot be modelled; however, complex models can represent a close approximation of observed and measured actual conditions. The degree of idealisation achieved by isolating parts of the food chain, truncating upper and/or lower trophic levels by effective parameterisations, and simplification of controlling physics depends on the problem at hand (Fennel and Osborn, 2005). Considering that there are gains and losses in the choice of simple vs complex models, one property of any model must be its ability to describe the changes in a system with a varying degree of accuracy and generality. Although it is accepted that accurate models are better, the degree of acceptable accuracy remains an open issue amongst the scientific community.

Quite often it is preferable to set up a 1D model prior to a fully coupled 3D application as the latter requires very powerful machines able to execute simulations at reasonable time intervals. Thus a 1D version was initially applied in Pagasitikos focusing on different parts of the gulf, each one representing a sub-system with similar characteristics (Petihakis et al., 2000; Petihakis et al., 2005; Triantafyllou et al., 2001). The aim of the present study is to investigate the interactions between the physical and biogeochemical systems in the Pagasitikos gulf by coupling 3D hydrodynamic and ecological models. Apart from the scientific interest (this being the first time that a fully 3D model has been applied in Pagasitikos), such a tool can provide important knowledge necessary to every successful management policy. This work is linked to the work presented in a companion paper, where the circulation fields and the development of water masses in the Pagasitikos gulf were explored, hereafter referred to as part I (Petihakis et al., 2012a–this issue).