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A Tool for Ecosystem-Based Management Applied to Pagasitikos Gulf

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Abstract

Considering the importance of the marine environment, in this work first effort towards a Marine Management Tool are described and presented. Taking advantage of an extensive *in situ* program during 1998–1999 a highly complex biogeochemical model was customised and applied in Pagasitikos gulf delivering for the first time valuable information on the ecosystem governing processes. Furthermore, through appropriate scenarios the dynamics behind the formation of mucilaginous events were examined, revealing the underlying dynamics. In the same framework the impact of two fish farms was evaluated illustrating the significance of inputs in the functioning of this sensitive ecosystem. Considering the importance of fisheries, the marine traffic in the area and the associated risk of an accident, future developments include a) an Individual Bioenergetics Model (IBM) that describes the full life of the cycle of the European anchovy (Engraulis encrasicolus) and b) the development of a pollutant transport module capable of simulating the evolution of an oil spill.

Keywords: Management tool; Modelling; Pagasitikos

Introduction

The marine environment in the of apart from its role in the climate and ecosystem stability, it contributes significantly in the economic development supporting a large number of social and economic activities which to a large extent define the living standards. Both Pagasitikos gulf and the area of N. Sporades are unique systems in Greece, while the national park of Alonisos is the first and bigger (~2,220 km^2) marine protected area in Greece hosting the largest population of the monk seal (Monachus monachus).

Although the ribbon development around Pagasitikos is not considered significant, at the north part of the gulf is situated the city of Volos with a population of 120,000 and major industrial production. The development started during the 60’s characterized by population explosion, industrialization and intensive agriculture affecting the littoral and sub-littoral systems, which received considerable quantities of rural, industrial and agricultural effluents. Although a sewage treatment plant for the domestic effluents was planned as early as 1964 it took 23 years for it to become operational. Another important event was the draining of Lake Karla in the early 60’s via an aqua duct in the north part of Pagasitikos when large quantities of nutrient enriched waters were poured into the system. Although the lake is dried up, winter rains wash the soil in the wider area of Karla basin, becoming enriched with fertilizers, pesticides and particulate material a proportion of which finally reaches Pagasitikos. In addition large quantities of fertilizers rich in nitrogen, phosphate and sulphur are used annually in the scattered farmlands along the coastline where intensive agriculture of cereals and cotton is practised. Although there are no major rivers in the wider area, it is believed that a significant proportion of these nutrients enter the system during winter through a network of small torrents.

The first attempt to study the system of Pagasitikos goes back in 1975 while the sporadic appearance of mucilaginous events during summer further triggered a number of short field studies [1-8]. The first extended experimental program took place during 1998–1999 [9] adopting a holistic approach, where apart from the measurement of the important variables and key ecosystem processes, a significant effort was directed towards the modelling of the system. With the basic knowledge acquired and the models built the next steps where to a large extent defined. In this work the tools developed for Pagasitikos gulf are presented and future steps are discussed.

The Model

The model applied in Pagasitikos gulf, (Figure 1) consists of two, highly portable, on-line coupled, sub-models: the three-dimensional Princeton Ocean Model (POM) [10] and the ecological model based on the European Regional Seas Ecosystem Model (ERSEM) [11]. The physical model describes the hydrodynamics of the area and provides the background physical information to the ecological model. The ecosystem model uses a 'functional' group approach where organisms are separated into groups according to their trophic level and subdivided to similar size classes and feeding methods. The dynamics between the functional groups include physiological (ingestion, respiration, excretion, egestion, etc.) and population processes (growth, migration and mortality) which are described by fluxes of carbon and nutrients. The physical processes affecting the biological constituents are advection and dispersion in the horizontal, and sedimentation and dispersion in the vertical, with the horizontal processes operating on scales of tens of kilometres and the vertical processes on tens of meters [11]. The food web (Figure 1) is divided into three main groups, the producers the decomposers and the consumers each of which may be defined as having a standard set of processes. The first group includes the phytoplankton, which is further divided to functional groups based on size and ecological properties. These are diatoms P1 (silicate consumers, 20-200 μ),

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nanophytoplankton P2 (2-20 μ), picophytoplankton P3 (<2 μ) and dinoflagellates P4 (>20 μ).

Materials and Methods

The computational domain for Pagasitikos gulf model covers the area between 22.8125°E to 23.3025°E and 39.0°N to 39.43°N. It uses a Cartesian coordinate system consisting of 49×45 grid points with a horizontal grid resolution of 0.01° deg both in latitude and longitude. In the vertical there are 25 layers of variable thickness with logarithmic distribution near the surface and the bottom for greater accuracy where velocity gradients are larger.

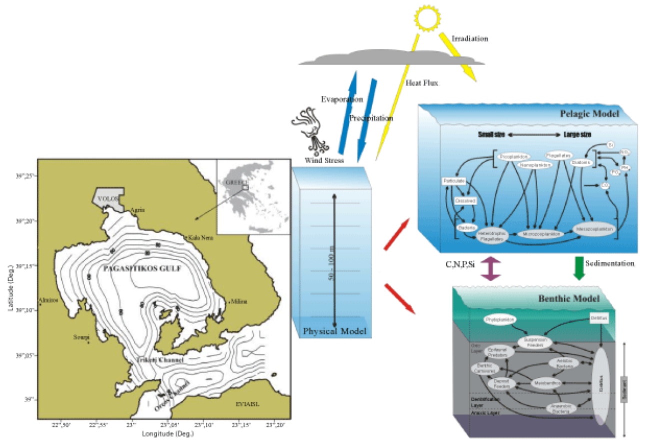

Figure 1: Pagasitikos Gulf and Modeled food web.

For the model's bathymetry direct measurements and naval charts were used. The model's climatological run was initialized with spring field hydrological data acquired during the research project "Development of an Integrated Policy for the Sustainable Management of Pagasitikos Gulf" [9], while, initial velocities were set to zero. The model was integrated using a 'perpetual year' forcing atmospheric data set. This data set was derived from the 1979–1993 6-hour European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis data (horizontal resolution 1°×1°) by proper averaging in time to get the monthly mean values [12].

In an attempt to use the model to evaluate the impact of the two fish farms operating inside Pagasitikos an appropriate scheme was built into the model. Thus at the corresponding grid points an input flux at the surface layer was imposed with the appropriate adjustment in terms of inputs per unit area as described in the following sections. Input of nitrogen and phosphorus supplied in fish feed is used to calculate the amount harvested as fish, excreted in dissolved form (Urea, NH_4, PO_4) and excreted in particulate form (uneaten feed, faeces). Various measurements have shown that the largest portion of nitrogen supplied is excreted in the dissolved form as Urea (41%) and ammonium (26%), while phosphates losses account for 22% of phosphorus supplied. Conversely particulates released consist mainly of organic phosphorus accounting for 44% of phosphorus supplied whereas particulate nitrogen losses account for 10% of the nitrogen supplied. It is also estimated that approximately 5% of feed is settling uneaten, either being consumed by wild fish or contributing to the organic load of the underlying sediment. Based on the above mentioned mass balance model, weekly loads of ammonium (aggregated with urea), phosphate, particulate organic nitrogen and phosphorus have been calculated and converted into model units (mmol/s).

Results-Discussion

Model simulations

From the simulation of Pagasitikos ecosystem becomes evident the necessity of a 3D complex ecosystem model, since the regional variation of the ecosystem parameters is a consequence of the circulation patterns and the thermocline development. The role of the stratification is very important, as the water column is divided into two layers for an extended time period, separating the coastal shallow areas from the central deep areas. This in conjunction with the almost permanent anticyclonic gyre at the central-east part of the gulf creates a deposition zone where the by-products of the benthic biologic activity remain trapped, impoverishing the photic zone. The coastal areas exhibit characteristics of a mesotrophic system with elevated chlorophyll concentrations and increased production rates. The shallow depth in conjunction with the dominant big phytoplanktonic cells results in the fast sedimentation and subsequent biodegradation of organic matter by benthic organisms, while the released nutrients are rapidly consumed by primary producers and bacteria in the carbon fixation process. On the opposite, the central gulf area is characterised by small phytoplankton cells with bacteria playing a significant role in the recycling of nutrients. During stratification periods bacteria strongly compete with phytoplankton for nutrients, while when the water column is mixed during winter, nutrients are transported into the euphotic zone, triggering primary production. It is during this period that organic matter is passed to higher trophic layers and not recycled only inside the microbial food web.

The significant variability of primary productivity as produced by the model indicates that opposite to the conclusion of Pancucci-Papadopoulou and Christaki [13] the ecosystem of Pagasitikos gulf although it exhibits oligotrophic characteristics there are clear tendencies towards eutrophic conditions according to the season. Thus high production rates are simulated in the central–external area in winter, and even though production is ultimately restrained by the low light and temperature conditions, this does not apply in the coastal areas where increased rates are produced in spring and summer. The elevated temperatures, the adequate light conditions and the shallow depth in conjunction with the high production rates can cause significant phytoplanktonic blooms. If one consider that most of the coastal zone receives significant quantities of enriched waters, the origin of the harmful algal blooms observed in the past becomes rather clear. Thus the coastal system can be characterized as particularly sensitive to nutrient enrichment.

Input simulations

The simulations of the ecosystem of Pagasitikos indicate that nutrient inputs at the north shallow parts close to the city of result in a more stable ecosystem with small monthly variations among the various parameters due to the existence of sufficient amounts of nutrients and adequate light to support primary production throughout the year. Even with rather small nutrient inputs the ecosystem of Pagasitikos responds with a significant increase in the primary production with diatoms playing a major role. Although the effect of the enrichment is mostly localized close to the area of inputs

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(internal Pagasitikos) the whole system responds with a shift to a more classical food chain.

Without nutrient inputs the pelagic system of the central–external part of the gulf is dominated by a microbial loop characterized by the competition for nutrients between bacteria and phytoplankton with a higher heterotrophic to autotrophic biomass. Enrichment develops a more productive system with high autotrophic biomass passing more energy to higher trophic levels. The approximately 400 gC/m^2/yr of net primary production produced at the north part due to nutrient inputs can result in serious eutrophic conditions with the development of intense algal growth.

Fish farm simulations

The seasonal variability of phosphorus and nitrogen inputs displays a significant difference between cold and warm months especially in the dissolved inorganic fraction. During winter months when water temperature drops, fish growth ceases and thus feed supply is reduced to levels required to only retain the acquired biomass. As water temperature rises, fish metabolism increases and farmers respond with more feed supplied, reaching maximum levels towards the end of August. This is of particular importance in terms of ecosystem functioning as the nutrient flux from the fish farms follows the variability of water temperature and photosynthetic active radiation creating favourable conditions for primary producers.

The different characteristics of the farms offered a great opportunity not only to test the model in a range of conditions but most importantly to examine the role of coastal geomorphology in this particular activity. In the open conditions of Almyros the inputs of the farm are quickly transported to other areas significantly influencing the northwestern part of the gulf, which is a rather sensitive area (Figure 2). This outcome becomes particularly important if it is linked with the observed mucilaginous blooms. In such conditions any monitoring program focusing on the nutrient and chlorophyll concentrations in the area around the farm will give an elusive picture. On the other hand in the enclosed and protected area of Trikeri cove the farm effect is very prominent with a significant increase not only in nutrients but also on all biotic biomasses. Although this isolation is a dominant feature there are cases when adjacent areas are also affected such as the central part of the gulf. In contrast with Almyros an impact assessment study focusing only in Trikeri would probably produce a very alarming outcome for the wider area. Even with an alternative scenario, with fish production being reduced to half, the farm effect at Trikeri is more significant at least at local level compared to Almyros.

Conclusions

It is often suggested the numerical models might be applied directly on environmental management issues, as forecasting tools for the response of the natural system under perturbations. The model should be used for the exploitation of the response into reasonable changes in parameters or processes that are included in the structure. Thus the only way to investigate the effects in the ecosystem such as Pagasitikos from enrichment is through the use of a simulation model, since the complexity of the natural systems makes impossible any other approach. Of course in order to forecast the evolution of the ecosystem after disturbance (e.g. inputs of enriched waters), a monitoring system should be established providing frequent detailed information on the major ecosystem variables. A future operational forecasting system should be the future goal.

Having laid the basis through past work it is mature to move to the next step towards a holistic and integrated management tool for the marine environment of Thessaly. To do so two components must be developed and incorporated in the current structure:

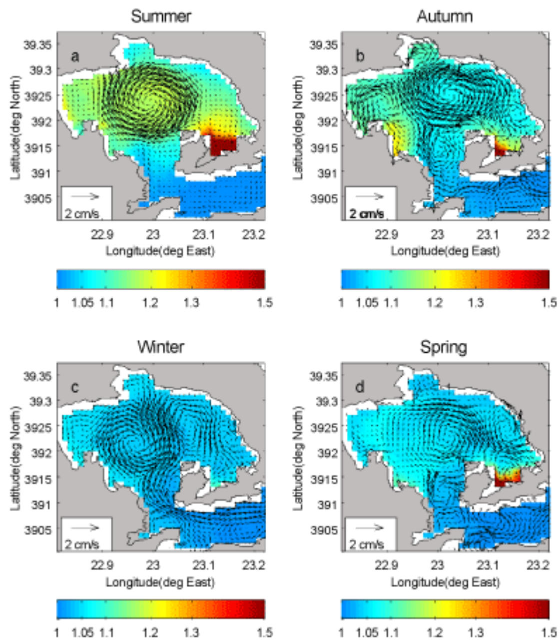

Figure 2: Simulated seasonal surface phytoplankton biomass and current velocity (cm/s), a) summer, b) autumn, c) winter and d) spring. Ratio of Scenario A/Reference run. Values >1 indicate increase due to the fishfarm.

Oil spill simulation models are increasingly used to provide preventive measures and to asses risks and generally to assist the development of strategies for oil spill contingency planning and response in the event of an accidental oil spill in the sea. Thus in the framework of POSEIDON operational system a pollutant transport model was developed and applied in four targeted areas in Greece [14]. Considering the heavy shipping activities in Pagasitikos gulf and the importance of the Alonisos MPA it becomes rather obvious that such a tool must be an integral part of the proposed operational system.

An individual bioenergetics model (IBM) that describes the full life of the cycle of the European anchovy (Engraulis encrasicolus) developed in the north Aegean Sea will be implemented for Pagasitikos Gulf. For modeling purposes, the anchovy population is represented by a number of “Super Individuals” (SI) with attributes (x, y, z coordinates, population, age, length, weight of the fish). This Lagrangian model is online two-way coupled with a biophysical model based on POM and ERSEM models. Processes at the level of organism are described by a bioenergetics model, while a population dynamics model describes the evolution of the number of individuals in each age class, depending on fishing and natural mortality. The SIs are transported as passive tracers while in the stage of eggs and early larvae. For the next stages, migration dynamic programming methods are introduced that allow anchovy to “move” in optimal areas by balancing food resources and processes due to memory and learning.

The vertical SI distribution is a function of food availability, optimal temperature and diurnal migration.

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