Final OGS products and results in the European Union project Mediterranean Targeted Project II - MAss Transfer and Ecosystem Response - Task VII: Mediterranean Ecosystem - PL 950401

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Summary: The energy dynamics encompasses physical, chemical and biological forms that interact and ultimately determine the space-time characteristics of the food web. To understand the biological response controlling the flow of the biochemical energy through the ecosystem, a deeper insight in the conceptual description must be reached. Specific areas of interest are: phytoplankton composition, the limiting nutrients, the role of microbial loop in sustaining production and the remineralization of biogenic detritus in the pelagic and benthic systems. The Mediterranean Sea is a favourable place for testing and modelling the ecological factors, biotic and abiotic, which determine the present day and trends of the distribution of pelagic and benthic fauna and flora. Important questions in this sense concern the stability of the ecosystem.

Keywords: Historical data, Ecological models, Process studies, Regional ecosystem modelling, Ecosystem evolution

Introduction

A basin scale assessment of nutrient budgets in the Mediterranean in all their forms is also a specific issue which is necessary to point out. Estimates of the fluxes of nutrients, particulate and dissolved organic matter across boundaries need to be made. These include exchanges across straits (e.g. Gibraltar, Otranto, Sicily), benthic and pelagic uptake recycling. All the biogeochemical processes connected to the remineralization of DOM and POM should be carefully investigated so to parametrize their effect at the scales significant for each model.
To create realistic initial conditions for the modelling experiments, the need is felt to create seasonal scenarios for the chemical variables, on the basis of the available data sets, both historical and recent. In particular, attention will be paid to the Adriatic-Ionian complex where the existing data seem to be relatively more abundant. A basin

scale assessment of nutrient budgets in the Mediterranean in all their forms will be attempted, and the investigation of the N versus P limitation will be addressed as well. All the biochemical processes connected to the remineralization will be investigated so to eventually parametrize their effects at the scales significant for each model. The combined effect of the physical forcing and the biological response (phytoplankton and detritus sinking, zooplankton dynamics) will be analyzed to give the net contribution on the photic to aphotic zone exchanges. The benthic/pelagic exchanges must be evaluated in order to be parametrized and included into the aggregated models.
The effects of the physical processes upon the ecosystem function have to be understood, in particular on the primary production. The importance of the vertical processes should be investigated: the vertical exchanges driven by Ekman pumping, the suction of cyclonic and the pumping of anticyclonic circulation, the mixing induced by internal wave braking, the entrainment caused by turbulent mixing at the bottom of the mixed layer, and the deepening of the nutricline determined by convective adjustments will be evaluated in light of the vertical exchanges relevance. The response to the seasonal and to the interannual variability of the forcings will be studied after the coupling with specific aggregated descriptions of overall and regional ecosystem.

Objectives and Strategies

Historical Mediterranean chemical data extracted from the available data sets will be analyzed in order to provide initialization and validation of ecological models. Time series of biogeochemical data in various areas of the Mediterranean Sea including also satellite CZCS - Coastal Zone Color Scanner data will be collected. A seasonal analysis will be carried out to determine the spatial variability of the processes in the Mediterranean, in particular the east-west variability.
The objective of the Work 503-Seasonal and interannual variability of the nitrogen and phosphorus budgets is to investigate the seasonal and interannual variability of the dissolved inorganic matter among the main subbasins of the Mediterranean Sea by using the Ecological and Computational Hydrodynamical model including the primary productivity processes.
A basin scale assessment of nutrient budget in all their forms is very dependent on the general circulation of the Mediterranean and on the biogeochemical processes active in the basin. The regional budgets and fluxes across straits of the nitrogen and phosphorus will be carried out. The dynamics of the dissolved and particulate matter on the overall Mediterranean Sea will be considered also in a time scale of some years. The effects of terrestrial and atmospheric input in the model will be taken into account. The exchanges among marginal seas and open seas will be investigated and the strong

diversity between the Eastern and Western part of the basin, in particular the increasing N/P ratio, will be studied by means of the model.
The objective of the Work 508-Response of the Mediterranean ecosystem to general circulation processes is to assess the effects of the physical forcings on the seasonal and yearly signals trophic levels dynamics.
The Ecological and Computational Hydrodynamical model developed at the overall Mediterranean scale during the project MERMAIDS II / MTP - Mediterranean Targeted Project Phase I will be improved and calibrated with available data and time series of the basin. In particular, the role of the limiting nutrient in the Mediterranean will be addressed using appropriate ecomodels. The response of the model to the seasonal and interannual variability of the forcings – winds, heat fluxes, irradiance – will be evaluated. The seasonal cycle and its fluctuations will be examined and compared with CZCS satellite data and in situ measures. A sensitivity analysis of the model will be carried out in order to identify the reliability of the results and to define the most relevant processes active on the ecosystem: hydrodynamics, irradiance, external nutrients inputs, etc.; an "unperturbed" run will be carried out as reference for the successive tests with increasing complexity and/or with enhanced typical features in order to obtain a sensitivity matrix.

Results

Work 503-Seasonal and interannual variability of nitrogen and phosphorus budgets:
The seasonal and interannual variability of the nitrogen and phosphorus budget was analysed by three-dimensional studies and box models to investigate the long-term evolution of the annual and trophic regime of the ecosystem.
An ecomodel of the seasonal cycle of the Mediterranean ecosystem with NPZD paradigm in a three-dimensional framework. Special attention was paid to the initial and restoring conditions to close the nitrate and phosphate cycle within the basin. An initialization that restores the Atlantic Ocean, similar to that used in the NPD model to obtain nitrogen fluxes in agreement with various estimates (Crise et al., 1998; Crispi et al., 1999), is also used for phosphorus and oxygen. Silicates are not considered after analysing the data in the Mediterranean Sea, especially the NODC dataset. Silicates do not generally appear among the limiting factors.
The station data were selected from the ATLANTIS II cruise report (Osborne et al., 1992). The reference latitude is 36.5N and the longitude of these stations ranges from 9.5W to 8.0W. The values are linearly interpolated to the discretized levels of the model and yield the profiles for oxygen, phosphate and nitrate. For the Adriatic Sea, a previous study confirms that it is difficult to model the dynamics of the northern

Adriatic with the resolution of a similar model with primitive equations. Therefore, it is better to introduce a box modelling the coastal current along the Italian coast. A central box of the Adriatic Sea is averaged. All casts between Rimini-Pola and Vieste-Spalato are selected if they are deeper than 80 m. The oxygen, phosphate and nitrate profiles are interpolated according to the depths of the layers. Three options were considered for the Aegean Sea: a measured flux at the Bosporus, an intermediate box at 36N (analogue to the one used in the Adriatic Sea), a full box including the Cretan Sea. While the first solution has to be considered when also resolving the benthic-pelagic coupling, the second solution is best suited to account for the fluxes through the Aegean Sea in view of future studies on the changing climatic situation in this area. These choices take into account the two main sources of nutrients in the Eastern Mediterranean, with the exception of the atmosphere. Further inputs into the euphotic zone of the Eastern Mediterranean can be taken into account when refining the model: the input from the Nile after damming, which is reduced to 5% of the former total, and an average of the atmospheric nitrogen and phosphorus input. For the western basin, the inputs from the Rhone and Ebro rivers in all their forms must be taken into account, after the balancing at the Strait of Gibraltar has been achieved by the Atlantic buffer zone described above.

The influence of the biological pump help maintains the trophic regime of the Mediterranean Sea through a box model of the nitrogen and phosphorus budget (Crispi et al., 2001).

The interannual variability of the ecosystem is evidenced in the Ionian Sea and other subbasins (Crise et al., 1999) and the interannual variability of chlorophyll is studied in the Mediterranean Sea (Crispi et al., 1999).

Work 508-Response of the Mediterranean ecosystem to general circulation processes: The Mediterranean ecosystem cannot be successfully reproduced by models based on the paradigm of the classical, open-ended food chain. The recycling of nutrients must be incorporated into the food web with increasing levels of detail, from an aggregated formulation of detritus to a refined functional formulation of the microbial loop. The nonlinear diffusion-advection-reaction equations are solved with the same three-dimensional grid as the hydrodynamics, i.e. a quarter degree as horizontal resolution and 31 levels as vertical resolution. The aggregated formulation has the advantage of being conservative under the simplifying hypothesis that the non-conservative processes of the nitrogen and phosphorus cycle – nitrification, denitrification, inputs from rivers and the atmospheric, nitrogen biofixation – are in dynamic equilibrium. The ecological model is initialized with different nutrient profiles at the level of a subbasin, while phytoplankton, zooplankton and detritus are initialized with homogeneous profiles in the entire basin.

The linear sensitivity analysis of the ten compartment multinutrient and multiphytoplankton ecosystem model integrated in the 1D water column shows a maximum sensitivity on an annual basis for the temperature parameters, followed by the parameters related to the metabolism of primary producers in conjunction with the growth and mortality of phytoplankton. Parameters related to grazing activity and water shading coefficient are also relevant. The identifiability study shows that no more than 5 of the 43 parameters of our model could be identified even when daily synthetic measurements of nutrients and chlorophyll a were available for one year and at three different depths, as the sensitivities of most parameters are highly correlated.

The parametrization of vertical diffusivity and viscosity as a function of Richardson number has a direct impact on large-scale tracer advection and also improves tracer trapping by synoptic eddies. The intensification of cyclonic patterns leads to stronger upwelling in the eddy core with a more effective nutrient input from deep layers into the euphotic zone. Due to the increased large-scale flow, advective transport predominates over diffusive transport. The turbulent mixing and the associated overturning, displace phytoplankton and other biotracers along the water column. Conversely, density stratification inhibits vertical transport by reducing the length scale of the energy-containing eddies near the pycnocline. Several attempts to parametrize turbulence and turbulence-driven processes have been proposed in the literature, but most of them refer to one-dimensional domains. On the other hand, 1D models are forced to artificially increase the vertical diffusion to compensate for the lack of vertical advection. Therefore, a three-dimensional approach is preferable if the vertical dynamics are to be fully resolved. Here, a comparison of the effects of different vertical mixing parameters on the variability of the lower trophic levels in the pelagic ecosystem of the Mediterranean Sea was carried out using MOM-NPD, a three-dimensional coupled ecological-hydrodynamic model, as a testbed. The hydrodynamical influences are determined by a primitive equation model, while the ecological dynamics are described by an aggregate model based on inorganic nitrogen, phytoplankton and detritus. We compared a simple A-physics closure scheme, hereafter AP, with a more complex parameterisation such as that of Pacanowsky and Philander, hereafter PP, while an attempt to use the MOM1 standard Mellor-Yamada closure scheme level 2.5 for the second moment prove infeasible due to the instability of the ecological submodel and the inability of this parametrization to deal with climatological constraints. A better developed mixed surface layer together with a sharper vertical density gradient is the most striking feature exhibited by PP and MY compared to the AP results. The cyclonic and anticyclonic patterns are intensified as a results of the altered thermohaline structure of the ocean. This has a direct impact on the advection of tracers on a large scale and also enhances tracer trapping by synoptic eddies. The intensification of cyclonic patterns leads to stronger upwelling in the eddy core with a more effective nutrient input from deep layers into the euphotic zone. It is therefore shown that different choices for the scheme of turbulent closures lead to a significantly different space-time evolution of the biological variables.

The influence of the inverse estuarine circulation in combination with downward fluxes of organic matter determines the presence of the trophic gradient in the Mediterranean Sea. The buoyancy content and wind stress act as preconditions for the trophic properties of the upper layer in winter and influence the intensity and timing of the onset of the spring bloom. Cyclonic and anticyclonic structures significantly alter the nutrient supply in the euphotic zone and act as a chemostad that traps the water with

its biochemical properties. The variability of wind stress is related to phytoplankton dynamics, both on a seasonal and interannual scale. All biological submodels are tightly coupled to a MOM-based hydrodynamic submodel of the Mediterranean Sea forced with either the 1980–1988 NMC 'perpetual year' or with monthly mean wind stresses. The results obtained from this analysis for the trophic conditions in the upper ocean can be classified according to the typical time scale. The nutrient inputs contained in the surface water entering the Strait of Gibraltar are redistributed zonally by the inverse estuarine circulation. The sinking of organic matter and recirculation in the Western Mediterranean contribute to the maintenance of the W-E trophic gradient. The nutrient distribution is influenced zonally by permanent cyclonic eddies that occur in the northern sectors of the two subbasins. The cyclonic eddies cause a bending of the isopycnals and an associated shoaling of nutrients, which normally reach deeper layers. Large anticyclonic areas in the southern part of the Eastern Mediterranean contribute to the deepening of the nutricline for the opposite reason. Both processes thus contribute to the maintenance of the meridional nutrient gradient. The trophic meridional gradient is also maintained by the coastal upwelling induced by the prevailing wind regime in some areas along the coastal upwelling induced by the prevailing wind regime at the northern boundaries of the two subbasins. The signal is recurrent and is also maintained in the 'perpetual year'. Ekman pumping and buoyancy contents have a seasonal effect on the meridional average of nutrient levels. The former through a positive or negative contribution determined by the convergence or divergence properties of the surface current, the latter through the creation of a spatially varying isopycnal barrier, that effectively determines the amount of work required to destroy stratification and rehomogenize the water column. Light and temperature in the seasonal cycle control the primary producers at depth. This control is in turn passed on to the upper trophic levels with a delay. Possible internal oscillations due to recycling processes by the food web are damped by the mean vertical regime, in which organic matter fallout is the main culprit for the progressive depletion of nutrients in the upper layer due to the net export of potentially available nutrients outside the euphotic zone during the stratification period. Vertical processes associated with turbulent entrainment and convective episodes dominate during winter, the mixing season, giving way to the emergence of small-scale patterns, while horizontal processes appear to predominate after the onset of the seasonal pycnocline. The interannual signal appears to be transmitted to the primary producers by the intensity of the winter turbulent entrainment in the upper layer and the associated fertilization of the euphotic zone. Advection/diffusion processes transmit the biological signal along the main pathways determined by the general Mediterranean circulation.
The interplay between the vertical fluxes in the upper layer and the competition between the functional groups of phytoplankton fractionated by size plays an important role in the development of the onset of early spring bloom.

Acknowledgements: We thank the coordinator A. Monaco for the double OGS installation at the MATER booth at the Lisbon Conference 23–27 May 1998 with our ecological model, later

ECHYM, the poster “Modelling the open ocean ecosystem response to physical forcings variability by A. Crise, G. Crispi, C. Solidoro”, and the OGS-DOGA (1999) CDROM presentation of the preliminary 1998 version, with the MTP II poster by him and T. Tselepides.
In our article Crispi et al. (1999), originally published in ISSN 0924-7963 and now available as open access at https://www.sciencedirect.com/science/article/pii/S0924796398000852 on the Science Direct website, Figures 2 and 3 are reprinted with the kind permissions of Springer-Verlag Marine Biology and Gauthier-Villars Oceanologica Acta, respectively; special thanks also go to "Barale, V., Larkin, D., Fusco, L., Melinotte, J. M., Pittella, G., 1999. OCEAN Project: the European archive of CZCS historical data. Int. J. Remote Sens., 20(7), 1201–1218" for the content of the CZCS images used, which were published on the ISPRA website at the time of post-processing of the article.

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8 pp. January 2024