MODELING THE OCEAN SYSTEM IN A SUSTAINABLE DEVELOPMENT PERSPECTIVE

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Contents

Summary

The paper examines the characteristics of a reliable - and tractable - mathematical model from its evoluting attunement to its objectives, the selection of a limited number of representative state variables, the specification of well-defined spectral windows and the definition of sets of operant state variables on which the model efforts can be focused alternatively, and the related requirements and limitations on the resolution, predictability and realism of the mathematical simulation, considering especially long-term predictions in a sustainable development global perspective.

1. Introduction

The simple word of "model", - or worse the sulphurous duo "mathematical model" -, generates a mixture of enthusiasm and revulsion and no one is quite prepared to leave the survival of future generations, - which sustainable development is about -, to mathematical modelers, even if they are undoubtedly the only ones with a tunable view-finder on which one can play the worst scenarios of our present wandering in socio-economic-environmental endeavors.

Perhaps, the simplest way of reconciling scientists with mathematical models is with a comparison with the reduced scale models (of cars, say) children love to play with. A reduced scale model is obviously an enormously simplified version of a real car but it possesses all the characteristics, shape, color, wheels, … the child needs, to play with it games that, for his age and imagination, are realistic.

A mathematical model is, in a sense, nothing but a reduced scale model. It is a simplified *computer* version of the real world. While the latter can only be represented by an infinite number of state variables and parameters varying in four-dimensional space-time, the model deals with a limited number of *significant* variables, the evolution of which is governed by a *tractable* set of equations which can be used to forecast the system's evolution (as one forecasts the weather) or to explore the consequences of hypothetic economic and environmental scenarios.

The main thing to remember is that mathematical models cannot, anymore that children's toys, betray reality. A toy may be more or less sophisticated, - perhaps according to the age of the player -, a mathematical model may be more or less rudimentary, - presumably according to the questions being asked and the time available -, but they may not give a misleading view. Toy makers know what they must be attentive to, in this respect. In the following, one shall try to emphasize a few guiding principles in constructing "appropriately accurate" mathematical models of the ocean system.

2. Subject and Objectives of Model

This may seem as rather commonplace. Obviously the first characteristic of a mathematical model is its *subject*. Defining the subject, however, may not be as evident as it may appear. The development of a mathematical model requires a permanent dialogue between the modelers on the one side and the experimenters and deciders on the other side. The latter, still in a preliminary phase of data decoding or at an embryonary state of management, may seek information without being able to circumscribe them in a definite way. One may have to redefine the subject of a model. One must be prepared to provide the means of such reconsideration.

With the subject, the *objectives* must be specified : basic research, expertise, short term or long term management. These will determine, to a large extent, the kind of model which is needed.

3. The Overall Model's Dimensions

A model can describe the system in time and in all three dimensions of space but, in some cases, models with a reduced space definition can be just as efficient as, for instance, a model of an estuary considering only averaged values of the main variables over the river's cross section. Ideally, also a completely realistic model would describe an infinite number of variables but that model would be the real world itself. Computing facilities, of course, impose limitations on the number of variables but, independently of such restrictions, there are reliability and clarity constraints : a model with many variables incorporates as many different processes and interactions and involves a correspondingly large number of parameters and boundary/initial conditions which cannot be evaluated from existing data bases without an inevitable margin of error. On the other hand, the results of such a model can become impossible to interpret in terms of scientific diagnosis and management recommendations.

Trying to reduce the overall dimensions of a model, it is tempting, - and this approach has prevailed for a long time -, to separate the model into *disciplinary sectors* and to consider separately hydrodynamical, chemical, biological, economic … models.

This discipline-oriented approach, while naturally consistent with the early stages of model development, cannot be extended to models intended to investigations into sustainable development scenarios. These require global vision and long term perspective. The wider and the longer one looks at the earth system, the more one needs the understanding of all the disciplines of knowledge and of their intricated interactions to appraise all the consequences of environmental or man-induced activities.

4. A Diversity of Models

The pelagic, microbial food web sketched in Figure 1 may be looked at as a cartoon designed for a university textbook. In reality, it is much more than that. It represents possibly the most up-to-date understanding of the marine water column food-web, derived from major discoveries over the past two-decades. These includes (i) the existence of large populations of bacteria growing on dissolved organic carbon, (ii) a large fraction of primary production originating from very small autotrophs, (iii) a significant role of flagellate and ciliate predators, (iv) the importance of viral-induced lysis of bacteria and (v) the complex role of mixotrophic nutrition; all processes which have been largely underrated in previous generations of models.

In this respect, Figure 1 is in itself **a model**.

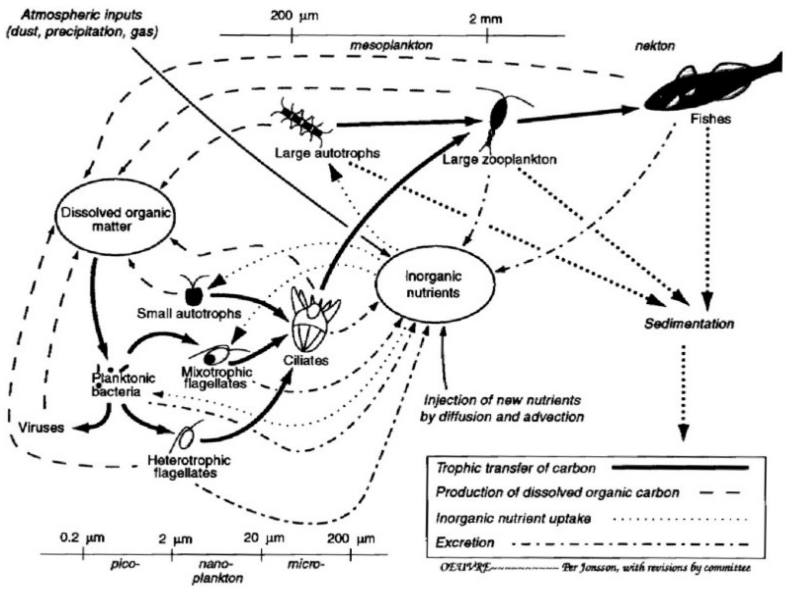

Figure 1. The pelagic, microbial food web.
(Courtesy of P. Jonsson, with modifications by the OEUVRE Workshop's Committee).

At this stage, however, it remains a *conceptual* process model and it contains very few quantitative information (except from indications of the sizes of the organisms, at the top and bottom) and no reference at all to the physical and biogeochemical processes in which this particular food-web is embedded.

Most ecological models are based on such a conceptual view of the system's structure. In practice, the elegant drawings of Figure 1 are replaced by boxes, representing stocks (of nutrients, organic matter …) and the arrows represent translocations of (living or non-living) material between them. In early models, indicative values of the mean annual stocks and translocation fluxes inscribed on arrows and in boxes provided, if not enough numerical information for mathematical modeling, at least an order of magnitude of concentrations and biomasses and of their typical time scales.

Mathematical models of course require *a mathematical formulation* of the rates of interactions between the variables as shown, for instance, in Figure 2.

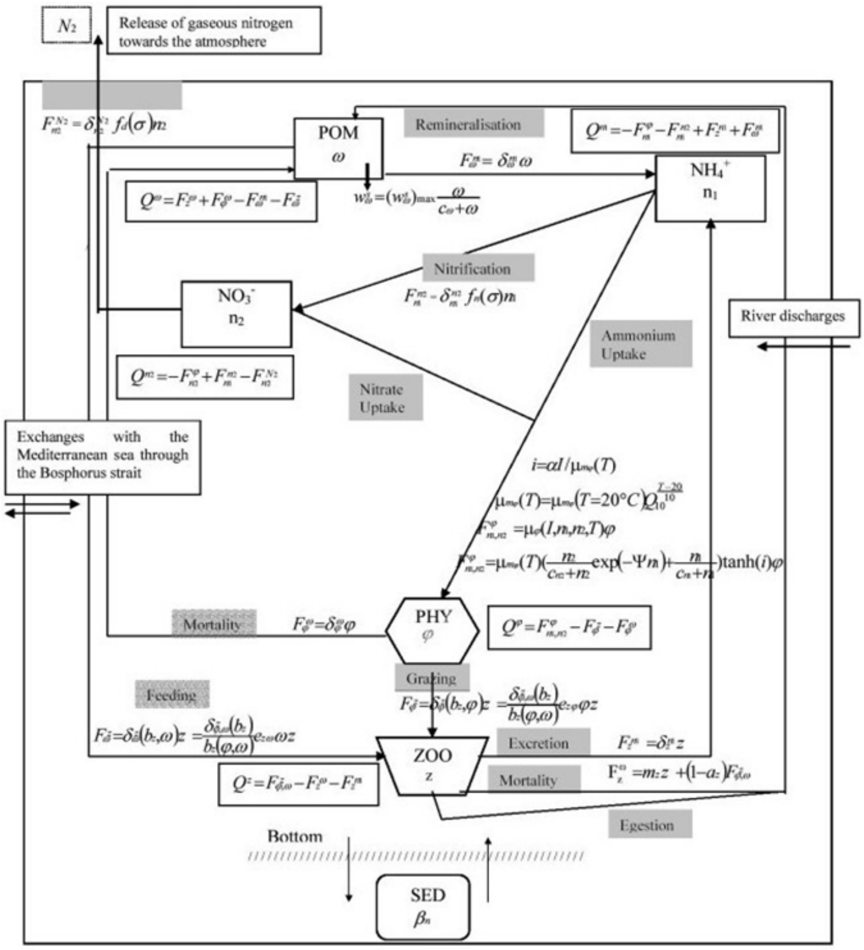

Figure 2. a simple conceptual model of the Black Sea's Pelagic Ecosystem showing interactions between two nutrients (nitrate NO_3^-, ammonium NH_4^+), organic matter, phytoplankton (PHY) and zooplankton (ZOO).

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Biographical Sketch

Jacques C.J. Nihoul - Born in Ans, Belgium, on June 6, 1937, Prof. Jacques C.J. Nihoul and his wife are currently residing in St. Severin, Belgium (his son, 34, an architect engineer is in charge of the maintenance and renovation of the University of Louvain's Campus Infrastructure; his daughter, 28, a D. Phil. in Political and Social Science is a Cabinet Adviser for European Affairs in the Belgian Government). After receiving his Engineering Degree from Liège University in 1960, Prof. Nihoul was awarded his M.Sc. Degree in Mathematics from MIT University (USA) in 1961 and his Ph. D. in Applied Mathematics and Theoretical Physics from the University of Cambridge (UK) in 1965. He served as an Air Force Officer during his National Service in 1964-1965 at the Royal Military College of Belgium and was elected to full Professorships in Liège and Louvain Universities in 1966.

Prof. Nihoul has sat on numerous international committees including SCOR, IAPSO and GLOBEC. He is at present Editor of the Journal of Marine Systems, Earth Science Reviews, Oceanography Section, and one of the Editors of Mathematical and Computer Modelling. President of the National Committee of Oceanography of the Royal Academy of Belgium, Prof. Nihoul is a Member of the Russian Academy of Natural Sciences and of the Academia Europaea. Author of some 200 papers in international journals, he was awarded the Francqui Prize for Medical and Natural Sciences in 1978.