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A Coastal Marine Ecosystem

Simulation and Analysis

With 80 Figures

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Preface

> One aim of the physical sciences has been to give an exact picture of the material world. One achievement of physics in the twentieth century has been to prove that that aim is unattainable.... There is no absolute knowledge. And those who claim it, whether they are scientists or dogmatists, open the door to tragedy. All information is imperfect. We have to treat it with humility.
>
> Bronowski (1973)
> The Ascent of Man

It seems particularly appropriate to us to begin this book with Jacob Bronowski's passionate message firmly in mind. Those who set out to construct numerical models, especially ones that are mechanistic and essentially deterministic, must work always with this awareness as a backdrop for their efforts. But this is also true for the most meticulous physiologist or observant naturalist. We are all dealing with simplifications and abstractions, all trying to figure out how nature works. Unfortunately, this common pursuit does not always lead to mutual understanding, and we have become increasingly aware over the past six years that many ecologists feel a certain hostility or at least distrust toward numerical modeling. In a number of cases the reasons for such feelings are personal and very understandable—hard-gotten data skimmed off by someone with little appreciation for the difficulties involved in obtaining reliable measurements, grandiose claims of predictability, the tendency for some model builders to treat other scientists as number-getters whose research can be directed in response to the needs of the model, etc. In other cases, however, it is often a lack of understanding of what is actually involved in building a mechanistic numerical model and what its uses and limitations are. Published articles tend to describe models briefly and in strictly mathematical terms, so as to stress some particular applications. Moreover, much of the modeling literature is very theoretical and appears to be concerned more with the behavior of differential equations than with living systems. It is difficult for the practicing biologist or ecologist who measures metabolic rates, or nutrient kinetics, or feeding patterns, to relate his efforts to equations with a few highly aggregated coefficients.

Part of our hope in writing this book is to make some contribution toward a synthesis of effort among those who work in the laboratory and the field, and those who are dealing with nature on a more abstract level. Or, if not a synthesis of effort, at least an increase in tolerance. For this reason, a large portion of the book is devoted to a review and discussion of the empirical basis for the choices of various functional forms and the values of coefficients. The difficulties and uncertainties involved in arriving at many values serve to reinforce the caution of those who make the measurement, but also to emphasize the value of numerical systems analysis in exploring the implications and consequences of that uncertainty.

The Narragansett Bay model is concerned largely with a mechanistic numerical description of phytoplankton-zooplankton-nutrient dynamics in a temperate estuary, and the ways in which these dynamics are influenced by light, temperature, and hydrography. While the effects of some higher trophic levels are also part of the model, there is virtually no mechanistic detail included for the microbial aspects of the system. Bacterial decomposition and regeneration are simulated entirely through empirical regressions relating net rates to temperature. This crude representation is primarily a consequence of the general lack of detailed knowledge about microbial dynamics in coastal marine ecosystems. Fortunately, this situation is changing rapidly, and many of the recent advances in marine microbial ecology will come to influence future ecosystem modeling efforts. In fact, the next volume in the Ecological Studies series edited by Dr. G. Rheinheimer presents an extensive discussion of the microbial ecology of Kiel Bight, with emphasis on the role of marine bacteria and fungi.

For the most part, the mathematics required in mechanistic ecosystem modeling are not elaborate. A few basic forms appear repeatedly, and an introductory calculus course should make the reader reasonably comfortable with the expressions used here. In order to serve as a review of some principles that are particularly appropriate to understanding the model, however, we have included a chapter on the mathematical concepts involved.

As anyone who has worked with simulation models is painfully aware, the development of the computer program or algorithm for the model is an integral part of the effort. It is no trivial undertaking to develop an efficient program for a system as complex as the Narragansett Bay model. For the most part, the translation of system-flow diagrams and equations into a computer program is discussed neither in descriptions of various ecosystem models nor in programming manuals. It has become increasingly clear to us that many people who are not computer programmers are completely mystified by this step in the modeling process. In some cases, the programming is dismissed as if it involved nothing more intellectually challenging than key punching. There are, of course, many levels on which one can discuss the development of simulation algorithms, and this book does not attempt to teach computer programming. However, to give some feeling for the problem involved in developing the Narragansett Bay model, we have included a discussion of the algorithm with examples at various levels of programming complexity. Even those with no knowledge of computer languages should be able to gain some appreciation of the process and the effort involved. For the experienced programmer, the model provides some intriguing challenges. We have described some of our solutions, but there are surely others equally as good or better.

Much of the preceding has described the effort we have made to provide a description of a numerical ecosystem model that will be useful to those who do not really consider themselves systems ecologists or modelers. However, we have also tried to provide a rigorous and detailed description of our particular model that will be of interest to others in this field. While it was developed for Narragansett Bay, there is really nothing in the model except for some of the forcing functions and the choices of initial conditions that ties it to this particular area. In the more general sense, it is a model of a temperate, plankton-based marine ecosystem with relatively constant salinity and a well-mixed water column. Our aim in developing the model has not been to get the best fit to a set of observed points or to make direct predictions about what the bay might do in the future. We have used the model to synthesize a great deal of information on marine ecosystems in general, and on Narragansett Bay in particular. We have then tried to go the other way and to use the model in an analysis of the bay ecosystem, to explore a number of hypotheses about which processes may or may not be important in forming the patterns that emerge in the natural system. We have tried not to confuse numbers with knowledge.

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