Ecological Modeling

W.E.G.
To Linda, Jennifer, Stephanie, David, Amanda, Jessica,
Steven, Jacob, Joseph, and Lindsey

T.M.S.
To Mom, Dad and Margie, Craig and Shawntel, Ashley, and John

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Ecological Modeling:

A common-sense approach to theory and practice

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Preface

Why did we write another book on modeling? Should you bother to read it? If you'll allow us to reflect a bit on the first question, you'll probably be able to answer the second.

The elder of us (WEG) has always wanted a simple textbook for the introductory systems modeling class he has been teaching in the Department of Wildlife and Fisheries Sciences at Texas A&M University since 1976. The first attempt to write such a text (Grant 1986) resulted from the fact that most modeling texts available in the 1970s and early 1980s were written for engineers, and ecological modeling books, including some landmark works, were primarily reference volumes rather than textbooks. A second attempt (Grant et al. 1997, 2001) a decade later resulted from a desire to have a textbook in Spanish for short courses that we (co-authors were Sandra Marín and Ellen Pedersen) had begun teaching in Latin America. During the process of writing the Spanish language text we found ourselves rewriting large portions of the text in English as well; a decade of student questions had brought new insights into relating theory to practice and advances in computers and software had provided interesting possibilities for giving readers a more hands-on introduction to modeling. This third attempt quite honestly was motivated initially by a desire to reduce costs to students via a shorter (paperback) version of the 1997 text and alleviation of ties to rather costly commercial software. But the ensuing scrutiny of the text from a new perspective, which emerged as a synthesis of another decade of reflection (WEG) and the innovative ideas of a new generation of ecological modelers (TMS), forced a reevaluation of what is essential to an introductory course. Independent of cost, the 1997 text now seems unnecessarily long and complex and the sophistication of associated software seems to distract attention from the simplicity of basic calculations.

Thus the present text is the result of a relentless culling of material that is not absolutely essential to the prudent development, evaluation, and use of systems models. We realize this reduction runs counter-current to the rapidly expanding range and sophistication of ecological modeling topics. We are in awe of the intellectual prowess of today's ecological modelers and of the stream of theoretical, analytical, and computational breakthroughs they produce (for example, see articles in the journal *Ecological Modelling*). But continuous innovation is a two-edged sword, potentially overwhelming beginners and, we would humbly suggest, blinding some experienced practitioners to basic errors hidden at the core of their sophisticated applications. Nowadays there is a wealth of books, journals, and websites that collectively describe virtually all aspects of ecological (biological, environmental, natural resource) modeling. What perhaps is less available, with all due respect to authors of current "Introduction to" modeling books, each with their particular strengths, is an introduction to the basic principles and practice of systems modeling within an ecological context. The question "What do I really need to know before I can build and use ecological models in a responsible manner?" is a critical one which hopefully is answered in the present text.

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Todd M. Swannack

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1 Introduction

The usefulness of ecological simulation modeling results as much from the process (problem specification, model development, and model evaluation) as from the product (the final model and simulations of system dynamics). Skill in the process of simulation modeling is gained primarily through (1) practice, (2) practice, and (3) practice. However, a keen awareness of what we are doing (in practice), why we are doing it (in theory), and why it makes (common) sense, is invaluable. Without this awareness we risk making silly, kindergarten-level, mistakes; even experienced modelers are not immune from these pitfalls, which often come hidden under a thick covering of sophisticated quantitative techniques and associated jargon. Thus, we have organized this book to emphasize the "oneness" of theory, practice, and common sense.

1.1 Common-sense solutions: three exercises

We begin in Chapter 2 with (1) practice, (2) practice, and (3) practice, in the form of three exercises. In each exercise, we are faced with a problem that requires us to project the dynamics of a particular system into the future under different scenarios of interest. The first deals with a group of hunter-gatherers harvesting food for the winter, the second with a population that might go extinct, and the third with management of a common pasture in which neighbors graze their animals. We first work through each problem in an informal, commonsensical way. We then present a short overview of the systems approach to problem solving, and briefly revisit the three problems from the systems perspective.

What should be obvious from these three examples is that projecting the dynamics of even relatively simple systems for which we have a good understanding and a solid database is not necessarily an easy matter. Apparently simple systems may exhibit surprisingly complex behavior; an understanding of the behavior of each part of the system does not guarantee an understanding of the behavior of the whole system. Attempts to deal with complex problems in a narrow or fragmentary way often lead to poor research design and ultimately to poor management decisions. We need an effective way of dealing with the complexity generated by interaction among the parts.

1.2 Modeling theory

We then take a more formal look at the simulation modeling process from the "systems perspective," describing development of the conceptual model (Chapter 3), quantification of the model (Chapter 4), evaluation of the model (Chapter 5), and application of the model (Chapter 6). The systems perspective, or systems approach, is both a philosophical perspective and a collection of techniques, including simulation, which emphasizes a holistic approach to problem solving as well as the use of mathematical models to identify and simulate important characteristics of complex systems. In the simplest sense, a system is any set of objects that interact, and a mathematical model is a set of equations that describes the interrelationships among these objects. By solving the equations comprising a mathematical model we can mimic, or simulate, the dynamic (time-varying) behavior of the system.

The basic approach is to (1) develop a conceptual model (box and arrow diagram) identifying specific cause–effect relationships among important components of the system in which we are interested, (2) quantify (write mathematical equations for) these relationships based on analysis of the best information available, (3) evaluate the usefulness of the model in terms of its ability to simulate system behavior under known scenarios and under an appropriately broad range of future scenarios, and (4) apply the model (conduct simulated experiments) to address our questions concerning system behavior under future scenarios.

1.3 Modeling practice

We next take a look at the practical application of simulation modeling, pointing out some of the pitfalls commonly encountered during model development (Chapter 7), and suggesting a strategy that we have found helpful in at least reducing the number of pits into which we fall (Chapter 8). Although theoretically it is convenient to describe the modeling process as proceeding smoothly through the four phases noted above, in practice we usually cycle through these phases several times. We seldom quantify the entire conceptual model before running simulations and evaluating model behavior. Rather, we usually construct a simple "running" model as quickly as possible and then expand it gradually through a series of small additions until we have quantified the entire model.

Pitfalls that we hope to avoid via this iterative approach range from the seemingly trivial, like failing to adequately define model objectives, to the foolhardy, like trying to track down numerical errors amongst tens or hundreds of interrelated equations that we (i.e., the computer) are solving for the first time. Common pitfalls include inappropriately bounding the system-of-interest, often due to inclusion of excessive detail in model structure, and underestimating the importance of time lags and negative feedback, often due to the erroneous idea that cause and effect must be tightly linked in time and space.

1.4 Theory, practice, and common sense

Having emphasized the oneness of "theory," "practice," and "common sense" as the organizational paradigm for this book, we feel obliged, perhaps somewhat ironically, to clarify the distinction we make among these three terms. By theory (Chapters 3–6), we do not refer to "high theory" in the sense of General System Theory or the Theory of Quantum Mechanics, but simply to four general activities that are viewed as essential to the development and application of any systems simulation model. By practice (Chapters 7 and 8), we refer to the practical application of these four general activities in a manner that experience suggests helps us avoid some common modeling pitfalls. By common sense, we refer to a logical, straightforward approach to problem solving, whether described informally or formally.

Thus, viewed on a continuum from "high theory" to "day-to-day practice," virtually all we present in this book is very practically oriented. Our goal is two-fold:

1 To show that the theory and the formal practice of ecological modeling blend seamlessly into a commonsensical approach to problem solving.

2 To demonstrate that the added rigor provided by a keen awareness of what we are doing, why we are doing it, and why it makes sense aids us greatly in dealing with dynamic systems whose complexity would otherwise by overwhelming.

1.5 Intended use of this book

We have written this book as a textbook for an introductory course in ecological modeling. We have relentlessly culled material that is not absolutely essential to the prudent development, evaluation, and use of systems models, with the goal of providing a useful answer to the