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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.

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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

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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

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question: "What do I really need to know before I can build and use ecological models in a useful, and responsible, manner?" We have emphasized the simplicity of the modeling process, and we firmly believe that mastery of the basic principles of ecological modeling is well within the grasp of any ecologist or student of ecology. Proficiency comes with practice.

Does this mean that after mastering the material in this book one is ready to develop ecological models that can advance ecological theory or improve natural resource management? An analogous question might be: "Does this mean that after mastering a foreign language one is ready to become a foreign ambassador?" Obviously, in both cases "it depends." We opened this chapter by stating that the usefulness of ecological modeling results as much from the process as from the models that result from that process. We believe anyone who deals with dynamic (time-varying) ecological systems can learn more about those systems via the modeling process as described in this book. Whether the benefits of that learning extend beyond the self-edification of the modeler depends on the questions being addressed and the level of ecological expertise of the modeler, or team of modelers, who is addressing them. Whether it would be useful to employ sophisticated mathematical and computational (computer) techniques during the modeling process likewise depends on the question being addressed and the level of mathematical and computer programming expertise of the modelers. We should not confuse the specific ecological, mathematical, programming or other expertise needed to address a particular problem with the basic principles of systems modeling, which provide a general problem-solving approach within which to apply this specific subject-matter expertise.

We do not present alternative mathematical formats or computer code for the examples in this book. Nor do we include references to the primary ecological modeling literature in the body of the text. We felt this would distract us from our main theme. There is a rich literature describing diverse types of ecological (biological, environmental, natural resource) models developed using a variety of mathematical and computer programming formats. Much of this literature is readily available on the internet, and readers should have no difficulty finding examples in their particular area of interest. We do provide 60 references to scientific articles containing ecological models in Appendix A. We intend these references to serve only as points of entry into the primary literature.

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