# 3

# ECOLOGICAL MODELING AND SIMULATION

Models have been in use in resource analyses as long as man has made attempts to understand, modify, or control part of the ecosystem. The models have often been only mental models, or they may have been written in the form of a project outline or work plan. Models have been increasing in complexity as more biological knowledge is accumulated. Present capabilities for rapid and accurate computations with electronic computers make it possible to build very complex models that include the analyses of many relationships between organism and environment.

How do we begin developing a model? The model starts with the formation of an idea. This conceptual model can be explained verbally to others, and can be described in prose form, outline form, or in a schematic form that illustrates the main components of the model being described in writing. This verbal model can become quantitative by representing the components of the model by numerical quantities. Thus there has been a progression from a conceptual to a verbal to a quantitative model.

This progression in no way guarantees that the model is of any value. The idea might have been poor, words might not adequately express the ideas, and the numbers may be poor representations of the actual strength of the relationships being considered. Its value is dependent on the level of realism associated with the model and the part of the real world that it represents.

The sequence of events in the building of a working model of biological

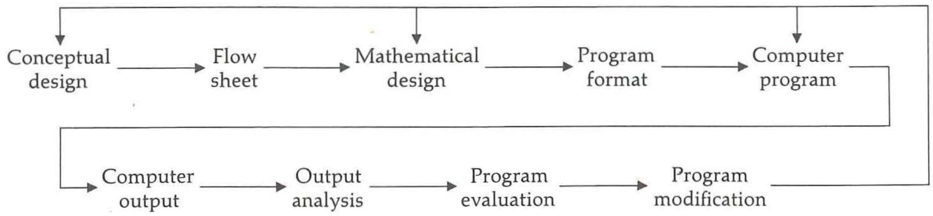


FIGURE 3-1. The sequence of events in the construction of a biological model for computer analysis.

relationships is illustrated in Figure 3-1. The conceptual design comes first; it is a representation of the thoughts or ideas of the model builder. The thoughts are then converted to words in the form of a flow sheet. A flow sheet is a schematic display of the relationships being considered in the model. Representation of these relationships by mathematical equations results in the formation of a mathematical design. The computer enters the picture when the mathematical design has been completed. The computer's main function is the rapid manipulation of the mathematical design, including storage of numerical quantities, execution of mathematical functions, and decision-making with respect to numerical values. The model builder must, of course, use the program format or language that his own particular computer requires.

The computer outputs can be analyzed to see how well they seem to represent the biological investigations under consideration. The program is then evaluated and any necessary modifications made in the program, in the mathematical design, or in the conceptual design.

Corrections in the computer program alone are simply mechanical. They are necessary when a mistake has been made in writing the computer program itself and are analogous to a spelling error. Corrections in the mathematical design or the conceptual design may result in a new model. If an orderly sequence of model building is observed, the new model will usually be larger than the previous one. This is often by intent; the first model that is developed must be within the scope of understanding—perhaps even a little below the full capabilities of the model builder. The use of the simpler models first for generating conclusions will make subsequent models more realistic.

## 3-1 MATHEMATICAL MODELS

An understanding of the basic characteristics of mathematical models is necessary before their usefulness can be appreciated in resource analyses and management. Models consist of two basic components, including (1) the factors or forces that constitute the model and (2) the relationships between these factors and forces.

A simple numerical example illustrates the basic structure of a model as follows:

$$[(10_1 \times 3) - 6 + 7] \times 10_2 - 50 = 260 \tag{3-1}$$

The numbers represent the factors themselves, such as the number of animals, the amount of forage available, or some other biological quantity. The mathematical signs ($\times$, $-$, $+$) represent the relationships between these quantities. Some are multiplicative; others are additive, either positive or negative. The parenthesis and brackets indicate the mathematical order that must be followed in arriving at an answer. The final output (260) represents the cumulative relationship between all factors in the model.

The model represented by equation (3-1) is a very simple one. Complex models can be built only after simpler ones have been assembled and tested, however. The increase in the size of models follows a pattern, as illustrated in Figure 3-2. The number of meaningful conclusions that can be reached is often directly related to the size of the model, assuming that the model contains good inputs that are treated in a biologically reasonable manner. The amount of waste may be quite independent of the size of the model.

The outputs of models that represent biological knowledge are variable owing to both natural biological variation and to error in measurement. The significance of the effects of either natural variations or error in a whole biological system is dependent on the characteristics of the factor(s) itself and on its relationships to other factors. Variations in the numerical factors in equation (3-1) will illustrate this characteristic of models.

Suppose that the factors could vary from their full value shown to one-half of their value shown. If the number $10_1$ is divided by 2, the final answer is 110 [equation (3-2)] rather than 260 [equation (3-1)].

FIGURE 3-2. The growth of models, illustrating the larger model size, the increase in conclusions, and the continual output of "waste" information.

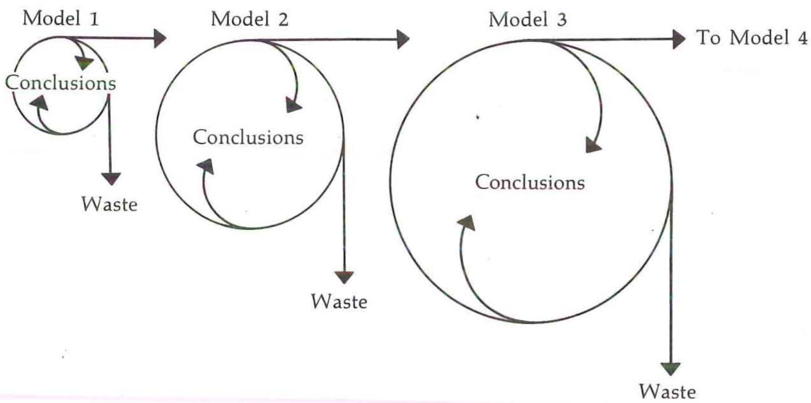

**TABLE 3-1** THE EFFECT OF A 50% REDUCTION IN EACH OF THE ORIGINAL VALUES IN THE MATHEMATICAL MODEL ILLUSTRATED IN EQUATION (3-1)

| *Original Value* | *Original Value* $\div 2$ | *New Answer* | *% of Original Answer* |
|---|---|---|---|
| 3 | 1.5 | 110 | 42 |
| 6 | 3 | 290 | 112 |
| 7 | 3.5 | 225 | 87 |
| $10_2$ | 5 | 105 | 40 |
| 50 | 25 | 285 | 110 |

$$\left[\left(\frac{10_1}{2} \times 3\right) - 6 + 7\right] \times 10_2 - 50 = 110 \qquad (3\text{-}2)$$

The new value is 42% of the initial answer. The division of each of the original number components by two results in new outputs ranging from 105 to 290, or 40% to 112% of the original output (Table 3-1).

Natural variations or measurement errors can occur in several factors at one time, however. The end result may be similar to the original, reflecting a compensatory effect, or it may be different owing to an additive or multiplicative effect. If 6/2 and 7/2 are substituted for 6 and 7, respectively, in equation (3-1), the result is 255, or 98% of the original. The two errors compensated for each other. If $10_1/2$ and $10_2/2$ replace the two original values of 10, the new output is 30, or 11% of the original. These errors are multiplicative, and the final output is very different from the original. In both of these cases a "constant" change was introduced; each of the two original values was divided by the same number, that is, 2.

The illustrations clearly show that the importance of any one value is dependent on its relationship to the other values. This is true mathematically and is also true biologically as the different factors and forces act together in a "web of life" that is dynamic and exceedingly complex.

The previous illustration of the use of models to represent ecological relationships cannot fully convey the excitement of computer analyses of these relationships. It is something that must be experienced to be appreciated. The rapid increase in the availability of electronic computing systems ranging in size from desk-top models smaller than a typewriter to central computers linked to time-sharing terminals in remote locations now puts this kind of analysis within the reach of most people in the natural resources field.

It is important to remember, however, that there is no magic in computer analyses. The value of the computer is illustrated by its use in the space program. The basic knowledge necessary for flights to the moon has been available for many years. The computer plays a vital role in the use of this knowledge through the execution of mathematical expressions. It does so with the speed necessary in the decision-making process that is so critical in space flights. The computer is a tool that must be used judiciously in the analyses of different physical or biological relationships. It is essential for the realistic analyses of complex relationships currently under consideration.

## 3-2 THE ANALYTICAL MODEL IN ECOLOGY

The development of a model that contains ecological dimensions is somewhat more difficult than the development of a mathematical model with numbers that are dimensionless and nonrepresentative of real relationships. Let us proceed to an example illustrating the development of a more realistic model that is both biological and mathematical in content.

Suppose that you are interested in the growth rate of an animal. You might know from past experience that this animal weighs 5 grams at birth and reaches a maximum weight of 105 grams in 50 days. What are the components of that biological relationship that will be of value in the development of a growth model? The two parameters present are weight and time. Given this information, you can assemble a first model that will result in the prediction of weight at any time during the growth period. The information given limits you at this point to the use of a simple model such as linear regression with the components $Y$, $a$, $b$, and $X$. Biologically, it can be said that $Y = f(a, b, X)$, where $Y$ is the weight at any point in time $X$, $a$ is the birth weight, and $b$ is the change in weight per day. The numerical equation can be calculated from the above information as follows: $105 = (5 + b50)$, which can be rewritten as $b = (105 - 5) \div 50$, which results in $b = 2$. Thus there is a growth rate of 2 grams per day, and the equation $Y = 5 + 2X$ can be used to calculate the weight at any given day.

The above model is a descriptive one, developed after certain known quantities are available. These quantities are empirical, and the predictive validity of the model is dependent on the similarity between the conditions during the measurement of these quantities and the conditions imposed on an animal whose growth rate is being predicted or assumed from this first model.

Program evaluation and review may result in the conclusion that the model might not be particularly good because time is not the *cause* of growth, but is simply a necessary constituent of the growth process. Other factors, such as metabolic rate, energy availability, protein, vitamins, minerals, activity, genetic characteristics, hormone balance, and others are related to the cause of growth. A second model, more useful for predicting the growth pattern of the animal, might take into consideration the rate of energy metabolism for the synthesis of body tissue. It is obvious that this requires more biological information for a realistic model.

What basic laws of energy and matter are useful in outlining a second model that becomes more realistic as a representative of the growth of the animal? First of all, the body of the animal contains a certain amount of energy and matter at birth and a certain amount at the cessation of growth. These can be measured, and the difference is the net increase in energy or matter over a period of time. Knowledge of the metabolic rate, or rate of energy metabolism during this period of time, permits the determination of the growth rate on an energy base, and ecological conditions that affect the rate of energy metabolism for productive purposes can then be considered in further predictions. In other words, the model is not restricted just to the effect of all metabolic processes through time, but alterations in the metabolic processes that would affect the growth rate can be taken into account.

The same procedure can be followed for protein, minerals, and productive processes such as egg production, milk production, and hair growth. The complexity of such models increases very rapidly, but at this point the student may find it more imposing than it should be because of insufficient supporting information. The story will become more complete in later chapters as the models illustrated become more complex in terms of the number of considerations. They are, however, simple in a way if the function of each component part is described in accord with some physical law relating it to the transformation of matter and energy.

The fact that no parameter can be considered in isolation in ecosystems suggests that tests of statistical significance are meaningful only when considered in the ecosystem context. The importance of variation in any one parameter cannot be determined until the effect of that parameter is considered in relation to other components of the ecosystem that it affects. Differences in snow depth can be used to illustrate this very important concept.

Suppose that snow accumulations on two different areas were compared and found to be statistically different, using a test of the slope of a regression line representing accumulations over time. If this snow never exceeded 10 inches, it would pose no problem to the movement of moose through it and hence would have no ecological significance with respect to the restriction of moose activity. If the distribution of forage was such that none of it, or so little of it, was located in the first 10 inches of the plant community that there was no shortage of food, then the snow would have little or no ecological significance.

The possibility exists that such snow depths would be important for the winter survival of *Microtus*, however. If the temperature was very low, the greater snow depths might be important in maintaining the thermal regime of the mouse. Suppose the critical snow depth for insulation purposes was 8 inches; then the area having that depth would be distinctly better than the other area having less accumulation. The statistical significance of differences in snow accumulations becomes important only after a depth of 8 inches is reached in this particular example. If the temperature never drops much below 0°C, there might be little effect due to differences in snow depths because the critical snow depth for insulation purposes would be small. Thus is can be seen that the importance of differences in snow accumulation is related to a larger number of factors ecologically. Deep snow may be good for *Microtus*, a problem for deer after depths of 20 inches are reached, but irrelevant for moose until 30 or more inches are on the ground.

It is important to understand how any parameter under consideration functions before deciding that variation within or between parameters is or is not important. This requires a simultaneous *n*-dimensional type of thinking that is a necessary component of the thought processes of an analytical ecologist.

## IDEAS FOR CONSIDERATION

Consider any biological process. Identify all of the factors and forces that could possibly be related to this process, following a format such as:

$$\begin{Bmatrix}\text{Growth}\\ \text{rate}\end{Bmatrix} = \begin{Bmatrix}f(\text{energy metabolism, food availability,}\\ \text{protein quality, vitamins, activity, } \ldots)\end{Bmatrix}$$

Divide each of these further, for example:

$$\begin{Bmatrix}\text{Protein}\\ \text{quality}\end{Bmatrix} = \begin{Bmatrix}f(\text{amino acid spectrum,}\\ \text{productive metabolic processes, } \ldots)\end{Bmatrix}$$

Are you bound up in a cyclic process of repetition and interrelationships? The system cannot be described in a linear fashion!

Develop simple predictive biological models using your present knowledge, with emphasis on the basic energy and matter relationships that regulate the biological parameters under consideration. Keep them workable!

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