MATHEMATICAL MODELING AND WILDLIFE MANAGEMENT: A CRITICAL VIEW

by
DAVID C. GUYNN, JR.[1], WARREN A. FLICK and MARION R. REYNOLDS
Department of Forestry and Forest Products
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

ABSTRACT

Increasing interest and attention to the application of mathematical modeling to large-scale wildlife management problems has given rise to questions concerning the appropriateness and reliability of these procedures to this problem area. An introduction to basic modeling concepts is presented. The characteristics and current status of wildlife management problems are discussed in conjunction with the capabilities and limitations of these procedures.

The virtues of mathematical modeling as a potential tool for large-scale wildlife management problems have been discussed at great length in the literature (Watt 1968, Hayne 1969, Giles and Scott 1969, Gross 1972, Gross et al. 1973). It has generally been implied that a "technological gap" exists between traditional wildlife management techniques and the powerful and diverse mathematical methodologies employed in other disciplines such as industry, business and economics. The growing interest in systems analysis and modeling has led to the suggestion that the future of wildlife management is highly dependent upon the utilization of these approaches. These points are well taken, but such efforts to date have yielded a very limited success relative to that enjoyed by workers in other fields of application. In the remainder of this paper we discuss some reasons why this has happened.

We became directly involved with this problem through a research contract with the Federal Aid Division of the Fish and Wildlife Service to develop resource allocation models to aid state agencies in developing comprehensive plans as outlined by Congress in 1970 (U.S. Congress, Public Law 91-503). A model was developed, tested and evaluated for relating agency expenditures and policy to man-days of hunting recreation. Based on this work we submit the following overview of the appropriateness and limitations of mathematical modeling to large-scale wildlife management problems.

BASICS OF BUILDING A MODEL

The recent emergence of model building in wildlife resource management has created an atmosphere of myticism and mistrust. The general idea has evolved that the model-building fraternity is endowed with some sort of genius (or idiot) insight into biological problems and should be considered a separate discipline from traditional wildlife management. The purpose of this section is to present the basics of mathematical modeling and hopefully dispel this misconception.

Forrester (1971) discusses how each of us uses models constantly in our everyday routines. The mental images of our environment that we carry around in our heads are models. One does not have a deer population or agency structure in his head, but only selected concepts and relationships which he uses to represent the real world. These mental images are the models on which most of our important decisions are based. The real question is not whether to use or ignore models, but rather to decide which should be used and which ignored.

Perhaps the major difficulty in understanding the nature of models results from the failure to see the parallel between Forrester's everyday models and models of wildlife resource systems. Reference to models as mathematical models often creates a mental block that hinders the understanding of model building. This makes it extremely hard for most wildlife biologists to grasp the idea that the everyday mental model can have an

[1] Presently Assistant Professor, Department of Wildlife and Fisheries, Mississippi State University. The authors are deeply grateful for the support of this work by the Division of Federal Aid, U.S. Fish and Wildlife Service.

analogous mathematical counterpart, even though a mathematical model can be built only after the existence of a mental model.

The relationship between an everyday model and its mathematical counterpart will be illustrated with data concerning the reproductive rates of Bison (*Bison bison*) on the 7,503 hectare National Bison Range in Montana (Gross et al. 1973). It is a generally accepted concept that as a big-game population on a given area increases the reproductive rate will eventually decrease. This represents an everyday mental model that all of us can agree on. By plotting the data as presented in Fig. 1, we can visually represent the relationship conceptualized in our mental model. It is quite evident that as the population increased, the number of young per adult female decreased. But this model has certain limitations. How, for example, does one determine the reproductive rate for a population of 227 animals? Construction of a mathematical model could be accomplished by matching a line with the general trend of the data. If a linear model is assumed, the relationship can be described by the equation Y=a+bX, where Y equals the reproductive rate and X equals a population size. By determining the intercept (a) and slope (b) of this line, the model can be written as a mathematical equation and the reproductive rate calculated for any specified population size. It is important to stress that the mathematical model and the everyday model describe exactly the same relation between reproductive rate and population size.

Notice, however, that this model does not fit the data perfectly and that many lines could be drawn through the data which would seemingly describe the situation well. This gives rise to two very important questions: 1) which model "best" describes the relation,

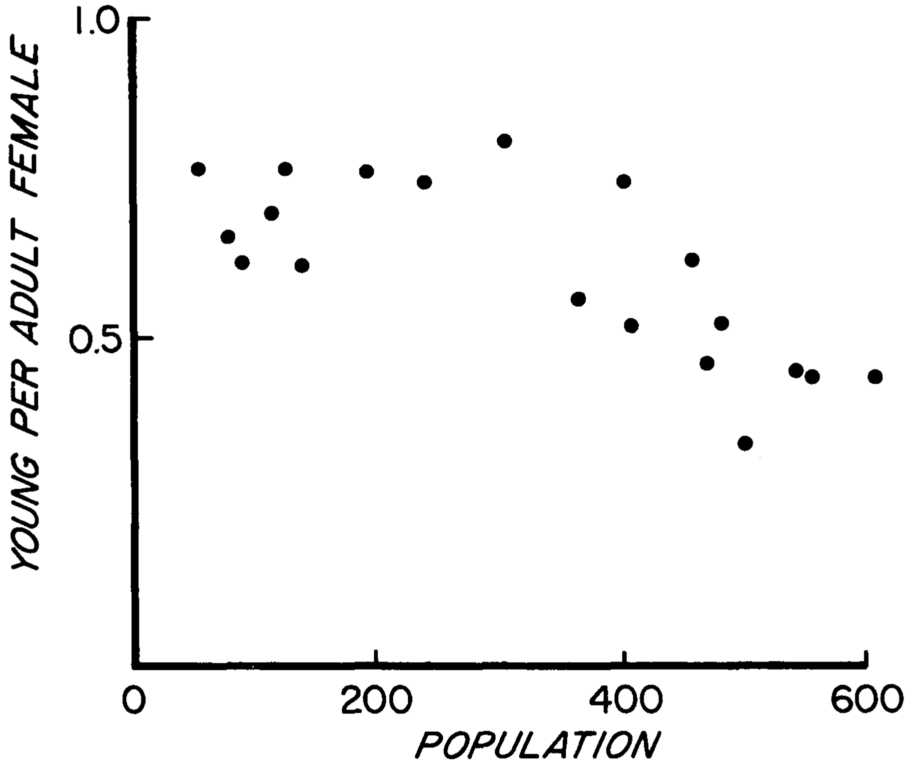

Figure 1. Bison reproductive rates, 1910-1930, for the National Bison Refuge, Montana. (Gross et al. 1973)

and 2) how much confidence can we place in our predictions? A strict mathematical model cannot provide the answer to either of these questions, but a statistical model which treats reproductive rate as a random variable can. In this instance, simple linear regression techniques would yield a statistical model that answers both questions. This statistical model provides a measure of the strength of the relationship by calculation of the coefficient of determination and allows confidence statements to be made about the estimated reproductive rate for a specific population size. The model is described by the equation $y_x=0.759-0.00055X+\varepsilon (r^2=.55)$, where y_x equals the reproductive rate, X equals a specific population, and ε represents the error term. It is quite possible that we could represent a mathematical model of the relationship with the equation $Y = 0.759 - 0.00055X$. Both models would yield exactly the same estimate of reproductive rate for a given population, but only the statistical model allows us to make a statement about the degree of confidence that can be placed in the estimates. This is of extreme importance to us as wildlife managers, since we seldom encounter biological relationships that can be adequately described by strict mathematical models.

This leads us directly into the realm of simulation modeling. Simulation is simply defined as the representation or imitation of real processes. Simulation models can be constructed with mathematical or statistical relationships, but simulation is often differentiated from other kinds of mathematical modeling by its ability to incorporate a large number of random events. This is accomplished by describing many variables with probability distributions and writing equations that show the relationships among the variables. Suppose that we wanted to construct a detailed simulation model of the Bison population previously mentioned, and that the reproductive rate-population relationship was only one of many interrelated equations in the model. Having used a regression model to establish this relationship, we can also derive a confidence estimate of reproductive rate. We wish to address the question, what effect will various values of reproductive rate have on the overall model estimates? Allowing the value of reproduction to vary within the confidence limits governed by a specified probability distribution and repeating the calculations many times would answer this question.

The remainder of this paper will deal directly with simulation modeling and its applicability to larger scale wildlife management problems. However, comments are equally appropriate to all mathematical modeling procedures since simulation is the most general and flexible of all modeling approaches.

MODELING AND WILDLIFE MANAGEMENT

Since World War II many mathematical and simulation techniques have been developed and successfully applied to complex decision problems in industry, business and other management sciences. Modeling such decision systems entails identifying decision variables (those directly controlled by a manager), output variables (those the manager wants to control indirectly), and the relationships between these two sets of variables. These procedures have provided much needed decision information about complex problem environments and greatly increased management effectiveness. It would seem that these procedures would be equally applicable to wildlife management problems. Before we pass judgement on this presumption, let us first look at the environment where these procedures were created and compare it with the situation we face in current wildlife management problems.

Traditional applications of modeling in other management sciences have dealt with strictly defined and controlled problem environments. Important variables were easily identified and relatively small in number. Because many of the variables of interest are directly dependent on man-made physical processes (such as assembly lines), relevant data could be easily obtained for specifying associated probability distributions. For example, quality control of manufactured products is an area where simulation modeling has been used extensively. A common situation is to have several steps or machines involved in a production process. Each step has associated with it a certain variability in production. The variables at each step are easily defined and data concerning these variables can be readily obtained. Models can be constructed to identify areas that need refinement, steps where additional machines or operators are needed, establish overall sampling procedures to determine quality control, and define optimum operational procedures.

In contrast, such problem environments are rare in wildlife management. Even small wildlife resource systems are very open and complex, and both the number of variables affecting such systems and the inherent variability associated with these variables is very large. These variables are not just simple physical variables like those that describe man-made systems, but consist of biological, political and social variables as well. The biological variables are obviously necessary, but meaningful biological information is difficult, time consuming and expensive to collect. Estimating wildlife population numbers is a prime example. Biologists frequently face the problem of managing a population to provide maximum human benefits without harming the population itself. It would seem that knowledge of population numbers is essential to effective management. Yet for many populations this information is practically impossible to obtain. In modeling context, these data are necessary and generally estimated after many assumptions and extrapolations have been made. Many will argue that knowledge of population numbers is not really necessary for sound management, and that population characteristics and habitat can be used as a basis for management recommendations. This may be true for broad management practices such as decisions about either-sex hunts for big game, but how many animals should be harvested and what specific affects on the herd will result? These questions are crucial to the development of model relationships to describe this situation.

Consideration of the social variables involved in wildlife resource systems greatly complicates an already complex problem. Human activity does much to dictate the location and size of wildlife populations. Changes in economic conditions can radically influence land-use patterns and public sentiment toward wildlife resources. The conversion of the vast Mississippi Delta forests to row crops is a startling example of the habitat destruction that has occurred in this country during the last two decades. The recent economic recession had dramatic effects on hunter participation and usage patterns. Public sentiment toward forestry practices such as clear cutting and the recent upsurge of the anti-hunting movement have created additional factors that must be dealt with by the manager. To effectively model large-scale wildlife resource systems, these factors must be included even though they represent variables over which the manager has no direct control.

Finally, all of us are aware of the effects of political pressure on the formulation of management policy. Management variables such as season structure and length or bag limits which directly affect populations and man-days of recreation are often politically controlled. In a modeling context, these should be decision variables, but managers often have little input into such decisions. License fees which constitute a major portion of state agency budgets are also controlled by politics. Here again, we are faced with an important systems segment that we can not realistically describe in modeling situations.

The above discussion emphasizes the two major problems to be faced when modeling techniques developed for other disciplines are applied to large-scale wildlife management problems. First, we have very little knowledge of many important variables that must be included to adequately describe the system. To make matters worse, most of these variables should be considered as random variables and we have little or no knowledge about the appropriate density functions that describe them. Second, there is the problem of establishing the relationships between these variables. Much time-consuming and expensive research will have to be conducted to provide the necessary data to establish these relationships.

There are three other factors that have created difficulty in the application of modeling to wildlife management problems. These are the training of wildlife biologists, the difficulty of validation, and the problem of defining an optimal solution. Each of these will be discussed briefly.

Managers in such disciplines as business, economics and industrial management are well versed in quantitative techniques and concepts. Most can at least converse with the systems analyst or model builder. The average wildlife biologist, however, is ill-prepared to think in these terms. Moreover, since the wildlife manager already receives training in a number of disciplines, to require him to undergo intensive training in mathematical and analytical techniques is generally impractial. Thus, not only is the average wildlife biologist ill-prepared to function as a model builder, but he may be reluctant to accept the findings of others who use models because he cannot fully comprehend their operation.

The value of many modeling efforts has been left in question by the belief that construction of the model completes the task (Barton 1970). This has been especially true of simulation studies of wildlife management systems. After development, the model should be used with past data to see how closely it approximates the reproduction of past occurrences. Statistical tests can often be used to determine whether differences in simulated and actual data are significant. Once the model has been validated and its credibility established, it can be applied to management problems. Sufficient data seldom exist in wildlife management problems to accomplish this important phase of model building.

The structure of most models in traditional applications has provided for the identification of an optimal solution. This involves defining an objective function composed of output variables and constrained by decision variables, and solving for values of the decision variables which yield a minimum or maximum value for the objective function. In business and industrial applications this generally consists of identifying the solution which minimizes costs or maximizes profits. Most wildlife management modeling efforts to date have dealt only with prediction, although some have suggested that solutions be carried to the stage of defining an optimal solution for a stated objective function. This phase of modeling will be extremely difficult to attain in wildlife management problems for two reasons. First, the number of output variables involved in a practical objective function will be large and the relationships of these variables and decision variables will be extremely difficult to formulate. Much discussion has already been given to this point. Second, many of the outputs of such systems have nonmarketable values that are extremely difficult to quantify. Even if they can be individually quantified, the problem of establishing a comparative unit of value must be solved.

CONCLUSIONS AND RECOMMENDATIONS

Simulation modeling techniques have developed primarily in closed and controlled problem environments where variables are directly dependent on man-made physical processes. The number of variables involved is relatively small and relevant data can be easily and quickly gathered. This is in direct contrast to the problem environment characteristic of wildlife management systems. Because of this difference, the success of applying these techniques to wildlife management problems is going to be limited relative to the successes enjoyed in other disciplines. This is because simulation modeling requires knowledge of all important variables and the relationship between them. Such knowledge about wildlife resource systems is scarce. Much research is needed to describe biological variables and the relationships among them, but of even greater importance is the lack of specific information concerning the social and political variables. These important system segments must be described well if models of large-scale wildlife management systems are to be operational on a management level. In view of this general conclusion, we offer the following recommendations.

Research efforts should be directed to identifying the variables which affect wildlife resource systems, the probability distributions that describe them and the relationships between the variables. Concentrated, long-range research will be required to describe relationships such as those between population levels and habitat conditions. But of even greater importance is the almost total lack of information concerning the human aspect of wildlife management systems. To date, most of our research efforts have dealt with the animal segment of the system with little or no emphasis on the social variables. We feel that major research efforts should be directed to describing social variables.

The complexity and open nature of large-scale wildlife management systems restricts the applicability of traditional simulation modeling techniques. It is, therefore, important that problems be well conceived and described by variables that can be identified and measured, and whose solutions will be useful for management purposes. This will necessitate applying modeling techniques to small, specific segments of wildlife management systems. Much work of this type has already been started. The works of Preston (1973), Fowler and Smith (1973), Lobdell et al. (1972) and Gross (1972) have already provided insight into specific wildlife population systems. These studies should be viewed as a starting point and can be improved as more information becomes available. Even though such studies may not be conclusive, they are often extremely valuable in that they identify the kinds of data needed for effective management. Work of this type should be continued and expanded as knowledge of wildlife systems increases. If viewed in this perspective, simulation modeling will prove a valuable asset to certain aspects of wildlife management.

LITERATURE CITED

Barton, R. F. 1970. A primer on simulation and gaming. Prentice-Hall, Inc., Englewood Cliffs, N. J. 234pp.

Forrester, J. W. 1961. Industrial dynamics. The M.I.T. Press and John Wiley and Sons, Inc., New York, N. Y. 464pp.

Fowler, C. W., and T. Smith. 1973. Characterizing stable populations: An application to the African elephant population. J. Wildl. Manage. 37(4):513-523.

Giles, R. H., Jr., and R. F. Scott. 1969. A systems approach to refuge management. Trans. N. Am. Wildl. Resour. Conf. 34:103-115.

Gross, J. E., J. E. Roelle, and G. L. Williams. 1973. Program ONEPOP and information processor: A systems modeling and communication project. Colo. Coop. Wildl. Res. Progr. Rept. 327pp.

____________________. 1972. Criteria for big game planning: Performance measures vs. intuition. Trans. N. Am. Wildl. Nat. Resour. Conf. 37:246-259.

Hayne, D. W. 1969. The use of models in resource management. *In* Halls, Lowell K. (Ed). 1969. White-tailed Deer in Southern Forest Habitat. Symp. Southern For. Exp. Sta. 130pp.

Lobdell, C. H., K. E. Case, and H. S. Mosby. 1972. Evaluation of harvest strategies for simulated wild turkey population. J. Wildl. Manage. 36(2):493-497.

Preston, E. M. 1973. Computer simulated dynamics of a rabies-controlled fox population. J. Wildl. Manage. 37(4):501-512.

U. S. Congress. 1970. Federal aid in wildlife restoration: Public Law 91-503. H.R. 12475. Washington, D.C.

Watt, K. E. F. 1968. Ecology and resource management—A quantitative approach. McGraw-Hill, New York, N. Y. 450pp.