The Utility of a Digital Simulation Language for Ecological Modeling

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Summary. Dynamic modeling of ecological phenomena has been greatly facilitated by the recent development of continuous system simulator programs. This paper illustrates the application of one of these programs, S/360 Continuous System Modeling Program (S/360 CSMP), to four systems of graduated complexity. The first is a two species system, with one feeding on the other, using differential equations with constant coefficients. The second and third systems involve two competing plant species in which the coefficients of the differential equations are varying with time. The final example considers the management of a postulated buffalo herd in which the dynamics of the herd population and composition by sex and age is combined with various strategies to control its size and to optimize buffalo production.

Recently developed "continuous system simulator" languages make it possible for the ecologist to construct digital computer models of biological systems with a minimal input of effort and mathematical expertise. These languages permit him to concentrate on the biological phenomenon of interest rather than the intricacies of numerical analysis and digital computer programming (Brennan, 1968; Yates et al., 1968). This paper provides an introduction to S/360 CSMP1, perhaps the most powerful of these languages, and illustrates its application to several simple ecological systems.

Theory relating to the number and kinds of plants and animals found in nature and their order and interactions has developed considerable sophistication in recent years. Slobodkin (1961) has stated that such a general theory is a solvable problem and that the procedures involved in its solution are available at least in principle. In general, the solution must be sought in the mathematical expression of relationships. The most convenient mode for defining such processes is in systems of algebraic or differential equations. But most processes in nature are essentially non-linear, and the analytical solution of all

1 "S/360 CSMP", or more properly, "S/360 Continuous System Modeling Program", is a continuous system simulator developed by IBM for its System/360 Computer System operating under OS/360 on systems with 128K core memory or larger.
but the most trivial system of non-linear algebraic or differential systems of equations is impossible or at least extremely cumbersome (Franks, 1967). Watt (1966) and Patten (1966) among others have suggested using systems analysis techniques with general purpose computer languages (e.g., FORTRAN, ALGOL, PL/1). This makes possible the solution of many problems not amenable to analytical resolution, but requires considerable mathematical facility on the part of the researcher and usually the services of a professional programmer to handle the many details of program writing and debugging.

The utilization of a simulation language for work in this area has received little attention as yet by ecologists, although their usefulness has been indicated by Garfinkel and Sack (1964), Paulik and Greenough (1966), and de Wit and Brouwer (1968). Recently-developed simulation languages have several advantages for those with a limited mathematical and computer background. First, they are relatively simple to learn. Rather than worrying about the details of programming (which have been taken care of by the language developer), one can concentrate on relational concepts and problem conceptualization. Second, because of the dynamic aspects of the modeling permitted, one can observe relationships not apparent from steady state solutions, and thus can ascertain inadequacies and ambiguities in the postulated model. This may lead directly to the formulation of incisive experiments.

**Description of S/360 CSMP**

S/360 CSMP is a continuous system simulation language which enables the user to define the structure of a model starting from either a relational block diagram or a differential-equation representation of the model system (IBM, 1968). This language feature is an accommodation to the observation that people are of distinct cognitive types: those who conceptualize dynamic phenomena in pictures and those who do so via mathematical notation. To the ecologist this means he may use such simulation languages in whatever manner seems most convenient for the particular investigation. For example, he may view exponential smoothing as a process provided by a functional block into which he sends certain signals and from which is obtained an output, or he may consider it a mathematical operator of specific difference or differential equation form. The distinction is entirely conceptual; in each case the operation must be specified with precision. While simulation languages facilitate model building and verification, they contain no magic to transform muddled thinking into scientific investigation.

The program provides a complement of 34 functional blocks (also called functions) for modeling a continuous system. These functions