PROCEDURES AND PROBLEMS IN MODELLING ECOSYSTEMS: AN AGRICULTURALIST'S VIEWPOINT

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INTRODUCTION

Any discussion of systems modelling is handicapped by the systems jargon that has developed in the literature. The communication problem is a major one, even for persons working in the same field. For the purposes of this paper, systems modelling is defined as an activity involving the construction of a mathematical model of a system, generally but not necessarily followed by manipulation or experimentation with the model. The model may simply describe the behaviour of the system over time or space (a simulation model), or it may be based on optimising techniques such as linear or dynamic programming. Systems modelling is part of what is variously referred to as systems analysis, systems research or the systems approach (Dale, 1970; Watt, 1966; Wright, 1973).

Over the last decade systems analysis, or in the context of ecology, ecosystem analysis, has attracted considerable attention. It is clear, however, that systems analysis is really no more than the use of the scientific method to study complex systems (Dale, 1970), and as such can hardly be regarded as "new". The only aspect that is new is the greater use made of mathematical models. Developments in systems modelling have largely paralleled the increasing power and availability of computers, and the acceptance by scientists of the computer as a research tool.

Systems modelling appears to be well established in ecosystem research as evidenced by the major emphasis given to modelling in the U.S. component of the International Biome Progromme (Hammond, 1972). The appeal of systems modelling to many ecologists is understandable in that it allows them a potential means of experimenting with systems for which real life experimentation is difficult or impossible. Apart from problems of cost and time, the consequences of experimenting with many ecosystems may be biologically or socially unacceptable. By contrast, systems modelling in agriculture, as one field of applied ecology, is by no means an accepted technique. The relatively cautious approach of many agricultural scientists is understandable in that their research is based on an ability to experiment with real systems. For this reason, the potential advantages of experimenting with computer models are probably less apparent to the agriculturist than to the ecologist .

There are additional reasons for caution. When one looks at what has been achieved by systems modelling in relation to expectations, in both ecology and agriculture there are grounds for concern. Because of the lack of conclusive evidence, Massey University and the Ruakura Agricultural Research Centre have established a joint systems modelling project at Ruakura with the specific objective of exploring and evaluating the role of systems modelling in an agricultural research programme. The comments on procedures and problems in this paper are in part based on experience gained in this project.

OBJECTIVES

Many of the problems of systems modelling projects arise from inadequate specification of objectives. The usual objectives can be summarised as:

(i) to gain or improve understanding of how a complex ecosystem functions,

(ii) to predict how an ecosystem will respond to natural or induced perturbations,

(iii) to solve problems relating to manipulation of the ecosystem to achieve given ends.

Because prediction and problem solving imply an initial understanding of the system, the first of these objectives is, or soon becomes, the most important in the minds of many researchers. Yet as Brockington (1972) has noted, a vague definition of objective on the lines of understanding how the ecosystem functions is not generally sufficient.* Models

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* An exception could be where modelling is used as an aid to teaching.

developed with such objectives are never satisfactory as it is always possible to see areas where further refinement may lead to increased realism.

Most persons involved in a systems modelling project do claim that their understanding of the system has been improved. However, any form of intensive study (e.g., a literature review, or simply observation of the real system) is likely to have a similar result. A model does provide a framework around which information about a complex system can be assembled, but the basic question is whether modelling is more efficient than alternative means of learning about the system. The answer is likely to vary depending on the nature of both the system and the individual researcher. Apart from benefits accruing to the individual, it is difficult to find examples in the literature where modelling has increased understanding for persons not directly involved in the project.

Even when original objectives are defined in some detail and related to problems, researchers too often seem unwilling to tackle the problem of providing answers until they have developed more realistic models. There is the additional danger noted by Paulik (1966), that modelling itself could prove to be so fascinating that the original objectives will be lost. A glance at some of the published reports on systems modelling studies indicates that these are very real dangers.

The feedback value of systems modelling is often emphasised. The argument is that weak links in knowledge about the system are highlighted, and guidelines are provided for research to fill these gaps. This is apparent, for example, in some of the large-scale ecosystem studies. The concluding sections of progress reports on such projects often read like a shopping list of research resources required to improve the model to the stage where some answers to the original problem can be provided. The problem is that modelling may merely be a complex means of proving the obvious!

In the Massey-Ruakura project we have encountered most of these problems. Our overall objective (exploration and evaluation) is fairly general, and in order to make progress it was decided to restrict the project to the study of intensive pastoral beef production systems. The specific objectives for model development were then laid down by the group in terms of what the model should be able to do, if it was to be of use in designing and evaluating alternative production systems. In the course of time, some of these objectives proved to be impractical due to lack of information on which to base the model.

There are many sections of the model where we believe that further refinement would lead to added realism, and there are many interesting things that could be done with the model. We are consciously trying to put these aspects aside, except where it is felt that they are essential to the objectives of the project. The modelling exercise has certainly highlighted deficiencies in knowledge about the system, but in all cases this lack of knowledge was already known, although it may have been salutory for some of the people involved to be reminded of the nature and extent of these deficiencies.

A final point that is highlighted by the project, is that while clearly defined objectives are important for ensuring results, a well defined and relatively inflexible end point may be of equal or greater importance. Among other things, this has forced us to allocate the available time between developing the model, and using it to obtain results. Without such safeguards, it is easy to see how modelling studies will absorb any given amount of resources without necessarily producing any results.

APPROACHES TO MODELLING

In many respects systems modelling is still more art than science, and there is an undoubted need for a sound theory of model building (Hudetz, 1973). The problem is illustrated by the different approaches taken in the U.S. IBP projects (Hammond, 1972).

One approach is to start with a crude model of the "whole" ecosystem (however "whole" might be defined), and to develop successively more detailed sub-models to fit into the overall model. This is the approach that has been adopted in the Grasslands Biome.

An alternative approach used in the Deciduous Forest Biome is to start with models of fundamental processes, and when these are satisfactory, to integrate them into an overall model. As yet there is no indication of which approach will lead to the most accurate models. Neither has so far developed ecosystem models which are regarded as being useful for problem solving, in spite of the tremendous input of resources!

A third approach used in the Desert Biome is to develop models around problems. The model only incorporates detail relevant to the particular problem, and there is no attempt to model the entire ecosystem. Unless a general objective of increased understanding can be supported, then I believe this latter approach is the one most likely to yield positive results for a given input of resources. At least it focuses attention on a problem and the need to provide answers to that problem.

A problem-oriented approach is likely to combine elements of the first two approaches referred to above. The starting point may be a relatively crude model which is progressively refined in relation to the problem. This may present some difficulties as relatively few scientists with their training in precision, are happy about crudity. Yet this is the quickest way to progress towards a working model, and improvement can then be made with the emphasis on producing better results, rather than on the level of refinement of particular components of the model.

It may be possible to build models utilising other models of fundamental processes or system components. This is certainly beginning to occur in agriculture (e.g. Rice *et al.*, 1974), and the practice is likely to grow as more modelling studies are published. In our model of a grazing system, for example, the pasture and soil components were adapted from existing models and only the animal and management components were developed independently. Adaption of existing models involved both refinement for the pasture component, and simplification in the case of the soil component. The artistic nature of modelling, however, is often reflected in a preference to use one's own creation rather than existing models. This has one virtue in that having built a model from the ground up, one should be thoroughly aware of its limitations.

A final comment on approaches relates to the use of simulation models versus optimising models. Most of the models reported in the literature are simulation models which merely describe the behaviour of systems. The use of optimising models has an obvious appeal when answers to problems are required. To use an optimising procedure an objective must be specified in terms of something to be maximised or minimised, and each "run" of the model produces solutions to the problem. Solutions as distinct from descriptions are rather harder to come by using simulation. However, many biological scientists are happier working with simulation models, as the model can be developed around the way they think about the system, rather than their having to conform to a framework dictated by an optimising technique. The best of both worlds may lie in the use of an interactive simulation-optimisation approach (Swartzman and Van Dyne, 1972).

MODELLING BY INDIVIDUALS AND GROUPS

It is unlikely that in the foreseeable future we will have the resources available in New Zealand to support the large-scale, multi-disciplinary, multi-institutional modelling projects currently operating in the U.S.* Modelling activities here are most likely to be carried out by individuals or by small groups. The following comments are largely based on my own involvement in modelling both as an individual, and as a member of a group.

The individual venturing into modelling faces major difficulties. He must of course be proficient in his particular field of interest, as a model is more likely to reflect than overcome deficiencies in knowledge. He must also have some skills in computer programming and possibly in computer operation. The self taught programmer can construct and run computer models, but it can be an inefficient and frustrating process. Most importantly, the individual should have the self discipline to set objectives, to evaluate his progress, and to terminate unproductive efforts. Unless he can find people to share and stimulate his interest in modelling it can be a rather lonely activity.

In New Zealand there are very few agricultural researchers who have progressed beyond the learning stage in modelling, and I suspect the situation in ecology may be very similar. Nevertheless, progress is most likely to stem from individual efforts, and the only way to learn about modelling is to do some. Initial attempts however, should be viewed as a learning exercise rather than as a guaranteed path to success.

Modelling by small groups is more likely to be productive than individual efforts, particularly when the objective is to model "whole" systems rather than components or processes. The members of the group can contribute expertise from their own discipline which partly overcomes the problem of no single person having all the necessary skills. However, the individuals should also have an inter-disciplinary outlook. For example, any modelling study of a grazing system should involve an agronomist, but his contribution will be all the more valuable if his interest extends to the whole of the soil-plant-animal-management complex. A secondary benefit of a team approach is likely to be the promotion of inter-disciplinary communication and co-operation. There in some evidence of this occurring in the Massey-Ruakura project.

The modelling group should be small to be effective, and while there are no firm rules, a core of three or four would seem to be the optimum size. Our own group involves six persons which is probably too large, but it is in an experimental situation. Benyon

* Such projects create special problems of organisation and management. See, for example, Van Dyne (1972).

(1972) suggests an upper limit of 15 for a team with an expert for each of the relevant disciplines attached to a core of computer scientists and mathematicians. This may be possible in large organisations where people can be directed towards projects, but it is unlikely to be workable if individuals have other commitments in research, teaching or administration. At various times during our project, the involvement of most individuals has been restricted due to other commitments of this nature. Fortunately, this has not seriously affected progress, but it is obviously a potential problem for group modelling.

In theory, greatest progress in systems modelling will be achieved if the individual members of the team are leaders in their own fields. In practice, such persons have usually acquired other responsibilities, and are often the ones least able to commit themselves to full, or even part time involvement in a project. In addition, the benefits of modelling to top scientists may be minimal, as they may well have reached the top because of their ability to understand complex systems without the aid of formal mathematical models.

The key person within the group will be the leader or co-ordinator.* He will have the major role of seeing that objectives are defined and adhered to, and of generally providing the stimulus for the group. Most likely he will be the person responsible for initiation of the project. In fact Morley (1973) argues that progress is more likely to stem from strongly motivated individuals making use of specialist colleagues, than through the formal organisation of studies in groups. However, my own experience is that the contribution of such specialists is of most value when they have some formal involvement in the project.

CONCLUSION

The tone of this paper has been cautionary rather than evangelistic, but I believe this is a fair reflection of the current state of systems modelling. The initial enthusiastic response to systems modelling is probably over, and even though the methodology needs further development, persons working in the field will be expected to produce answers to problems, rather than endless descriptions of interesting models.

In the real world, society is constantly making decisions about problems that concern agriculturalists and ecologists. These decisions are being made, often with imperfect knowledge, and will not be postponed while the researchers develop their "realistic" models. It needs to be shown that systems modelling can help in making better decisions now, even though optimal decisions may not be achieved for some time, if ever.

* See Armstrong (1973) for a discussion of the role of a co-ordinator in a group.

REFERENCES

ARMSTRONG, J. S. 1973. The Implementation of Systems Research Projects. *Proceedings of the Agricultural Systems Research Conference, Massey University*. 76-80.

BENYON, P. R. 1972. Computer Modelling and Interdisciplinary Teams. *Search* 3: 250-256.

BROCKINGTON, N. R. 1972. An Agricultural Research Scientist's Point of View. In: Jeffers, J. N. R. (ed.), *Mathematical Models in Ecology*. Blackwell, Oxford, 361-365.

DALE, M. B. 1970. Systems Analysis and Ecology. *Ecology* 51: 2-16.

HAMMOND, A. L. 1972. Ecosystem Analysis: Biome Approach to Environmental Research. *Science* 175: 46-48.

HUDETZ, W. J. 1973. Ecosystem Models and Simulation. *Simulation* 21: 81-83.

MORLEY, F. H. W. 1973. The Organisation and Administration of Systems Research: A Research Leader's Viewpoint. *Proceedings of the Agricultural Systems Research Conference, Massey University* 82-87.

PAULIK, G. J. AND GREENOUGH, J. W. 1966. Management Analysis for a Salmon Resource System. In: Watt, K. E. F. (ed.). *Systems Analysis in Ecology*. Academic Press, New York, 215-252.

RICE, R. W.; MORRIS, J. G.; MAEDA, B. T. AND BALDWIN, R. L. 1974. Simulation of Animal Functions in Models of Production Systems: Ruminants on the Range. *Federation Proceedings* 33: 188-195.

SWARTZMAN, G. L. AND VAN DYNE, G. M. 1972. An Ecologically Based Simulation-Optimization Approach to Natural Resource Planning. *Annual Review of Ecology and Systematics* 3: 347-398.

VAN DYNE, G. M. 1972a. Organisation and Management of an Integrated Ecological Research Programme. In: Jeffers, J. N. R. (ed.), *Mathematical Models in Ecology*, Blackwell, Oxford, 111-172.

WATT, K. E. F. 1966. *Systems Analysis in Ecology*. Academic Press, New York.

WRIGHT, A. 1973. A Systems Research Approach to Agricultural Research and the study of Grazing Systems, *Proceedings of the Agricultural Systems Research Conference, Massey University*, 5-11.