Chapter (non-refereed)

Jeffers, J. N. R.. 1987 The role of expert systems in temperate forest research. In: Yang, H.; Wang, Z.; Jeffers, J. N. R.; Ward, P. A., (eds.) *The temperate forest ecosystem.* Grange-over-Sands, NERC/ITE, 171-174. (ITE Symposium, 20).

The role of Expert Systems in temperate forest research

J N R JEFFERS
Institute of Terrestrial Ecology, Grange-over-Sands, England, UK

Abstract
In the management of temperate forests, there is a need, as in many other kinds of resource management, to make use of the latest information available from scientific research, and from the field experience of practical foresters. Some of this information can be gained from books and training courses, but the number of experts and teachers is insufficient to provide the advice and information where it is required. This paper emphasizes the need to take account of recent advances in ecological research in the management of biological resources, as in a forest, and suggests that Expert Systems provide one possible way in which such advice can be made available quickly and cheaply.

1 Introduction
During the last few years, a new development has taken place through the combination of computer programming, mathematical theories of artificial intelligence, and the knowledge and skill acquired by human beings in the management of practical affairs. We call the products of this new development 'Expert Systems', and it might be helpful for me to define precisely what we mean by the use of those 2 words.

'An Expert System is a computer program that embodies some fraction of the knowledge characteristic of an expert in a specialized area and which can use that knowledge to suggest the same types of conclusions as the expert would reach if confronted with the same information, and can justify those conclusions.'

The emphasis in this definition is on the incorporation of specialist knowledge which would not otherwise be generally available, and on the use of this knowledge to solve particular classes of problems from the same information that would be available to a human expert, or which would be requested by the human expert from whom advice was sought. However, an important additional property of Expert Systems is that they are able to provide the reasons for the use of the solution of the problem, and it is this property which sets Expert Systems apart from other types of computer programs.

The emphasis on the solution of particular kinds of problems is also quite deliberate. The academic community has long been accustomed to the importance of allowing scientists to develop theoretical approaches to their fields of interest without too much regard for the practical value of those approaches. If the theory has a practical 'spin-off', so much the better, but the need to solve practical problems must not be allowed to inhibit the development of research and theory. In contrast, today's principal requirement is for the application of what we know now to problems which we can already perceive and anticipate. Access to the required information is restricted by the formats which have been adopted by scientists for the publication of their results, aimed inevitably at other scientists, and, in general, intelligible only to other scientists. Simplified accounts of scientific results are almost always incomplete or inaccurate in essential details, so that resource managers, decision-makers and administrators have little access to the scientific information which they need to solve their problems. In-house advisors who may have been trained as scientists can provide some help, but themselves quickly fall behind current developments by the simple fact that they are no longer doing research themselves.

2 The role of ecology in temperate forest management
A proper understanding of the complex interrelationships between organisms, including man, and their environment is essential if we are to manage temperate and tropical forests rationally. There are 3 essential criteria for the ecological management of forests:

i. maintaining essential ecological processes and life-support systems;
ii. preserving genetic diversity;
iii. utilizing species and the forest ecosystem sustainably.

These criteria can only be achieved by knowledge and by the application of that knowledge in practical decision-making.

However, ecological research is greatly complicated by the fact that the interactions between individual organisms and between organisms and their environment are dynamic, in the sense that they are time-dependent and constantly changing. Furthermore, the interactions frequently contain feedback, ie the carrying back of some of the effects of a process to its source or to a preceding stage so as to strengthen or modify it. Such feedback will sometimes be positive, in the sense that the effect is increased, and sometimes negative, in the sense that the effect is decreased. The feedback itself may be complex, involving a series of positive and negative effects, with various results depending on a series of environmental factors. In addition, living organisms are themselves variable – variability being one of their essential characteristics. This variability may be expressed in terms of effects on other organisms, for example by competition or predation, or it may be expressed in the response of organisms, either collectively or singly, to environmental factors. Such response will be reflected in variable rates of growth and of reproduction, and even in variable ability to exist under strongly adverse conditions. When this characteristic is added to independent variations in environmental factors such as climate and habitat, changes in ecological processes and systems are not easy to predict from simple 'common-sense' rules.

Nevertheless, ecologists have been successful in developing a body of ecosystem theory which can be used to predict how ecological systems will behave under certain conditions. This theory depends on a set of concepts which are themselves relatively complex and frequently counter-intuitive in their prediction of changes in organisms and communities. As a result, the only effective way that ecologists have found for managing the complexity is through the use of mathematical models. The abstract language of mathematics provides a representational symbolic logic which simplifies, but does not markedly distort, the underlying physical and biological relationships. These representations, in turn, enable us to make comparisons between our model systems and the real systems which decision-makers have to manage, and, in this way, to test the adequacy of the model against observations and data derived from the real world – the appeal to nature which is a necessary component of the scientific method.

3 Models and decision-makers

While the use of mathematical models may be convenient, even essential, for those of us engaged in ecosystem research, such models do not solve the problems of communicating the results of scientific research. Few of the resource managers, decision-makers and administrators who need to understand the consequences of their proposed policies and management practices on temperate and tropical forests are likely to be able to find sufficient time to understand the models which are used to describe such ecosystems. Today, we use computers to make the calculations necessary to show the effects of changes on the forest, and the unfamiliarity of forest managers with these computers adds to the difficulties of understanding.

The effective use of mathematical models for the solution of practical problems also depends on the correct estimation of key parameters in the model, and the knowledge of these values lies with the decision-maker. Identification of the correct values depends on the ability of the scientist to communicate the precise meaning of the parameters, and the role which those parameters play in the model. For example, in many situations in which it is necessary to control the population of one or more species of animals in, say, a National Forest Park, it is essential to have some measure of the rates at which animals are harvested or culled, but quite difficult to identify the basis of the calculation of rates as used by game wardens, etc. The degree of genuine agreement between what is assumed by the scientist and what is understood by the decision-maker needs constantly to be checked if the model is to be useful.

4 Role of Expert Systems

The role of Expert Systems is 2-fold. First, they act as an intelligent interface between the models built by ecologists and the users of those models. The interface guides the user by structuring questions to which answers are required, in the correct order, and by leading the user through a complicated series of procedures so as to enable him to make effective use of the knowledge which has been gained through scientific research. The answers to key questions can be checked by asking the questions in several different ways so as to ensure that the responses are consistent. In more complicated situations, it may be especially important to devote time to establishing the correct background to the problem, before choosing the most appropriate solution.

Second, Expert Systems can be used to provide more detailed explanations of why particular solutions are obtained from the use of the models that have been developed by the scientists. Such explanations often require the systematic display of fairly simple relationships between the key variables in a temperate forest system, perhaps related to equally important variables in the associated economic or social systems. The variables can then be grouped in combinations controlled by the user so as to build up an understanding of the non-linear or feedback mechanisms which so often dictate outcomes that are unexpected or unwelcome. By placing the whole of the explanation phase under the control of the user, he does not feel threatened in the same way that a decision-maker may when confronted by a scientist telling him that some proposed policy or project simply will not work.

As more and more specialists become involved in the preparation of the interface, the Expert System builds up a body of knowledge which is greater than that which would be provided by a single specialist, or even a small team of specialists. Contradictions and inconsistencies are gradually eliminated as the System is tested and improved. Weaknesses can be remedied as they are pointed out by the users, and omissions repaired. Every Expert System used as an interface in this way should, therefore, contain a section which reports on the pathways taken through the system during its practical use, and on any points at which the System failed. Such a tracing facility provides the specialists who are attempting to co-ordinate their expertise with a 'map' of where difficulties occurred in the interpretation of their advice.

5 Expert System applications in temperate forests

Although Expert Systems will almost certainly play a major role in most practical applications of ecological theory to forest management, there are 4 principal areas which will be described briefly in this paper, as illustrations of what is currently being developed. Expert Systems do not have to be either extensive or expensive to be useful. Indeed, it is usually better to start 'small' and grow by collaboration between the specialists and the decision-makers.

5.1 Vegetation succession

One of the critical areas of forest research is that of vegetation dynamics and succession. The classical theory of succession in forestry assumes a gradual development towards a climax vegetation from the first colonization of bare ground.

This climax vegetation may then be disturbed by some natural occurrence, like a fire, flood or earthquake, or by some man-made intervention, such as the felling of a forest, ploughing of grassland, or the elimination of herds of grazing animals. The vegetation then goes back to some earlier stage in the succession, before gradually returning to the climax vegetation, in the absence of any further intervention. The system may actually be very much more complicated, with the existence of truncated successions resulting from invasions by species of plants which do not allow further invasions, and hence prevent the full development of the successional states.

One especially important problem in many countries is concerned with the development of forest vegetation after the occurrence of fire. Overprotection of many forest systems against small brush fires may lead to the build-up of so much inflammable material that a subsequent 'hot' fire does more damage to the system than regular small fires. The effect of fire on vegetation succession is especially important in arid zones and in the Mediterranean region. Other examples of the value of a knowledge of succession include the management of shifting cultivations, land reclamation, and the protection of ecologically fragile areas against overexploitation.

Dr I R Noble of the Australian National University has developed an Expert System to predict the successional changes in ecosystems from a knowledge of the species which are known to exist in the communities of the various successional states. The Expert System is based on a theory of 'vital attributes' of plant species, which determines the ability of a species to survive various kinds of 'intervention' and to reproduce. The characteristics of each plant species are determined by the Expert System through a dialogue with users of the System who are assumed to have at least some basic knowledge of the plants in their vegetation communities, although the answers to the questions are checked by the System itself for inconsistencies and inaccuracies. Repeated use of the Expert System for the same communities draws on the knowledge which has already been provided about individual species. This Expert System has been tested extensively in Australia and was recently tried out in the temperate forest region in China. The results are certainly promising, both in indicating solutions to practical problems and in stimulating further research.

5.2 Identification of plant and animal species

A continuing problem in the management of forests is the correct identification of species of plants and animals. The expertise necessary for correct identification is highly fragmented, any one individual usuall being a specialist in one group of organisms and having only a very general knowledge of other organisms. Where the numbers of species in a group are small, as for the mammals, reptiles or birds, the problems of identification are not particularly severe, but identification of insects, mosses and microbes, for example, poses especially difficult problems because of the large numbers of closely related species and the small size of the differentiating characteristics. The traditional method of identification is through the use of taxonomic keys, but where attributes are difficult to determine on an individual specimen, or are perhaps missing from the specimen, such keys quickly become useless. It is interesting to note that the specialists in particular groups seldom use taxonomic keys but have their own, often unwritten, ways of recognizing species, helped by their knowledge of the likelihood of finding a particular species in that location and of the degree of variation which species exhibit in certain attributes.

Expert Systems are ideally suited to this kind of problem, being able to hold the taxonomic keys themselves, and to combine them with the knowledge used by human experts to take short-cuts in the use of the keys. Bayesian inference techniques can direct the user's attention to the species most likely to be found in a given location, and can help to make a guess at the most probable identification, even when some of the important information is missing. The estimated probability of the identification being correct provides a measure of the confidence which the user can place on his consultation with the Expert System. Use of modern computer graphics can supply the user with a picture of his identified organism for comparison with the actual specimen, and can illustrate the technical terms used in the taxonomic descriptions. Taxonomic Expert Systems are currently being developed by ecologists and seem likely to play an increasingly important role in both research and management.

5.3 Ecosystem management

The management of the extensive forest systems of the world has always presented man with problems to which he has failed to find satisfactory solutions. Time and again, apparently common-sense policies and practices have led to the destruction of forest systems we have been trying to preserve. The recognition that many ecosystems are fragile and vulnerable to unexpected influences has stimulated concern and interest in wildlife and habitat conservation. In almost every country of the world, National Parks and Reserves have been set up in an attempt to halt the destruction of wildlife, as well as to provide opportunities for recreation, observation and research. The management of these Reserves, however, depends on our understanding of ecosystem processes, and Expert Systems offer one important source of practical advice to National Park and Forest Reserve managers. Sound management depends in part on the correct identification of objectives, and Expert Systems can play a valuable role in making sure that the managers themselves ask the right questions when setting objectives within international, national and regional perspectives. How should the objectives for particular areas be related to the wider problems of land use and conservation policies? What are the relative priorities in the conservation of organisms and habitats? Should we continue to allow most attention to be directed towards organisms which are conspicuous and obviously attractive, like large animals, birds and butterflies, or to organisms which play an essential role in forest ecosystem dynamics, for example the micro-organisms mainly responsible for the essential processes of decomposition in the nutrient cycle?

Having decided on the objectives, management of vegetation by cutting, fire, or the use of herbicides, and management of animal populations by harvesting, culling, or the use of predators offer many possible combinations of options to the manager. Many widely differing types of scientific expertise are required, and the practical manager is unlikely to have access to all of them, or even to more than one or 2 of them. If they can be combined into an Expert System specifically designed to enable the manager to monitor the changes taking place in the ecosystem he is seeking to manage, and to select appropriate forms of management to achieve the desired objectives, the results of ecological research will be made available in the most practical way possible. Some preliminary trials of such Expert Systems are currently being made, initially concentrating on particular kinds of ecosystems, for example lowland heaths, wetlands and woodlands. The combination of many different types of system into the kind of mosaic likely to be found in, say, a National Park poses problems of spatial and dynamic heterogeneity which still have to be solved. Nevertheless, we expect to have workable Expert Systems for the management of forest ecosystems within 5 years.

5.4 Environmental impact assessment (EIA)

So far, EIA methods have been largely based on confrontation between those who wish to develop some industry or project, and those who oppose the development on the grounds of a predicted environmental impact. Very little of what is asserted by either side in this confrontation has much basis in hard science, or in any deep understanding of the ecological theory that underlies the arguments, principally because of the inaccessibility of that theory. Expert Systems offer one possible solution to making the results of ecological theory available to those who will have to assess the likely effects of any proposed project on the environment. Attempts to build such Expert Systems have only just begun, but, in their overall effect on practical decisions affecting the environment on which we all depend for our natural resources, they may be the most important of all applications of such Systems.

6 Conclusions

This paper does no more than sketch out the beginnings of the use of Expert Systems to provide ecological advice to forest managers, administrators and politicians. Clearly, there is much still to be done before such Expert Systems are accepted as an alternative to the present-day reliance on advice from human experts, reports and scientific publications. Nevertheless, even the limited experience we now have of such Systems has shown the exceptional promise they offer of being able to make ecosystem theory accessible to decision-makers in practical and understandable ways.