AN EXPERT SYSTEM APPROACH TO DECISION MODELLING FOR SAVANNA MANAGEMENT

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DECLARATION

I declare that this thesis, unless otherwise stated, is my own unaided work. It has not been submitted before, for any degree or examination, in any other university.

D. BERLINER

JUNE 1990

'Things-in-themselves are unknowable, our notion of reality is a construct of human reason.'

Immanual Kant

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Preface

There is currently an unprecedented interest taken by administrators, managers, politicians and the general public in the changes taking place in the environment. There is a demand for concise, well-packaged ecological information.

The publication of scientific papers can no longer be regarded as satisfactory end-products of research. Agricultural and ecological information needs to be presented in a form which is easily accessible to managers and decision-makers.

Modelling and, in particular, user-friendly expert system models are seen as a means to reach this end.

Artificial intelligence and, more specifically, expert-system technology have introduced new and exciting concepts into ecological modelling. Importantly, there has been a shift in emphasis from models built essentially out of quantitative data, to models built from **knowledge** (which may include both quantitative and qualitative information).

An attempt has been made here to document the process, the results and the consequences of expert system modelling.

This presentation is divided into three sections.

Section 1, INTRODUCTION AND BACKGROUND consists of three chapters. Chapter 1, the introduction discusses the aims, justification and approach. Expert systems and modelling in general are described. Chapter 2 describes the steps involved in the development of expert systems, including conceptualization, knowledge acquisition, and knowledge representation. Chapter 3 investigates the nature of ecological knowledge.

Section 2, THE MODELS, consists of two chapters. Chapter 4 discusses the development of the stocking rate model GRASTOCK. Chapter 5 discusses the development of a bush clearing model, BUSHCLEAR.

Section 3, DISCUSSION AND CONCLUSIONS, consists of two chapters. Chapter 6 discusses and evaluates the models. Chapter 7 provides conclusions to the aims of the thesis.

The object behind developing the models was to investigate the process of expert system modelling. For this reason, they cannot be considered as the final word, but rather as prototypes to the development of commercially available models.

The models, written using the expert system development shell EXSYS, are presented as a 'floppy-disc appendix'.

Acknowledgements

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The successful completion of this study would not have been possible were it not for the subtle academic inspiration and flexible guidance provided by my supervisor, Professor Mike Mentis. This thing called science is beginning to become clearer.

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A very special thanks to my friend and typist, Mrs Pat Fischer, who has been invaluable in converting the scrawled and often misspelt manuscript into a scientific document. Also thanks to Kim Fischer for his amazing diagrams.

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Summary

This study explores the possible uses of expert system modelling for savanna management, and the process of ecological knowledge engineering.

To provide a working medium for the above investigation, two prototype models were developed, GRASTOCK and BUSHCLEAR.

The models were developed using the expert system shell EASYS. TURBO PASCAL subroutines were used to improve the user friendliness of the models GRASTOCK and REGROWTH.

GRASTOCK evolved out of the model POLICY. POLICY considers the most important factors affecting a stocking rate policy. The model provides a useful conceptual framework in which the question of rainfall predictability was investigated. Data from four North Western Transvaal rainfall stations are considered. It is concluded that the highly erratic rainfall patterns for these areas are unpredictable. For this reason, it is felt that unless supplementary feeding or drastic reduction in stock can be made at short notice, a fixed stocking rate policy is advocated for game/cattle farms in these areas.

The model GRASTOCK provides descriptive advice regarding 'suitable stocking rates' for game/cattle farms in semi-arid savannas. The term 'suitable stocking rate' implies a stocking rate that complies with the level of risk acceptance of the farmer, and which falls within the biological constraints imposed on the area. The term 'suitable

stocking rate' is used rather than 'carrying capacity' which, for semi-arid savannas, is seen as a vague and elusive concept. Cumulative rainfall probabilities are used to estimate risk levels. In the presentation of GRASTOCK in chapter 5 emphasis is placed on the conceptualization of the problem. GRASTOCK provides a framework in which a large body of research data has been assimilated and distilled into relevant concepts.

The bush clearing model, BUSHCLEAR, consists of three sub-models, DEBUSH, HERB and REGROWTH.

DEBUSH provides generalized advice on the suitability of a site to bush clearing. DEBUSH is a simple model which provides realistic answers only in typical situations.

HERB recommends a suitable herbicide, application method, dosage and estimate of cost. HERB comprises mostly of heuristic (rules of thumb) and data-base type information.

REGROWTH simulates the regrowth of trees and the annual grass production for 15 years after a bush clearing operating. REGROWTH involves dynamic simulation modelling. REGROWTH displays how expert system modelling can extract information from different sources in the literature, bringing it together into a functional unit.

In the presentation of the bush clearing models in chapter 6, emphasis is placed on the process of knowledge representation.

The process of ecological knowledge engineering is discussed using experience and information gained from this project and from the expert system literature. How knowledge is collected, organized and represented as a computer programme forms the basis of this discussion.

The process of transferring knowledge from humans to computers results in a close examination of the nature and structure of the knowledge involved. From this investigation it is concluded that ecological knowledge is largely contextual in nature. There are few true rules or theories. Ecological knowledge comprises mostly concepts. The poor predictability of ecological events can largely be explained by the 'white noise' and uniqueness of ecological events, the predominance of second order indeterminism, and that ecological systems are medium number systems.

The potential uses of expert system modelling for savanna management are discussed. Reasons why expert systems are seen as both suitable and unsuitable for ecological modelling are mentioned.

It is concluded that the ideas and technology of artificial intelligence have encouraged the development of the second generation of ecological models. Furthermore, expert systems are seen as a means to provide a new and marketable end product for agricultural and ecological research.

SECTION 1 : INTRODUCTION AND BACKGROUND

CHAPTER ONE

INTRODUCTION

1.1 Aims of study

The aims of the present study are to

(1) explore the possible uses of expert system modelling for savanna management;

(2) explore and illustrate the process of ecological knowledge engineering for the development of ecological models;

(3) explore the challenge of artificial intelligence to ecology and agriculture; and

(4) develop prototype models for two important savanna management problems, namely, determining suitable stocking rates for grazing herbivores, and bush clearing.

The prime object behind developing the models in aim (4) was to provide a practical working medium through which the first three aims of the study could be reached.

1.2 Justification

Modelling represents a radical change from traditional academic forms of research in which the scope of investigation is divided and limited by the size of the research project suitable to be undertaken by the individual. Modelling is an attempt to meet the need for agricultural and ecological information to be provided in a usable form.

'The Man and the Biosphere Programme' (UNESCO MAP Report, 1972) adopted the philosophy of systems analysis as the basis of its fourteen major projects, not because modelling was regarded as a substitute for empirical studies, but because the concept of integration is the basis of systems and modelling approaches in ecology. This concept is central to ecology.

The process of modelling itself is seldom, if ever, recorded or published, and the procedure and technology of ecological modelling has not been captured. Jeffers (1976) points out that unless we record experiences gained during model development and document project orchestration, the fragmentation and abuse of modelling will continue.

This thesis documents the process of ecological expert system modelling, and attempts a suitable evaluation of the procedure.

Expert system technology is being applied in many areas of science, technology and commerce. Expert system applications for resource management have been suggested and discussed by Starfield and Bleloch (1983), Starfield and Louw (1986), Ferrar (1986), Coulson et al.

(1987), and Noble (1987).

Expert systems have been developed for various natural resource management problems in South Africa. These include Starfield et al. (1987); O'Keef et al. (1987); Murphy and Faggle (1989); and Mentis and Walker (1987). To date few, if any, expert systems developed for savanna management problems in South Africa have been published. This thesis addresses this shortcoming.

1.3 Approach

The models were developed for the semi-arid savanna regions of the north and north-western Transvaal.

The following approach was adopted

(1) a survey was conducted into the nature and extent of various management problems facing game and cattle farmers in the north-western Transvaal (Berliner, 1984);

(2) literature on the basic principles of artificial intelligence and expert systems was studied;

(3) the process of knowledge engineering and various aspects of cognitive psychology was studied;

(4) a suitable expert system shell was selected;

(5) literature concerning the relevant ecological management problems was collected;

(6) 'toy expert systems' were built from knowledge extracted from the literature - problems unsuited to expert system development were discarded;

(7) various experts and farmers were consulted;

(8) improvements to the models were made through successive iterations of the development cycle described in chapter 2;

(9) in the light of experience gained in ecological knowledge engineering, the structure and nature of ecological knowledge was investigated; and

(10) various aspects and consequences of modelling were considered.

1.4 What are expert systems?

Parsay and Chignell (1988) define an expert system from a functional point of view as being

> 'A corputer program that relies on a body of knowledge to perform a somewhat difficult task usually performed only by a human expert. The principal power of an expert system is derived from the knowledge the system embodies rather than from search algorithms and specific reasoning methods. An expert system successfully deals with problems for which

clear algorithmic solutions do not exist'.

Noble (1987) provides a more descriptive definition

> 'An expert system is a computer program capable of holding an apparently intelligent conversation with the user. It asks questions and the order of the questions changes with the responses given. Based on the knowledge held by the system and the answers to the questions, the system eventually states or validates a conclusion or decision. It is able to explain how and why this conclusion was reached.'

1.5 Examples of expert system application in resource management

A few examples of the type of applications that expert systems have been used for are briefly described. America and Australia appear to be leaders in this field.

Examples of expert systems developed in South Africa

(1) A rule-based ecological model for the management of Lake St. Lucia (Starfield *et al*. 1988). This model provides a qualitative description of the effects of fluctuations in the salinity level on the biotic components of the lake.

(2) An expert system approach to the assessment of the conservation status of rivers (O'Keeffe *et al*. 1987). This model provides a flexible method for classifying rivers according to their conservation status and acts as a semi-numerical model to simulate the effects of proposed development plans on specific rivers.

(3) A knowledge-based consultation system for coastal-zone management and development planning (Murphy & Fuggle, 1989). This model provides advice for decision makers undertaking preliminary environmental assessments of water-related resort developments in the coastal zone of the South-Western Cape Province.

Examples of expert systems developed in Australia

(1) SHRUBKILL (Ludwig, 1988) : An advisory system for the use of prescribed fire to control dense shrubs in the semi-arid woodlands of Queensland, Australia.

(2) FIRES (Davis et al. 1986) : A fire management expert system for Kakadu National Park, Australia. This model provides advice on the ecological effects of wildfires in the area.

(3) Other models currently under development (McKeon, 1989) include:

(i) RAINLOVER : provides analysis of historical rainfall trends, and assesses current rainfall conditions against past records (McKeon, 1989).

(ii) GRASSMAN : helps beef producers compare strategies for the management of native pastures in Eucalypt woodlands (Scanlan & McKeon, 1989).

Examples of expert system application in America

(1) COMAX : An expert system for cotton crop management (Lemmon,

1986). This model determines the best strategy for irrigating, applying fertilizer, and defoliants and cotton ball openers. Sensors in the cotton fields automatically report weather conditions to the system.

(2) GMA : The grain market advisor (Edmunds, 1988). This model helps farmers determine the best method of marketing the grain they produce.

1.6 From simulation modelling to expert system modelling

The use of simulation modelling and the 'systems approach' has been advocated for use in agriculture (Jones, 1976; Jones 1978), and in ecology (Walker, 1974; Walker, 1978). Essentially, these authors urged the use of mathematical modelling as a conceptual tool. The modelling process was seen to provide a framework for bringing together parts of a system which are otherwise too complex to organize and comprehend. The object was to provide a predominantly quantitative description of the inter-relation of a system, so that a comprehensive understanding of the processes involved in the system could be obtained. If the model was found to simulate successfully, it could then be consulted to predict the possible outcome of various management options.

Walker (1974) described two approaches that were adopted in ecological simulation modelling : firstly, the 'total ecosystem approach' in which the object was to develop an understanding of the ecosystem in its entirety (the 'holistic approach') and, secondly, the 'management game approach', which aimed at assessing the outcome of various management strategies which could be applied to the ecosystem in question (for example, Walters & Bunnell, 1971).

The 'management game' approach to modelling helped to shift the emphasis from the functional understanding of ecosystems to a more pragmatic, management tool type approach.

Simulation models are often regarded with suspicion by field managers. They are usually seen as 'academic toys' in which ecological or agricultural concepts are hidden behind obscure and often meaningless mathematical symbols. These models are usually developed by scientists from accumulated quantitative data. Field managers are seldom, if ever, consulted and their empirical and intuitive knowledge accumulated through years of practical experience is seldom drawn upon. The ability of expert systems to utilize qualitative information, and the 'user-friendliness' of expert system shells are beginning to change this. The use of near-English in programming, and the ability to display on request the line of reasoning, has helped to break down the black-box image of ecological models, thereby narrowing the gap between researcher and field manager.

Just as expert system technology is being viewed as an evolution of conventional computer programming paradigms (Parsaye & Chignell, 1988), so, too, will expert system type modelling be considered as a new paradigm in ecological modelling.

1.7 The expert system shell EXSYS

The expert system development shell EXSYS (Huntingdon, 1987) was used for this study.

EXSYS is designed for the PC. It is a relatively simple yet quite competent, rule-base system. It has better mathematical handling capabilities than do most other PC based systems. Variables can also be assigned by using the THEN and ELSE part of its rule (Edmunds, 1988).

In common with most of the smaller PC based shells, EXSYS can only represent knowledge in the form of rules. This limits the ability to develop a more structured knowledge-base, as would be possible with frame based representation (see section 2.5.2). Furthermore, EXSYS is limited in its ability to express meta-knowledge (i.e. knowledge about knowledge). This is due to the inability to use rules as condition statements within another rule (i.e. rules about rules).

EXSYS is considered to be suitable for small- to medium-scale ecological modelling. For larger projects, a shell that uses a combination of rules and frames would be preferable.

The price, and the ease at which EXSYS can be used, make it a particularly useful environment for the development of prototype models. Improved versions of the model could then be rewritten using a more sophisticated shell or a suitable progamming language.

CHAPTER TWO

THE EXPERT SYSTEM DEVELOPMENT CYCLE

2.1 Introduction

If an expert system is to emulate the way humans solve particular problems, then it must acquire a portion of the knowledge that human experts possess. How this knowledge is collected, organized and represented as a computer program is the subject of this chapter.

The term 'knowledge engineering' was coined by Feigenbaum (1980) to encompass the process of reducing a large body of knowledge to precise set of facts and rules. Edmunds (1988) describes knowledge engineering as involving the transfer of knowledge from a specific area of expertise to a computerized representation as a knowledge-based component of an expert system. This task involves accumulating the facts and rules (knowledge acquisition) and placing this information into a knowledge base (knowledge representation). This task is handled by a skilled individual known as a knowledge engineer.

The task of a knowledge engineer is not unlike that of a systems analyst in conventional programming. The important difference is that, whereas a systems analyst helps a user design computer systems which carry out specific procedures, a knowledge engineer helps design systems which incorporate knowledge from an expert (Hart, 1986).

Knowledge engineering is considered by Feigenbaum (1980) to be a fundamental problem in expert system applications and is generally seen as a major bottleneck impeding applications to new domains.

Although guidelines about knowledge engineering techniques have been published and psychological problems of knowledge transfer have been analyzed, no scientific framework for knowledge engineering has been established. Present techniques are based on intuition, experience and empirical results, rather than deep foundation (Gaines, 1987).

Parsaye and Chignell (1988) feel that recent advances in the field of automated knowledge acquisition tools, along with machine learning techniques will minimize the effect of the knowledge acquisition bottleneck.

Expert systems development does not follow a series of well-defined steps. The inherent complexity of the system building process precludes laying out all the steps in advance (Waterman, 1986; Edwards, 1988). Expert systems normally evolve from simple to hard tasks by incrementally improving the organization and representation of the systems knowledge. The incremental approach means that the system itself can assist in the development effort. As soon as enough knowledge is acquired to construct even a very simple system, it is used to provide feedback to direct and focus effort (Waterman, 1986). This approach was found to be very useful by the author, who spent the initial stages of this project building 'toy expert systems'. Toy expert systems are highly simplified versions of the problem. The object behind building these was, firstly, to get a feel for the nature of the problem and the type of knowledge involved and, secondly, to become familiar with the software used.

The building of expert systems often involves the problem of 'not knowing where you are going until you have been there'. Figure 2.1 illustrates the steps involved in developing expert systems (after Parsaye & Chignell, 1988). It must be stressed that these steps are highly interdependent and overlapping. Although these steps may follow a logical order, at any time during the systems development the knowledge engineer may loop back to engage in any of the processes.

2.2 Feasibility analysis and problem identification

Waterman (1986) feels that expert systems should be considered only if expert system development is possible, justified and appropriate.

Any organization which is thinking of developing an expert system would like to know from the outset if the expert system approach will work for their particular problem. Although it is difficult to generalize, a few important guidelines can be provided. Firstly, expert system development is possible only if the experts or expertise exists. Secondly, the problem domain should be reasonably well understood and not too complex (Waterman, 1986). Complex tasks could be segmented into smaller, relatively independent sub-tasks, each of which may be a candidate for an expert system. (This is what was done in this study for the bush clearing model presented in this thesis.)

Many biological problems are poorly understood and require basic

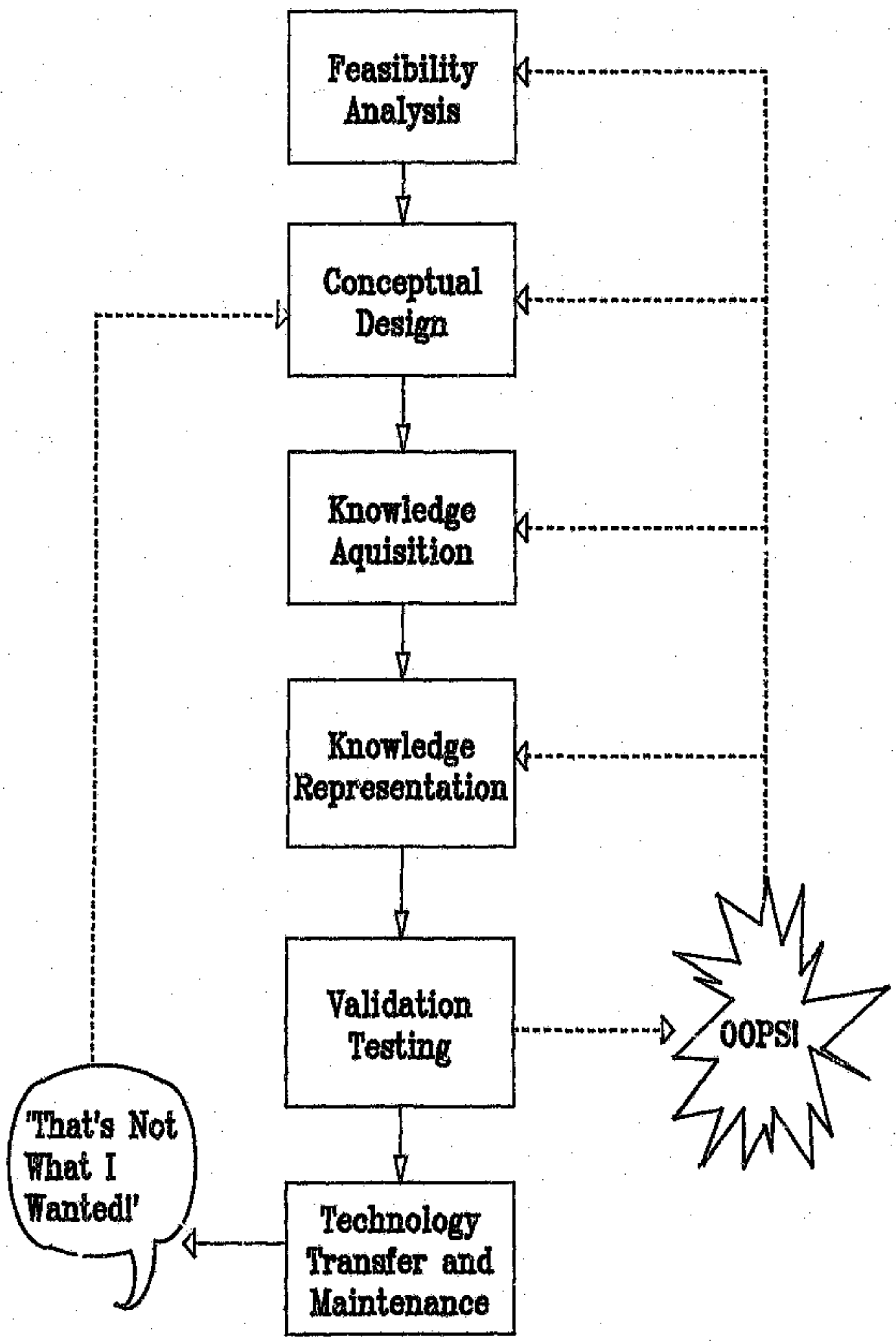

Figure 2.1 The Expert System Development Cycle (After Parsaye & Chignell, 1988).

research to find solutions. Obviously, building an expert system for these problems cannot be expected to provide reliable solutions. However, the process of attempting to build the system may have many benefits in itself. For example, the process of attempting to explicitly state links between information and final decision will often help clear up misunderstanding (Starfield, 1983). Furthermore, in many poorly understood ecological systems, management decisions must be made, based on implicit hypothetical assumptions. By developing an expert system, these assumptions are explicitly stated and hence can be criticized and constructively defended.

The question of whether expert system development is justified will depend to a large extent on a cost/benefit analysis. Waterman (1986) points out that in situations where human expertise is being lost, or is scarce, or is needed in many locations, expert system development should be justified. This 'institutional memory' aspect of expert systems would be obvious justification for the development of expert systems for many natural resource management problems.

Finally, one must decide whether expert system development is going to be appropriate. This will depend on the nature, complexity and scope of the problems. Problems that are typically solved with heuristics (rules of thumb) as opposed to algorithms (formal procedures) are good candidates (Waterman, 1986). Regarding the complexity of the problem, it is important that the problem is not too simple. Expert system developers can easily fall into the trap of developing trivial expert systems for problems that would be better solved by look-up tables or nomograms.

Waterman (1986) regards the choice of a proper scope to be the most crucial aspect determining the success of the expert system. One of the biggest pitfalls in the expert system building is choosing a problem that is too broad or general to handle adequately (Waterman, 1986). Parsaye and Chignell (1988) state that the best expert system tasks are rather limited in nature and have a narrow focus.

Savanna management, as a whole, is an example of a problem that is too broad to handle in one expert system. The domain may be narrowed down in several ways. First, the geographical area over which the expert system is valid may be limited. Second, the scope [illegible]lem may be narrowed. For example, the problem of herbivor[illegible]cking [illegible]es was found to be too broad and complex to be dealt with at any level of detail. While the scope of the problem was narrowed down by considering only the stocking rate of grazing herbivores, the geographical applicability of the system remained relatively wide (namely the semi-arid savannas of the Transvaal).

2.3 Conceptual design

Conceptualization is an exploration by the knowledge engineer and the expert into the main concepts and relations which make up that expert's problem-solving knowledge (Parsaye & Chignell, 1988).

A useful side-effect of deliberately carrying out conceptual design as a separate phase in the development cycle is that it allows experts to explore the structure and nature of their knowledge (see chapter 3 of this thesis).

Parsaye and Chignell (1988) list some of the questions which must be addressed during this phase. They include the following.

(1) What are the major objects, concepts and entities in the knowledge domain?

(2) How should the objects, concepts and entities be described?

(3) What are the important relationships that exist between the objects?

(4) What are the general characteristics of the problem that will be dealt with?

(5) How will the expert system obtain information about the current problem?

Chapter 4 of this thesis provides a detailed description of the conceptualization of a problem (in this case, determining suitable stocking rates for grazing herbivores).

2.4 Knowledge acquisition

This phase deals with the task of obtaining knowledge and formalizing it so that it can be included in the expert system's knowledge base. Since expert systems rely heavily on the quality of knowledge they possess, knowledge acquisition is a crucial part of the development cycle (Parsaye & Chignell, 1988).

At this stage, it is important that the knowledge engineer retains the enthusiastic and willing involvement of the expert. Problems arise if an expert does not fully understand the knowledge engineering process, or develops a subconscious hostility, or may just lose interest. These problems are likely to arise if the expert does not have a personal or financial commitment to the project. These problems were experienced in varying degrees with some of the experts used in this project.

2.4.1 Problems in knowledge acquisition

One problem in knowledge acquisition is the natural tendency to underestimate the difficulty in acquiring implicit knowledge. Similarly, when looking at knowledge that has already been codified and packaged into the knowledge base of an expert system, it may be difficult to recognize how much effort went into structuring the knowledge in that form (Parsaye & Chignell, 1988).

At a relatively early stage in the development of an expert system, a knowledge engineer should decide if the problem domain can be adequately represented with shallow, task-orientated knowledge, or if deeper knowledge structures are going to be required (see section 3.3 for further explanation). Shallow knowledge would typically be represented by empirical heuristic type rules. Deep knowledge would attempt to represent fundamental relations in various process models. However, even if the problem domain can be represented by shallow knowledge, it may still be necessary during the knowledge acquisition phase to carry out the excursions into deep knowledge in order to understand and validate the shallow knowledge (Parsaye & Chignell, 1988).

One problem that was found to be particularly relevant to this project was deciding what information source to use. A common and time-consuming mistake is to collect knowledge from the first available, or most convenient source. Knowledge sources may include books, journals, reports and human experts. Parsaye and Chignell (1988) feel that using the literature as the prime information source (as opposed to the expert) may lead to the incorporation of knowledge that is either not part of the practical reasoning, or that has exceptions that the expert has had to discover and work around. The human expert contains the knowledge in a well-packaged form that is especially designed for efficient reasoning.

Generally, the development of expert systems with deep knowledge structures will make greater use of literature information sources than would a expert system with shallow knowledge structures. Expert systems with shallow knowledge structures are more concerned with uncovering empirical relationships and heuristic rules used by human experts. For example, the model GRASTOCK was built using relatively deep knowledge structures obtained solely from literature sources, whereas the more shallow knowledge structures of DEBUSH and HERB were built predominantly from information obtained from experts.

An important pitfall is the collection of irrelevant knowledge. Knowledge can be difficult to recognize when it has to be extracted from a noisy background of hints and possible relevant events. Knowledge acquisition can be likened to a distillation process where the essential facts and rules must be isolated (Parsaye & Chignell, 1988).

Gaines (1987), quoting Collins (1985), points out a common psychological problem in knowledge elicitation. Much human activity is not accessible to awareness. This implies that some knowledge may not be accessible through the expert, not only because he cannot express it, but also because he may not be aware of its significance to his activity. If one considers the simplistic model of human expertise as involving a pattern matching exercise - that is, matching data patterns of problems to the data pattern-deduction relationships stored in the mind of the expert - then it is reasonable to expect that some of these data pattern-deduction relationships have become ingrained into the subconscious. It is this 'subconscious knowledge' of an expert that a knowledge engineer will find difficult to extract. It is suggested here that the so-called management by gut-feel, or intuition, of many experienced field managers is done using this 'subconscious knowledge'. This is an obvious stumbling block when trying to uncover heuristic rules used by these field managers.

2.4.2 Strategies for knowledge acquisition

There are two distinct ways of looking at the knowledge acquisition problem. Firstly, the top-down approach, where one begins with what the expert does and works backwards to identify the structures the expert uses. Secondly, the bottom-up approach, where one formulates an analytical model based on the components of the knowledge. One then attempts to fit the knowledge and behaviour of the expert into the model (Parsaye & Chignell, 1988).

The DEBUSH and HERB models described in this thesis were built using the top-down approach. The more analytical models of GRASTOCK and REGROWTH used the bottom-up approach.

Knowledge acquisition can be manual or automated. Manual knowledge acquisition methods include interviewing and verbal protocol analysis. Hart (1986) provides information on the different questioning techniques used in interviewing experts.

Verbal protocol analysis is used to track the process of expert reasoning 'as it occurs'. The expert is encouraged to 'think out loud' while performing the task (Parsaye & Chignell, 1988).

Recent advances in automatic knowledge acquisition and machine learning (in which rules are induced by a computer from case history information) reduce some of the problems involved in knowledge engineering (Parsaye & Chignell, 1988).

2.5 Knowledge representation

Knowledge representation involves determining how knowledge is stored within a knowledge base. There are a number of ways of representing knowledge. The most commonly used techniques include semantic networks, production rules and frames (these are discussed below). Often expert systems may make use of more than one knowledge representation technique. These are referred to as hybrid systems

(Edmunds, 1988).

The problem of knowledge representation in artificial intelligence has obtained much inspiration from the related field of cognitive psychology. For example, Parsaye and Chignell (1988) point out that the knowledge representation technique of semantic networks was inspired by psychological models of human memory.

2.5.1 Knowledge representation using rules

Rules represent knowledge in the form of IF-THEN statements. The IF part contains a condition, premise or antecedent that represents a computer- recognizable pattern. The THEN part contains a result, conclusion or consequence which specifies an action to be taken by the computer when the data matches the pattern in the condition (Edmunds, 1988). If the input data matches the conditions in the IF part of the rule so that the THEN part is executed, the rule is said to fire.

Rule-based systems use a popular and easy to understand approach to knowledge representation. Most expert systems use rules. The size of the expert system is often measured by the number of rules it contains.

2.5.1.1 Inference modes

Inference modes refer to the technique used by that portion of the computer program (i.e. the inference engine) to access and apply the knowledge stored in the knowledge base.

Backward and forward chaining are two inference modes in which rules can infer new information or reach conclusions.

(1) Forward chaining. This refers to the direction in which new information is inferred. The computer tries to match the IF part of the rule, with information existing in the working memory (i.e. information obtained from the user, or from other rules, or from a database). Bramer (1982) refers to a forward chaining system as being data, pattern or condition driven. Figure 2.2 illustrates the process.

(2) Backward chaining. A search goal (i.e. a hypothesis to prove or disprove) is set up to try and validate the THEN part of a concluding rule. Rules are searched for IF statements which will eventually lead to ascertaining the THEN part of the concluding rule. A system that attempts to reason backwards is said to be goal-driven (Bramer, 1982). Figure 2.3 illustrates the process.

The expert system shell EXSYS provides the option of using forward chaining, backward chaining, or both. All the prototype expert systems developed for the thesis used a combination of forward chaining first followed by a backward chaining search for missing vari[illegible]

In some expert systems it would be more efficient to use only one of the inference modes. For example, if there is only one possible solution from a host of possible solutions, in backward chaining mode only the relevant questions are [illegible]. (In forward chaining mode all the rules are tested.)

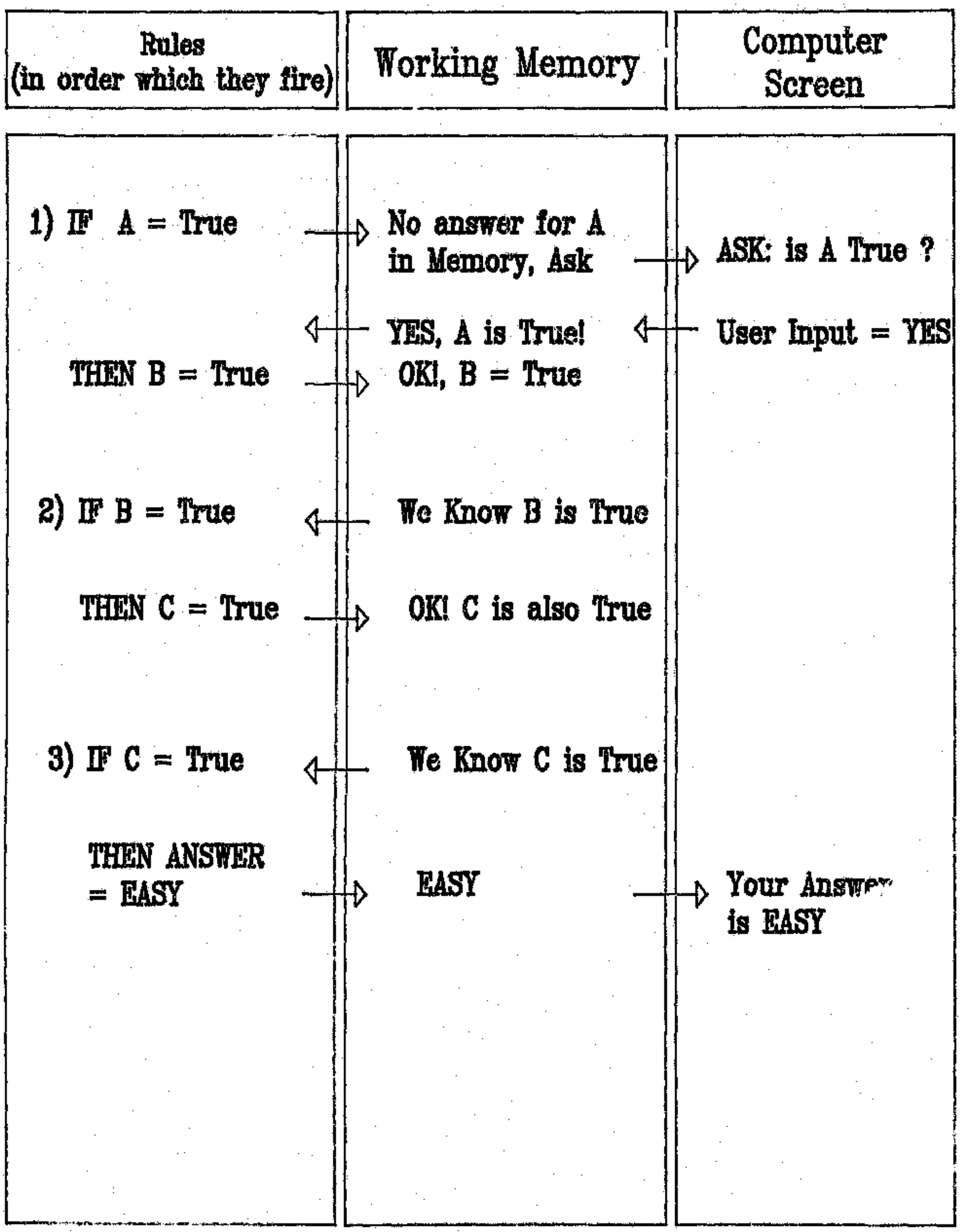

Figure 2.2 Diagram Illustrating Foreward Chaining.

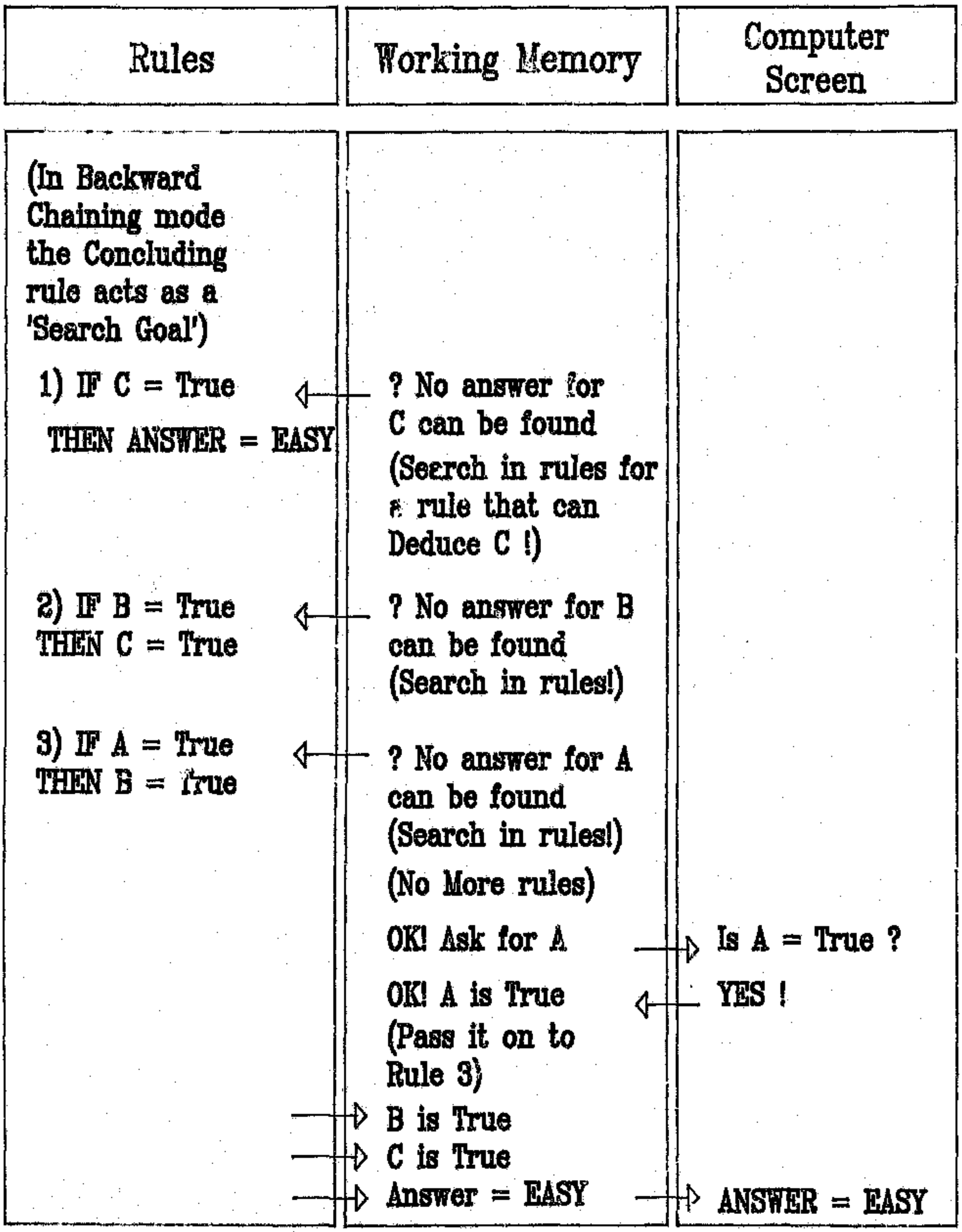

Figure 2.3 Diagram Illustrating Backward Chaining.

2.5.1.2 Ways in which rules can be used

The expert systems developed in this thesis make use of rules in three slightly different ways.

(1) Heuristic rules. (Rules of thumb), i.e. certain conditions will result in a certain action being taken. For example (rule 31 of HERB)

IF Percentage clay is < 21
and Herbicide dosage is > 4Kg/ha
and Size of target area > 100ha
and Average tree height ≥ 1.5m
THEN Herbicide application method = Aerial

(2) Rules used as 'mini-databases'. For example, (rule 15 of HERB)

IF target species = *Grewia flava*
THEN Possible herbicide = TORDON 101
or Possible herbicide = TORDON SUPER
or Possible herbicide = RECLAIM

(3) Rules used to carry out mathematical procedures. For example (rule 5 of GRASTOCK)

IF Information on herbivore stocking rates is required
THEN [PRODHIGH] = 3,65 x [CALCRAIN] + 433 x [PFERTHIGH]/100 x [TCF1]
and [PROMED] = 0,87 x [CALCRAIN] + 1706 x [PFERTMED]/100 x [TCF2]
and [PRODLOW] = 1,32 x [CALCRAIN] + 1196 x [PFERTLOW]/100 x [TC3]

This rule calculates grass production on high, medium and low fertile soils using regression lines from Dye and Spear (1982). There is a built-in tree correction factor, [TCF], based on Scanlan (1987).

The above rule has an IF condition that will always be true. This ensures that the rule always fires so that the calculations are always executed.

2.5.2 Other methods of knowledge representation not used by EXSYS

EXSYS can represent knowledge only in the form of rules. The other important knowledge representation techniques of semantic networks and frames are briefly discussed below.

2.5.2.1 Semantic networks

Waterman (1986) defines a semantic network as a knowledge representation method consisting of a network of nodes which represent concepts or objects connected to each other by arcs. Arcs describe the relations between the nodes.

Typical nodes would include objects such as 'plant or animal species x' or a concept such as 'drought tolerance'.

Arcs provide a simple verbal description of the relationship between nodes, for example, is-a, has-a and caused-by.

The semantic network approach allows knowledge tc be represented as hierarchical relationships. Hierarchical relationships allow knowledge components to inherit information from other knowledge components, thereby reducing the need to duplicate information within a knowledge base (Edmunds, 1988).

Semantic networks are the standard technique used for models of human memory (Edmunds, 1988).

The principle of semantic networks is illustrated in figure 2.4.

2.5.2.1 Frame-based representation

Frames are described by Parsaye and Chignell (1988) to be a way of packaging knowledge within a well defined structure.

Knowledge representation based entirely on rules tends to become clumsy and difficult to manage as the total number of rules in the system increases. For deep knowledge structures, newly added rules will often duplicate or contradict rules that already exist. Furthermore, the knowledge engineer becomes less aware of the interaction between different rules as the total number of rules grows.

Frame-based systems provide a complex but powerful form of knowledge representation that allows knowledge to be efficiently organized and structured.

The basic idea of a frame was outlined by Minsky (1975). Minsky (1975) felt that theories of knowledge representation in artificial

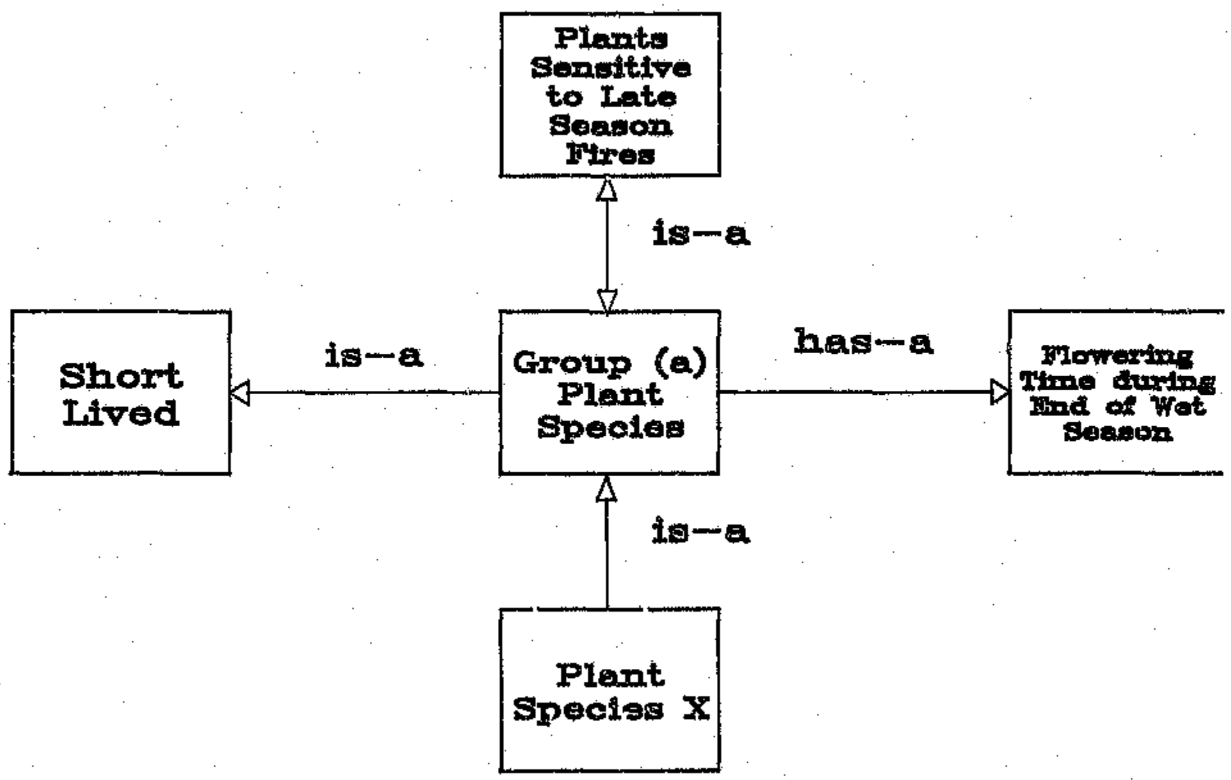

Figure 2.4 A semantic network illustrating the inheritance of knowledge by plant species X.

intelligence and in psychology were too minute, local and unstructured to account for the effectiveness of common-sense thought.

Frames are the result of attempts to represent knowledge in larger, more structured 'chunks'. Parsaye and Chignell (1988) describe frames as 'packaged knowledge'.

These packaged structures make it easier to organize and retrieve knowledge. It appears as if human memory contains similar knowledge structures which aid in recall of information (Parsaye & Chignell, 1988).

2.5.2.1.1 <u>The basic structure of frames</u>

Frames can be thought of as a collection of knowledge about a specific object, concept, or situation. A frame contains related bits of information about the subject of the frame. Each bit of information is contained in what is termed a slot. Each slot has a name and a value (Edmunds, 1988). Slots may contain several types of information about the frame. For example, a slot may contain a property which describes the frame, a rule that applies to that frame, or a procedure for calculating a value. Slots may also contain entire frames, i.e. frames within frames.

Frames make use of the semantic network concept of inheritance. Frames can be connected to one another in a hierarchical manner. This allows frames to inherit the properties of frames which are higher above them in the hierarchy, and to pass properties 'down' to frames which are lower on the hierarchy (Edmunds, 1988).

Each frame has a name and a parent (which describes its links to other frames in a hierarchy).

Figure 2.5 illustrates a possible frame for representing knowledge on bush clearing.

Frames free the knowledge engineer from the restriction of needing to have all knowledge encoded as rules. Frame based representation would appear to be particularly useful in representing contextual knowledge. For example, a 'package of information' becomes valid only in certain circumstances. This method of representation would appear to be particularly suited to ecological knowledge representation.

Frame name : SEEPLINE

PARENT : Bush clearing zones

Slot 1 :	Vegetation	:	*Acacia* woodland with *Terminalia* fringe
Slot 2 :	Geology	:	If in lowveld Then geology = granitic
Slot 3 :	Suitability to bush clearing	:	High
Slot 4 :	Length of seepline	:	L = (unslope length) x 0,4
Slot 5 :	Clearing methods to avoid	:	Granular herbicides

Figure 2.5 An example of a possible frame representing knowledge on seeplines within a bush clearing expert system

CHAPTER THREE

THE NATURE OF ECOLOGICAL KNOWLEDGE

3.1 Introduction

Improved understanding of the nature of a body of knowledge can be obtained by attempting to describe the knowledge. In this chapter, ecological knowledge is described using three broad frameworks, namely in terms of its components, depth and structure.

The related concepts of emergent ecological properties and the contextual nature of ecological knowledge are also investigated. Finally, this chapter looks at the problem of poor predictability of ecological theory.

The purpose of this chapter is to obtain a better understanding of the fundamental nature of ecological knowledge in the light of it being used for modelling.

Recent developments in computers have given rise to new questions and areas for the scientist to explore, and have revolutionized the way in which he thinks about his subject (Starfield & Louw, 1986).

The process of transferring knowledge from humans to computers will result in a closer examination of the nature and structure of the knowledge involved.

Philosophical infusions into ecological thinking (for example, Saarinen, 1982; Loehle, 1988; and Mentis, 1988) have encouraged ecologist to 'take a step back' and reconsider the way in which they think about their subject and the very nature of ecological knowledge. Similar effects have been experienced during the process of expert system modelling.

Expert system models may encourage an epistemological awareness amongst model builders and model users.

Understanding the nature of a body of knowledge will assist in developing suitable knowledge representation structures.

3.2 Describing knowledge in terms of its components

Parsaye and Chignell (1988) describe the basic components of knowledge as being naming, describing, organizing, relating and constraining.

These components of knowledge are generally present within any knowledge representation systems. However, each knowledge representation method deals with these components in its own way.

3.2.1 Naming

To represent knowledge it is necessary to denote objects by name. The function of naming is performed by using nouns. Naming includes the process of declaring variables, for example the variable [SOIL FERTILITY].

3.2.2 Describing

The function of describing is performed by an adjective, or a number such as 'hot', 'dense' or '80%'. Describing is usually used to assign a value to a variable, for example [SOIL FERTILITY] = 'high'.

3.2.3 Organizing

Organizing involves developing conceptual categories and hierarchies. For example, the variable [SOIL FERTILITY] is a property of the variable [SITE PRODUCTION POTENTIAL] which is required in determining the variable [GRASS PRODUCTION].

3.2.4 Relating

After naming, describing and organizing objects, we need to relate them. When describing relationships between objects, it is important to choose the right level of analysis and the right number of particular entities in a relationship. The number of entities involved depends on the level of analysis and depth of knowledge used (Parsaye & Chignell, 1988).

Some kinds of relations can be expressed in terms of the organization of the knowledge. For example, [SOIL FERTILITY] is determined-by [% CLAY]. Other types of relations are more complex and may be expressed as procedures. For example, the variable [POTENTIAL GRASS PRODUCTION] is related to the variable [ANNUAL RAINFALL] by 3,65 x [ANNUAL RAINFALL] + 433.

3.2.5 Constraining

Constraints are used to limit ranges of values, relationships, and organizational structures. For example, ,a constraint is used to express th. fact that the variable [SOIL FERTILITY] is determined by the variable [% CLAY] only if % clay is below 20.

Constraints are used to protect the integrity of the knowledge-base and to define the limits of its applicability.

3.3 Describing knowledge in terms of its levels or depth

Knowledge can be represented at different levels, depending on the degree to which fundamental principles and causal relationships are taken into account. Shallow knowledge handles only surface level information that can be used to deal with specific situations. Deep knowledge on the other hand, represents the internal and causal structure of a system and considers the interactions between its underlying components (Parsaye & Chignell, 1988).

Deep knowledge of a system implies that there is a good understanding of the fundamental relationships involved. Surface knowledge implies that there is a degree of empirical predictability of the eventual effects within a system, but a basic inability to explain underlying causes.

3.3.1 Advantages of deep knowledge structures

Noble (1987) has stated that the impact that expert systems have on e ological theory will depend on the degree to which deep knowledge is used in formulating knowledge bases. Deep knowledge structures provide a better understanding of ecological processes, and also provide more opportunities for interactions between ecological knowledge bases that combine several domains of expertise. For example, in this thesis, the rainfall-tree density-grass production relationships in the stocking rate model GRASTOCK were represented using relatively deep knowledge structures. The same relationships were used in the bush clearing model REGROWTH.

One approach to representing deep knowledge is to capture the underlying principles by modelling the functions carried out by each variable within the knowledge domain. This functional model can then be used for 'what if' simulation. 'What if' simulation or 'gaming' is useful in ecological management, in particular for determining the most important variables within a system (i.e. 'sensitivity analysis') and to determine likely outcomes of various management decisions.

Deeper knowledge structures enable an expert system to explain its reasoning using fundamental principles. This is important if the objective of the expert system is to impart knowledge and not just decision making. Furthermore, the ability to explain why a certain decision was reached enhances the credibility of the system.

Deep knowledge expert systems can invoke deep knowledge structures to solve difficult or unusual problems (i.e. 'solving a problem using first principles') (Parsaye & Chignell, 1988).

3.2.2 Should expert systems be built with deep or shallow knowledge structures?

The answer to this question will depend firstly, on the amount and nature of knowledge available for a particular problem and secondly, on the purpose for building the model.

Caswell (1976) recognizes two extreme types of models, namely theoretical and predictive. Theoretical models requiring deep knowledge structures are essentially concerned with insight into mechanisms and processes. The emphasis is on explanation of cause and effect.

Predictive models, on the other hand, may be built out of shallow or deep knowledge structures. They are not independent of the understanding of the mechanisms and processes, but they focus on relationships, especially on effect rather than cause.

For many ecological problems, causal relationships may be poorly understood. In these cases, it may only be possible to build shallow knowledge structures from empirical information. Such knowledge bases would typically consist of a set of heuristic rules. These models would have limited explanatory abilities. For example, a heuristic rule for the problem of determining suitable herbivore species mix ratios on game farms could be

IF Area = Bushveld
and Rainfall = ± Average

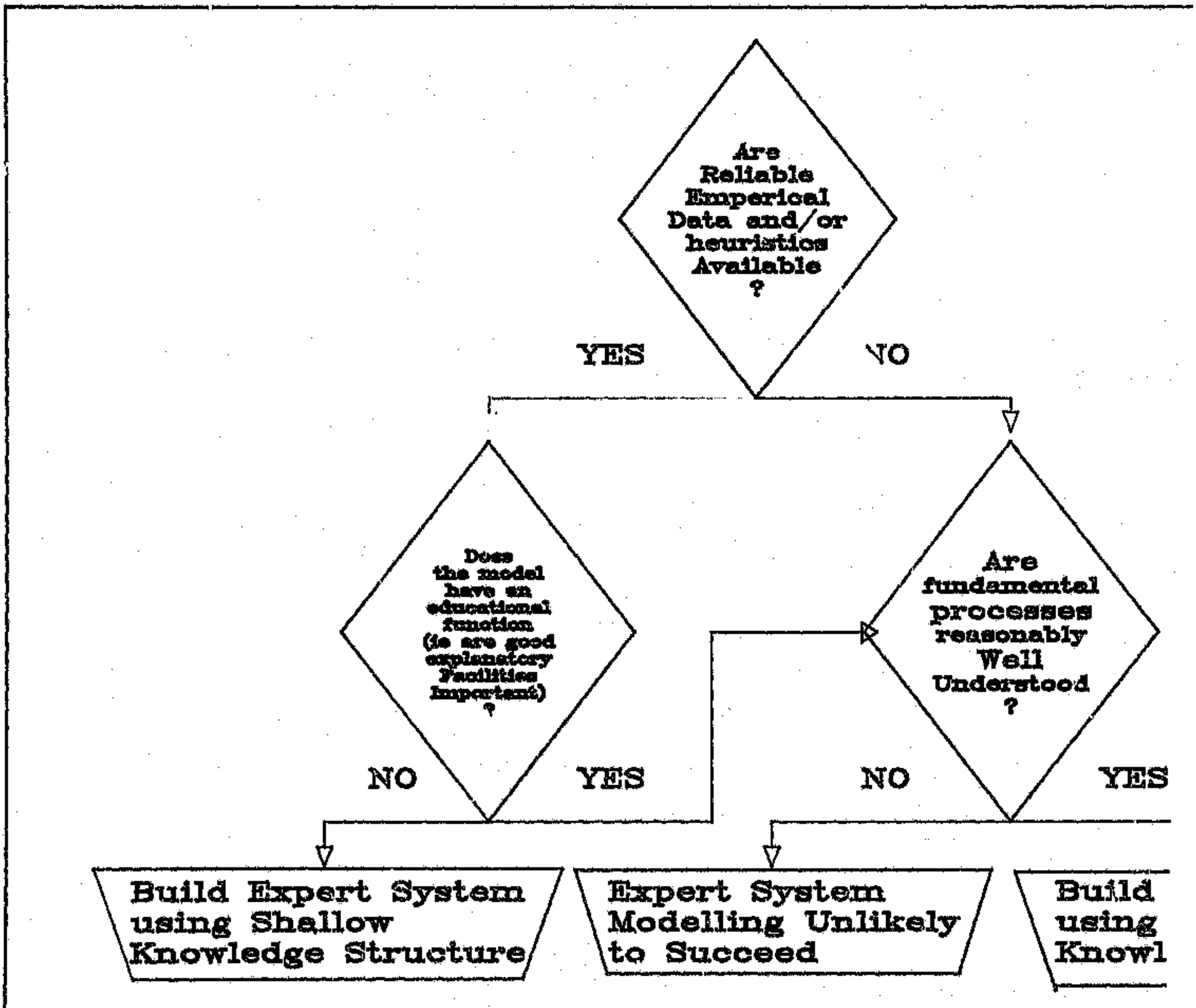

Figure 3.1 Algorithm Determining the Type of Knowl
Structure to use in Expert System Modell

and Bush encroachment = Not excessive

THEN Species mix ratio (in Au) = 3 Bulk grazers : 2 concentrate grazers: 1 Browser

For some problems the reverse situation may apply, i.e. reliable empirical knowledge and heuristic rules may be difficult to obtain. In such cases it is necessary to build deep knowledge structures in which fundamental processes are simulated. For example, the model GRASTOCK estimates suitable stocking rates by considering the fundamental concepts involved in stocking rate decision making. This was necessary due to the absence of any reliable empirical information concerning stocking rates.

Expert systems with surface knowledge structures are relatively quick and easy to build, provided that reliable empirical information about the problem is available. They do, however, run the risk of appearing trivial, and may cause one to ponder if the knowledge could not have been represented just as adequately in a look-up table or nomogram.

Figure 3.1 describes an algorithm used to determine whether deep or shallow knowledge structures should be used.

3.4 Describing ecological knowledge in terms of its structure

Ecology is commonly criticized for its lack of theoretical approach. Margalef (1963) feels that ecologists have been reluctant to place their observation and findings in the frame of a general theory, and that present day ecology is extremely poor in unifying and ordering principles.

The pressures created by recent demands that ecological theory provides more effective guidelines for management of natural resources, has created what Odum (1977) calls the 'new ecology'. This involves a shift away from mere descriptive ecology to a search for unifying theories and principles.

A science is usually described as a conceptual scheme or a system of theories, hypotheses and laws, which serves to explain observed facts and allow prediction of events (McIntosh, 1982).

A sound theory and body of empirical information is necessary to develop a scientific structure that can be applied to practical problems. However, as Slobodkin (1988) has pointed out, the development of ecological theory in the absence of practical questions is in danger of deluding itself by a vain hunt for generality, answering only easy questions that it poses for itself, and becoming irrelevant to anyone outside its own academic village.

3.4.1 Ecological concepts and theories

Slobodkin (1988) describes ecological theory as models or equation systems that describe the commonalities shared by classes of answers.

Theories are essentially hypotheses that have been verified. Concepts on the other hand need not necessarily be falsified, their only criterion being that they are useful. Ecology has often been criticized for being more concerned with developing concepts than with producing theories (McIntosh, 1982).

All scientific ideas can be classed as theories (predictive or falsifiable statements about the universe), or as concepts (not necessarily falsifiable). Only theories comprise a science. Ecological concept and theory are often confused so that non-predictive ideas impede scientific advance (Peters, 1982).

3.4.2 Ecological principles

McIntosh (1982) defines a principle as a 'fundamental underlying reason or cause from which other things follow and can be deduced'.

Successive ecologists have attempted to reduce ecological theory into cardinal principles. For example, Ganong (1904) and Alle and Park (1939). More recently, Smith (1974) has described ten principles that focus on the concept of the ecosystem, for example 'when an ecosystem is exploited and that exploitation is maintained, the maturity of the ecosystem declines'.

3.4.3 Ecological laws

A scientific law, although variously used, commonly refers to an observable event that can be confirmed or refuted by observation, i.e. an empirical law. Ideally, a scientific law should be a universal generalization. Theories are distinguished from laws in that they are statements that may not necessarily refer to direct observation. They are abstract relationships linking diverse phenomena and incorporating and explaining laws (McIntosh, 1982).

The question of whether true laws occur in ecological theory is debatable. McIntosh (1982) describes one of the difficulties in developing ecological laws as being able to recognize, in the 'untidiness of complex biological systems, the neat regularity which lends itself to mathematization, explanation and prediction'. Claims of ecological regularity are often pitched at so broad a level of generality that they are not very enlightening. Counterparts of the laws characteristic of physics are difficult to identify in ecology.

It has been argued by Loehle (1988), quoting Simberloff, pers. comm., that ecology is largely ideographic (explaining particulars) rather than nomothetic (derives universal laws). Loehle (1988) feels that truly universal ecological laws do occur. He cites as examples, 'no population can increase without bounds', or 'energy is dissipated across any tropic transfer'.

Over the years a number of similar generalizations have been proposed variously as hypotheses, principles or laws, without achieving any consensus (McIntosh 1982).

The most recent law advanced in ecology is Yoda's 3/2ths thinning law (Yoda <u>et al</u>. 1963, as quoted in McIntosh, 1982). This law relates the logarithm of the weight of individual plants to the logarithm of their density. This has been claimed to be the first basic law demonstrated for ecology.

In ecology, the lack of laws, constants and regularities, comparable to those of physics is seen by most ecologists to plague the pursuit of a comprehensive ecological theory, seen as necessary if ecology is to mature into a so-called 'hard science'.

The attainability and desirability of ecology attempting to emulate the scientific criteria inherent in the 'hard sciences' has been questioned by some ecologist. For example, Slobodkin (1965) feels that the normal criteria of scientific quality which are used by biologists are not the same as those of the physicist and mathematician, and that empirical science must develop its own standards of quality. The grounding of the quantitative mathematical theory of ecology stems from the conviction that underlying the manifest complexities are simple mathematical theories, as found in physics. Slobodkin (1965) describes this as an illegitimate analogy. MacFadyen (1975) describes this aspect of ecological epistemology as a faith in the belief that ecological systems conform closely enough to patterns and operate sufficiently within discernible constraints for it to be worthwhile trying to find out what those constraints are.

Because ecosystems are highly complex and involve numerous variables, the tools and techniques used by the physical scientists cannot be easily applied. Nor can the knowledge be expected to be as precise and as predictable as the knowledge in, for example, chemistry or physics.

3.3.4 Ecological generality

In accordance with the hierarchial structure of ecosystems (O'Niell *et* al. 1986), ecological knowledge can be perceived as being arranged in 'layers', moving from the general to the specific. At the upper layer of the hierarchy, ecological theory is concerned with large scale predictions. At these levels ecological models can be built from empirical generalizations that extend beyond single species. These generalizations can then be rationalized in the context of known mechanisms. Unfortunately, as Slobodkin (1988) points out, only a very small class of practical questions can be answered at this level of generality.

To answer practical ecological questions, it is usually necessary to include deeper knowledge, or knowledge at a lower hierarchical level. This involves extrapolating from the general to the specific. Slobodkin (1988) has remarked on the narrow extrapolation range of descriptive ecology. This is attributed to the unique natural histories of the multiple organisms which defy generalizations.

Given the difficulties of ecological theory, it is tempting to use general, natural-history-free models to make field predictions. These predictions will be too coarse to be reliable. Improving the accuracy of the model would require the inclusion of much relevant detail - this would considerably narrow the range of applicability of the model (Slobodkin, 1988).

Unfortunately, the choice is not between perfect and imperfect advice to managers, but between crudely imperfect advice and no advice at all (May 1984, as quoted by Slobodkin, 1988).

3.5 Emergent properties

No discussion on the nature of ecological knowledge would be complete without mention of a special category of ecological knowledge originating from the hierarchal organization of ecosystems (O'Niell *et al*. 1986).

An important consequence of hierarchal organization is that as components, or subsets, are combined to produce larger functional wholes, new properties emerge which were not evident at the next level below (Odum, 1977).

Salt (1979) defines an emergent property of an ecological unit as one which is wholly unpredictable from observation of the components of that unit. Furthermore, the emergent property of an ecological unit is only discernible by observation of that unit itself.

The difference between emergent properties and the collective properties of an ecological unit are not always clear. Collective properties are essentially characteristics of components of the ecological unit, obtained through summarizations of the behaviour of the component of the unit studied. For example, the age-class structure of a population is a result of the combined ages of all the individuals which make up the population (Salt, 1979).

Alfred Whitehead described the mechanistic analysis of nature that had previously dominated Western thinking as 'one-eyed reason, deficient in its vision of depth'. 'Mechanistic materialism' was the name Whitehead gava to this mode of abstraction which selected from the multitude of experiences only those qualities which could be explained by physio-chemical laws (Worster, 1977).

The theory of emergence challenges the scientific notion that the consequent might be fundamentally different from its antecedents (Worster, 1977). The outcome of emergence could be a substance as basic as water - an emergent from two gases - or as complex as human consciousness.

Smuts (1926) coined the term 'holism', a concept used to account for the emergence of progressively more complex wholes. Smuts (1926) points out the relevance of emergence in the context of evolutionary theory by saying 'all reality is aggregative, contextual, emergent; and the progressive development of the resulting wholes at all stages - from the most inchoate, imperfect, inorganic wholes to the most highly developed and organised - is what we call Evolution'.

The application of systems analysis to ecosystems has helped cause a shift in emphasis from a reductionistic to a more holistic and integrated approach to ecological research.

It is suggested here that 'emergent properties' may be disclosed during the process of ecosystem modelling. To illustrate, various simulation runs of the bush clearing model REGROWTH revealed that the relative suppressive effects of tree basal area on grass production are higher in low rainfall areas than in high rainfall areas. This implies that, all else being equal, bush clearing would result in higher economics benefits in arid as opposed to mesic areas.

It could be argued that hypothesis induced from models, such as described above, cannot qualify an an emergent property of the ecosystem being modelled. It would be difficult to determine, particularly considering the difficulty in validating ecological models, whether the behaviour of the model is reflecting real emergent properties of the ecosystem, or whether these are just the consequences of the mathematical structure of the model.

3.6 The contextual nature of ecological knowledge

It has been argued that in the absence of laws no theory is possible. Typical theories in ecology are verbal or semi-quantitative. For such theories to be predictive they become highly dependent on unstated auxiliary assumptions or boundary conditions. This would support the notion that explanations for ecological phenomena are highly contextual and can seldom be obtained by referring back to 'first principles'. Furthermore, this implies that ecological models are largely based on knowledge that may be valid only within a specific context and, therefore, can only be used within that context.

Theories, generally considered as competitive, might be complementary in that each of them relates to only a limited range of circumstances. Accordingly, competitive theories have a situational falsifiability. For example, clemensian succession might be appropriate for some rangeland systems, whereas other systems might be better viewed as event-driven. In this light, the inapplicability of a given paradigm to a given situation cannot be grounds for universal refutation. Uncertainty may arise as to when a theory is simply inapplicable, or when it is indeed invalidated (Mentis, 1988).

3.6.1 Implicit and explicit knowledge

Stent (1978) has drawn attention to the semantic problems in deriving meaning from biological information. The meaning of semantic structures often depends on the context in which they are used. A distinction can be made between explicit and implicit meaning. The explicit meaning is that which a semantic structure has by virtue of the syntactic relation of its elements, i.e. the literal meaning of the information. The implicit meaning, by contrast, is not contained in the structure itself and arises secondarily from the explicit meaning by virtue of its context

For example, the information 'the veld has been burnt in spring' could have the sequence of meanings as seen in figure 3.2.

One level of implicit information is derived from the preceding level. There exists an hierarchy of implicit meanings. These meanings can only take on relevance within a **contextual hierarchy**. The higher the level of implicit information, the more dependent it becomes on its context. To illustrate, in the above example the relevance of information at 'implicit level 1' is dependent on the proviso that rainfall is not above average. Similarly, information at 'implicit level 2' may be dependent on the provisos that rainfall is not above average and that a heavy grazing pressure is maintained. Finally, for to a given situation cannot be grounds for universal refutation. Uncertainty may arise as to when a theory is simply inapplicable, or when it is indeed invalidated (Mentis, 1988).

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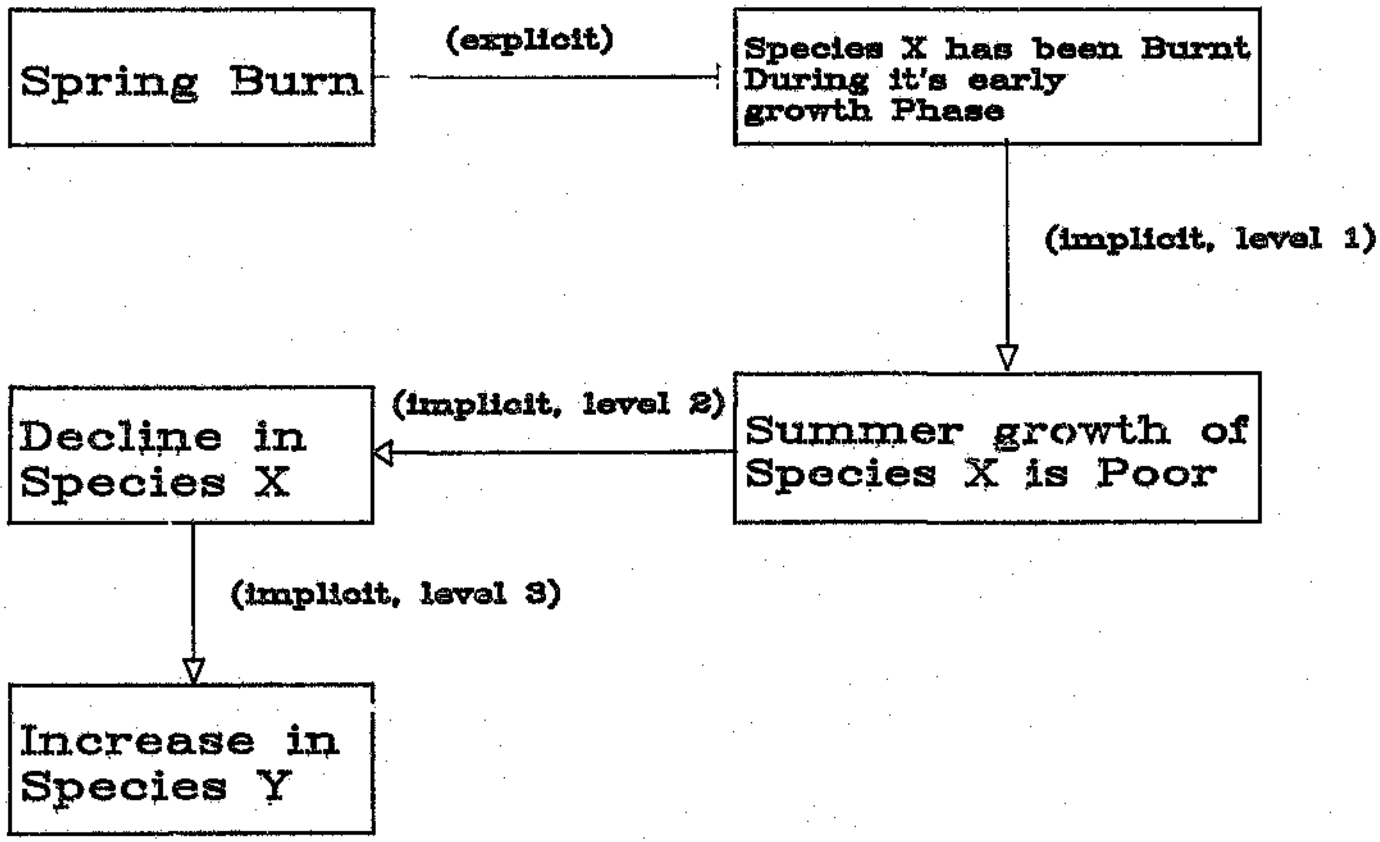

Figure 3.2 Example of a sequence of meanings demonstrating implicit and explicit knowledge.

information at 'implicit level 3' to be valid, a host of provisos may be required so that the statement 'a spring burn will increase the occurrence of species y' will only be true in a very specific context.

It is difficult to draw a sharp line of demarcation between explicit and implicit meanings, since the extraction of the explicit meaning is, itself, rarely context-free. The distinction between explicit and implicit meaning is relative rather than absolute, with a meaning being the less explicit and the more the implicit, the more dependent it is on the context (Stent, 1978).

3.6.2 Relative knowledge

The quantum theory and the theory of relativity have had a major influence in transforming the old mechanistic world view of Newtonian physics and absolute knowledge towards the idea that things are inherently relative and dependent on conditions and contexts.

Capra (1975), reflecting the view of modern physics and Eastern mysticism, believes that all knowledge is relative. Nothing is understandable by itself. Everything in the universe is connected to everything else and no part of it is fundamental. The properties of any part are determined not by some fundamental law, but by the properties of all the other parts.

It is argued by Prigogine and Stengers (1984) that even the old 'universal laws' of Newtonian physics are not universal at all, but apply only to local regions of reality. And these happen to be the regions to which science has devoted the most effort.

Prigogine and Stengers (1984) continue by saying that 'while some parts of the universe may operate like machines, these are closed systems, and closed systems at best form only a small part of the physical universe. Most phenomena of interest to us are, in fact, open systems, exchanging energy or matter (or information) with their environment. Most biological systems are open, which means that the attempt to understand them in mechanistic terms is doomed to failure. Furthermore, this suggests that reality instead of being orderly, stable and equilibrial, is seething and bubbling with change, disorder and process'.

Capra (1975) points out the problem of attempting to describe the natural world with rational knowledge. 'Rational knowledge is a system of abstract concepts and symbols, characterized by the linear, sequential structure which is typical of our thinking and speaking. The natural world, on the other hand, is one of infinite varieties and complexities, a multi-dimensional world which contains no straight lines, where things do not happen in sequence, but all together. It is clear that we can only expect an approximate representation of reality, and all rational knowledge is therefore necessarily limited'.

The realm of rational knowledge is, of course, the realm of science which measures and quantifies, classifies and analyses. The limitations of any knowledge obtained by these methods have become increasingly apparent in modern science and, in particular, in modern physics which has taught us, in the words of Werner Heisenberg, 'that every word or concept, clear as it may seem to be, has only a limited range of applicability' (Capra, 1975).

3.7 The predictability of ecological events

Scientific theories propose relations between observable phenomena. A good theory enables a scientist to make predictions from measurements of independent variables about the behaviour of dependent variables (Peters, 1982).

The poor predictability of so-called soft sciences (including ecology, economics and the social sciences) is often associated with the conspicuous lack of successful theories in these fields.

A more fundamental view of the poor predictability of ecology has been proposed by various authors (Mentis, pers comm). The view hinges about three distinct but interrelated concepts. These are briefly described below.

(1) 'White noise' and the uniqueness of ecological events.

Pielou (1972) suggested that ecological phenomena contain a degree of stochasticity that leads to an innate unpredictability, and that ecology could never equal the predictive power of physics and chemistry because of the white noise problem.

A scientist attempts to derive generalizations and, hopefully, laws through trying to detect some common denominator or structure in an ensemble of events. An event which is unique cannot, therefore, be the subject of scientific investigation, for an ensemble of unique events has no common denominator, and there is nothing in it to explain; such events are random, and the observer perceives them as 'noise'. So the basic problem of a scientific investigation is to recognize a significant structure of an ensemble of events above its inevitable background noise. The lower the background noise of a natural phenomenon - that is, the smaller the role of the uniqueness of its constituent events - the more unambiguous its theoretical structure (Stent, 1978).

(2) Second order indeterminism.

Mandelbrot, 1963 (as quoted by Stent, 1978) developed an epistemological argument which draws attention to a fundamental barrier of the capacity to discover new laws in both the natural and social sciences. Mandelbrot believes that most natural phenomena for which successful scientific theories had been worked out, prior to about one hundred years ago, are relatively 'noise-free'. Such phenomena were explained in terms of deterministic laws, which assert that a given set of initial conditions (antecedent situation) can lead to one, and only one, final state (consequent). Towards the end of the nineteenth century, the methods of mathematical statistics came to be trained on previously inscrutable physical phenomena involving an appreciable element of noise. This development gave rise to indeterministic laws, for example, the kinetic theory of gases and quantum mechanics. These indeterministic laws envisage that a given set of initial conditions can lead to several alternative final states. An indeterministic law is not devoid of predictive value because, to each of the several alternative final states, there is assigned a probability (Stent, 1978).

Mandelbrot feels that science is presently at the threshold of what he calls a second stage of indeterminism, in that many of the noisy phenomena which continue to elude successful theoretical understanding will not only be inaccessible to analysis by old-style determinist theories, but also to the statistics used to determine first-stage indeterministic theories. In most systems for which it has been possible to make successful first-stage indeterministic scientific theories, the ensemble of events of the phenomena observed display a statistical distribution such that the mean value of a series of observations converges rapidly toward a limit. That limit can be subjected to analysis of the classical deterministic type. Many natural phenomena (for example, annual rainfall) may possess a spontaneous activity which displays a statistical distribution, in which the mean converges only very slowly, or not at all, toward a limit. And here, according to Mandelbrot, it is difficult to ascertain whether any structure the observer believes to have perceived is real, or merely a figment of his imagination (Stent, 1978).

Systems displaying statistics where mean values do not easily converge to a limit follow what is known as Pareto distributions. For these systems, exceptionally large data sets will be required before second order indeterministic laws could be extracted from such systems (Stent, 1978).

It is being suggested here that the apparent lack of ecological laws and theories arises from the predominance of Pareto distributions in the basic phenomena to which ecologists address their quantitative analysis.

(3) Ecological systems considered as medium-number systems.

A certain paradox exists concerning the degree of complexity and the number of components of a system. For big-number systems, such as a macroscopic quantity of gas, physicists are able to make thermodynamic predictions relating to pressure, volume and temperature. This is possible not in spite of, but because of, the large number of similar components. The predictions are from averages. At the other extreme are small-number problems exemplified by the Newtonian consideration of our planetary system. Newton was able to make relatively accurate predictions concerning the motion of these planets. Between these extremes are the medium-number systems, such as ecological systems, which yield neither to the mechanical nor the statistical approach because there are too many components to describe each interaction with a separate equation, and the components are too different to permit averaging. Medium-number systems are usually assigned to second order indeterminacy (O'Neill et al. 1986).

Thus, the problem of ecologists is not that the object of study is complex. Other complicated systems have yielded to scientific investigation. The real problem is the type of complexity involved. Ecosystems, conceived as medium-number systems, can be expected to be particularly recalcitrant to analysis (O'Neill et al. 1986).

O'Neill et al. (1986) believe that if any success is to be had in analysing medium-number systems such as ecosystems, careful and explicit consideration of the organization underlying its complexity is required. To this purpose, they have proposed a hierarchical concept of ecosystems. Central to the theory is the concept that organization results from differences in process rate. Medium-number systems, like ecosystems, operate over a wide spectrum of rates. Behaviours can be grouped into classes with similar rates, and if the classes are sufficiently distinct the system can be considered as hierarchical and dealt with as a small-number system. O'Neill et al. (1986) argue that previous attempts to define ecosystems have been derived from spatio-temporally limiting viewpoints. Hierarchy theory is seen as a means of getting around this problem. Furthermore, hierarchy theory provides a unifying framework in which both the population-community and the process-functional viewpoints of ecosystems can be considered simultaneously (O'Neill et al. 1986).

3.8 Conclusions

This investigation into the nature of ecological knowledge reveals the following points. These points should be considered when developing ecological models.

(1) The contextual nature of ecological knowledge. Ecological explanations are highly dependent on auxiliary assumptions. Ecological theories may have a situational falsifiability (Mentis, 1988) (see section 3.6). This implies that the degree of generality built into ecological models is typically limited.

(2) Ecological knowledge comprises mostly of concepts. There are few real laws or theories (McIntosh, 1982). This implies that ecological problems can seldom be solved by 'going back to first principles'.

(3) Ecological knowledge may be considered as deep or shallow (Nobel, 1987). Deep ecological knowledge implies an understanding of fundamental processes.

(4) Much ecological knowledge may be emergent in nature (see section 3.5). A systems approach (as opposed to a reductionist approach) will assist in revealing emergent properties of ecosystems.

(5) The study of ecosystems have traditionally involved perceptions that are limited in time and space. Hierarchy theory as proposed by O'Neill et al. (1986) is seen as a way around this problem.

(6) The poor predictability of ecological events can be explained by three interrelated concepts (see section 3.7). These are

(a) the 'white noise' and uniqueness of ecological events (Pielou, 1972; Stent, 1978);

(b) the predominance of second order indeterminism and the fact that many ecological phenomena conform to Pareto distributions (Stent, 1978);

(c) the viewpoint that ecological systems are considered as medium-number systems (O'Neill et al. 1986).

The above implies that ecology can never attain the predictability of the hard sciences. Because of this, ecological decision models should aim to provide descriptive, as opposed to prescriptive, advice. Viewing ecosystems in terms of the hierarchy theory proposed by O'Neill et al. (1986) may improve the ability to provide predictive insights.

SECTION 2 : THE MODELS

CHAPTER FOUR

USING THE EXPERT SYSTEM MODELLING APPROACH TO DETERMINE SUITABLE STOCKING RATE POLICIES AND STOCKING RATE LEVELS

This section describes the development of two expert system models, POLICY and GRASTOCK. The section serves to illustrate how consolidating current wisdom, largely from the literature, can be engineered into decision models.

The knowledge engineering steps of identification (i.e. characterizing the important aspects of the problem) and conceptualization (identifying relevant concepts of the problem) form the bulk of this section. Attention is focused on critical and controversial concepts.

4.1 The model: POLICY. Determining suitable stocking rate policies for game and cattle farms in semi-arid savannas

POLICY is a small expert system comprising only ten rules. It has also been represented in the form of an algorithm (see Fig. 4.1). The concept of rainfall predictability is discussed at some length. This study has been important in shaping the approach adopted in the model GRASTOCK.

4.1.1 Objectives of the model : POLICY

The objectives of POLICY are to

(1) develop a simple decision analysis model that will assist farmers in reaching the most appropriate stocking rate policy;

(2) consider the most important factors that affect this decision, in particular, the question of rainfall predictability; and

(3) establish a background for developing the stocking rate model, GRASTOCK.

4.1.2 Options

There are four possible approaches that could be adopted

(1) Fixed stocking rate

(a) Relatively high

Stocking rates are kept at levels which require average or above average rainfall for adequate feed production from rangelands. The success of this policy depends on the farmer's ability to provide reasonably priced supplementary feed. The advantages of this policy are the 'bumper crops' obtained during good years.

(b) Conservative

Stocking rates are kept low so that supplementary feed will seldom be required (except, perhaps, during extremely dry years). The advantages are that there will be low risks of stock loss, production will be consistent, and the risk of veld degradation is minimized. Furthermore, low stocking rates will enable a build-up of dry material during good rainfall years, which allows for foggaging in sweetveld, or for the use of fire as a management tool to encourage rotational grazing, or for bush control.

(2) Variable stocking rates

Stocking rates are changed opportunistically in accordance with periods of high or low rainfall. The success of this method depends largely on the ability of the farmer to alter stocking rates at short notice and/or the ability to predict periods of below or above average rainfall.

(a) Tracking rainfall cycles

Stocking rates are allowed to increase during runs of good years, and are decreased during runs of bad years. Extra income derived during wet cycles is used to tide the rancher over the dry periods.

(b) Tracking rainfall years

This is the most opportunistic of all policies. It requires a high degree of flexibility with regard to changing stocking rates. This approach is probably only feasible for put-and-take operations, where stock can be bought and sold during the same year.

4.1.3 Determinants

The important considerations that determine what stocking rate policy to adopt, include

(1) the reliability and predictability of rainfall in the area;

(2) practical considerations regarding the ability to manipulate stocking rates at short notice and the ability to provide reasonably priced supplementary feed;

(3) the farmer's attitude to risk, and the degree of risk that he can afford to take;

(4) financial considerations of the farmer (conservative stocking may not be a viable option if the farm is too small, or there may be a minimum stocking rate to ensure repayment of debts);

(5) the ability of the veld to maintain its productive potential, its recovery rate, and its resistance to overgrazing and erosion;

(6) the management objectives of the farmer; and

(7) a bio-economic analysis of the most profitable policy.

4.1.4 Rainfall predictability

The predictability of rainfall is an important consideratior in determining a suitable stocking rate policy.

Two aspects of rainfall predictability were considered. Firstly, the predictability of rainfall cycles (or consecutive runs of 'good' or 'bad' years), and secondly, the predictability of rainfall from one year to the next.

4.1.4.1 Rainfall cycles

Tyson and Dyer (1975), Dyer (1976), and Tyson (1986) have shown how the summer rainfall region, taken as a whole, has experienced a regular pattern of rainfall fluctuation since 1910. Using space mean percentage deviations, they have shown how the periods 1916-1925, 1936-1944, 1954-1963 and 1972-1982 experienced above average rainfall, whereas the periods in between experienced below average rainfall.

Tyson (1986) believes that contained within the generally random year-to-year rainfall variability, is an underlying non-random component which has varied systematically for over eighty years. This non-random component seldom accounted for more than 20-30 percent of the variance in local rainfall.

Tyson (1986) furthermore believes that these 18-20 year cycles for the summer rainfall region of Southern Africa are unique in Africa. Weaker 10-20 year cycles were found to be operating by Pennycuick and Norton-Griffiths (1976) in the Serengeti ecosystem. These cyclic trends were too weak to use for predicting future climatic trends.

The hypothesis of a pseudo 18-20 year rainfall cycle as proposed by Tyson and Dyer (1975) has not been universally accepted. Opposing views are held by Markam (1980) and Pegram (1983), who are both of the opinion that there is no statistically significant evidence of the true pseudo-periodicity which may make it possible to predict future wet and dry spells. Markam (1980) has found consistency between actual rainfall data and a series of randomly permutated data. He concludes that rainfall data consist of independent observations that do not display any statistically significant periodicity.

If one accepts the Tyson-Dyer rainfall cycle hypothesis, to what degree could knowledge of these cycles be used to influence stocking rate policy? In Table 4.1 rainfall data for four north-western Transvaal rainfall stations are used to determine the number of 'drought years' which have occurred outside of the 'dry cycle' predicted by the Tyson-Dyer hypothesis for the summer rainfall region. A 'drought year' has been defined as any year receiving below 65% of the station mean. Taken as an average for the four stations shown, 38% of all 'drought years' occurred outside the predicted 'dry-cycle'. In practical terms then, if a farmer is using the Tyson-Dyer model to allow his stocking rate to track rainfall cycles, on average, 38% of all 'drought years will occur during the so-called 'wet cycle' (when stocking rates are above average).

The degree to which annual rainfall can be predicted by the Tyson-Dyer model for specific localities in the north-western Transvaal appears to be relatively low. It is felt that the benefits of allowing stocking rates to track these Tyson-Dyer rainfall cycles would be negligible.

Table 4.1 'Drought years' occurring outside of the Tyson-Dyer 'dry cycles' for four north-western Transvaal rainfall stations.

Station	Number of data years	65% of annual mean (mm)	Number of 'drought years'	Drought years occurring outside of 'Dry cycle'	
				Number	Percentage
Sterkfontein	54	480	7	3	43
Buffeldoorns	54	354	14	7	50
Groenvlei	54	314	7	2	29
Hoopdaal	54	344	7	2	29
MEAN		373	8,7	3,5	38

4.1.4.2 Predictive correlation

The possibility exists that different rainfall cycles may be operating at a localized level. If there is a strong non-random component underlying the rainfall variability at a particular locality, one would expect a high degree of correlation between the rainfalls of successive years.

Linear regression of annual rainfall for year n against rainfall for year n-1 for the rainfall stations of Groenvlei and Sterkfontein resulted in non-significant r^2 values of 0,05 and 0,01 respectively.

Further analysis was done to determine if this year's rainfall could be used to determine if next year's rainfall will be above or below average. A matrix was used in which fifty years of rainfall data for four north-western Transvaal rainfall stations were divided into either above, or below, average rainfall years. The number of years in which above average years were followed by above average years, and below average years followed by below average years, was recorded. The results have been summarized in Table 4.2.

Both the low r^2 values and the results presented in Table 4.2 support the view that annual rainfall is poorly predictable.

Table 4.2 Percentage of paired-years in which above average years were preceded by above average years, and below average preceded by below average years (for 54 data years).

Station	% Of occurrences of two successive above average years	% Of occurrences of two successive below average years
Sterkfontein	59	38
Buffeldoorns	7	57
Groenvlei	70	64
Hoopdaal	65	58
MEAN	66	54

4.1.4.3 Conclusion

To date, no method exists which can be used to provide a reasonably accurate prediction of year to year rainfall. At farm level the degree to which rainfall distribution can be predicted by the Tyson-Dye rainfall cycles is too weak to be of real use to management.

For the purposes of management, it is felt that annual rainfall should be treated as independently random occurring events. The only reliable statements that can be made about annual rainfall are the cumulative probabilities of receiving more than certain amounts. For this reason it is felt that unless supplementary feeding or drastic reduction in stock can be made at short notice, a tracking stocking rate policy cannot be advocated for the north-western Transvaal.

4.2 GRASTOCK : A model to recommend suitable grazing herbivore stocking rate levels

4.2.1 Modelling objectives

The aims of GRASTOCK were as follows.

(1) Provide descriptive (as opposed to prescriptive) advice regarding 'suitable stocking rates' on game/cattle farms in semi-arid savannas.

Note that:

(a) the term 'suitable stocking rates' rather than 'optimal stocking rates' has been deliberately chosen to avoid the implication that a mathematical optimization is involved, and

(b) the term 'suitable stocking rates' implies a stocking rate that complies with the objectives and level of risk acceptance of the farmer, and which falls within the biological constraints imposed on the area.

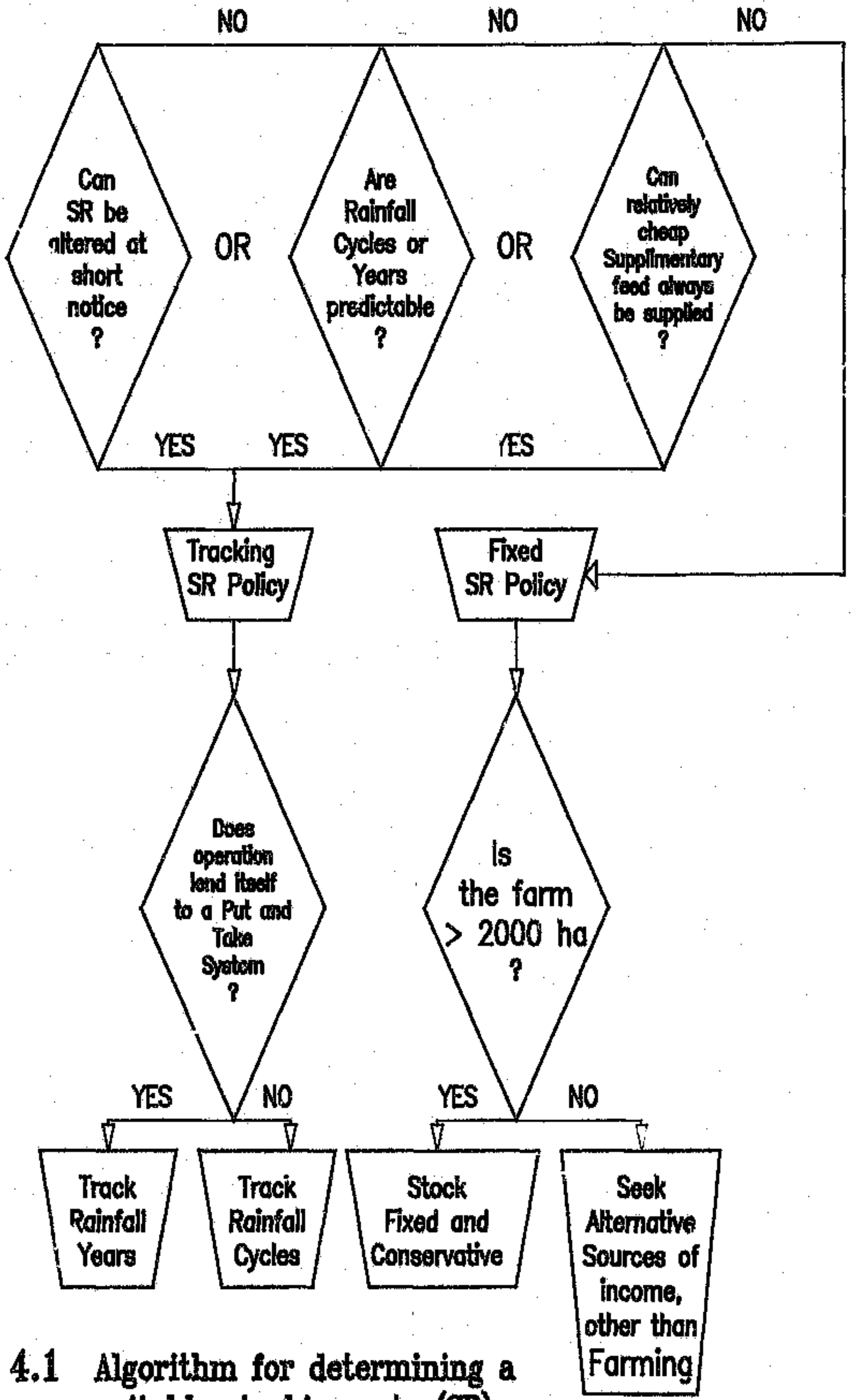

Figure 4.1 Algorithm for determining a suitable stocking rate (SR) policy for semi-arid savanna farms.

(2) Explore the fundamental issues that determine suitable stocking rates in semi-arid savannas.

(3) Illustrate the process of ecological knowledge engineering (in keeping with the objectives of this thesis).

4.2.2 The concepts of carrying capacity and non-equilibrial systems

Grazing or carrying capacity is a vague and often misunderstood concept. Danckwerts and Stuart-Hill (1988) give a broad definition of the concept as being an indication of the productivity of vegetation, in terms of the number of animals that can be maintained (at some level of production) in an area of land without deterioration to the vegetation or soil.

Essentially, carrying capacity can be seen as two related concepts; firstly, animal productivity and secondly, non-deterioration in veld condition. Recommendations of suitable stocking rates should always be qualified with the knowledge of operator objectives with regard to productivity per animal. Stocking rates for pastoralists or game farmers whose aims are to maximize animal numbers, may be considerably higher than those of a cattle farmer, whose objective is to maximize return on investments.

The concept of 'non-deterioration of vegetation' is not clear. Ecological theory does not enable us to identify a simple, single, upper safe level at which to stock; a level above which 'things fall apart'. It is realized that there may well be thresholds, the crossing

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An ecological definition of 'carrying capacity' is given by Caughley (1979). He describes it as the name given to a state of equilibrium between animals and vegetation. The position of that equilibrium is characterized by its density of animals. At equilibrium carrying capacities, the rate of forage production equals the rate of forage consumption. At relatively high animal densities (and relatively low forage densities) an equilibrium point will be reached, termed as the 'ecological carrying capacity'. At relatively low animal densities (and relatively high forage densities) an equilibrium point will be reached in which animal productivity is maximized. This point is termed the 'economic carrying capacity' (Caughley, 1979) (See figure 4.2).

Inherent in this concept of carrying capacity is the assumption that rangelands can reach stable equilibriums. Furthermore, it implies that there will be some optimal and constant 'stocking rate' at which animal production will be maximized and damage to vegetation minimized.

Under the equilibrium model (i.e. implying range succession) the object of management is to choose a stocking rate which establishes a long-term balance between the pressure of grazing and the successional tendency of the vegetation. The model recognizes that vegetation is affected when rainfall varies from year to year. The range succession model deals with varying rainfall by supposing that drought affects vegetation in a similar way to grazing and, conversely, that above average years have effects which can be understood as accelerating the successional tendency (Westoby et al. 1989).

A critical assumption about equilibrium grazing systems is that plant growth conditions are relatively stable (Noy-Meir, 1975; Ellis & Swift, 1988). Similarly, De Angelis and Waterhouse (1987) as quoted in Ellis and Swift (1988) state that systems frequently fail to demonstrate equilibrial behaviour due to the disruptive effects of stochastic events. This leads to major variations in growing conditions which prevent the development of strong biotic interactions and feedback controls which are necessary for equilibrial conditions. This implies that in semi-arid areas with erratic rainfall, equilibrium states rarely, if ever, materialize.

An alternative paradigm of semi-arid rangeland dynamics has been proposed by Ellis and Swift (1988), Walker (1988), Westoby et al. (1989), and Mentis et al. (1989). Essentially, these authors are proposing that the orthodox view of rangelands complying with equilibrium theory is no longer adequate to explain rangeland dynamics. In the alternative paradigm, moisture-limited rangelands are seen as event-driven systems. Their state is conceived to have inertia which must be overcome (by a disturbance event like flood, drought, herbivores and fire) for the state to change. This interpretation constitutes an 'event-driven' theory - a non-equilibrium model of rangeland function (Mentis et al. 1989).

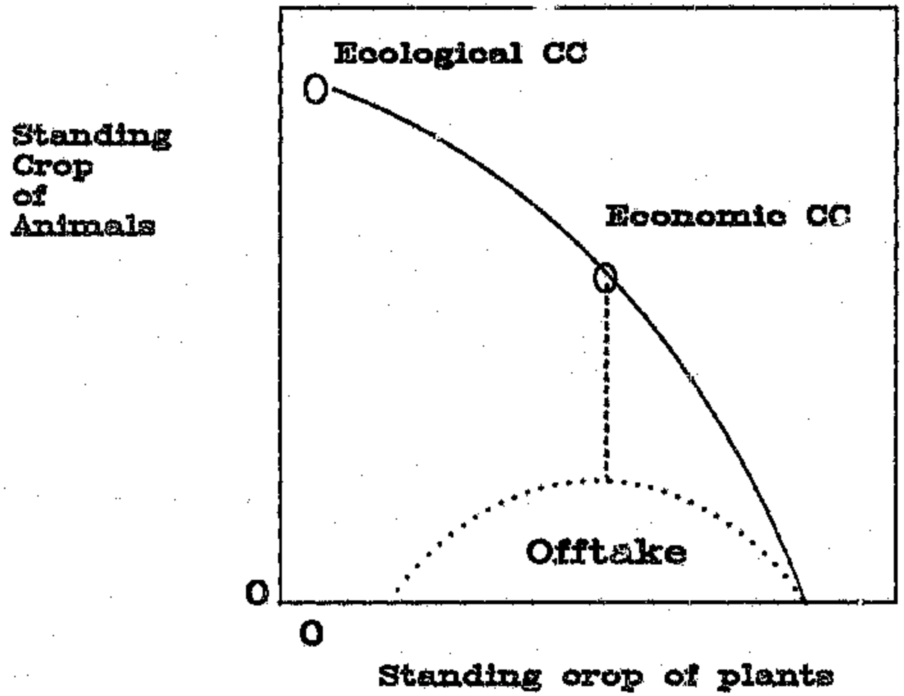

Figure 4.2 The zero-isocline of vegetation marking the position of all equilibria between plants and animals enforceable by hunting. The ecological carrying capacity point is the equilibrium in the absence of hunting whereas the economic carrying capacity is the equilibrium enforced by a maximum sustained yield (Caughly, 1979).

Westoby et al. (1989) concur that the weakness of the range succession model are most apparent in arid and semi-arid rangelands, where episodic events are important and influences of grazing and intrinsic vegetation change acts intermittently. To cope with this, they have proposed a state-and-transition model in which rangelands are described by means of catalogues of alternative states and catalogues of possible transition. Under this model a highly flexible and opportunistic stocking rate policy is advocated, in which grazing pressure is seen as a means to reach a positive improvement in the state of vegetation (Westoby et al. 1989). The difficulty in implementing a highly flexible stocking rate for wild herbivores has been discussed under section 4.1.4.3.

In non-equilibrium grazing systems, carrying capacity becomes a dynamic and elusive concept. In this thesis the concept of carrying capacity has been abandoned. In its place the less ambitious but more pragmatic term of 'suitable stocking rate' is used. This is defined as the stocking rate which complies with the level of risk acceptance of the farmer.

4.2.3 Overview of the model GRASTOCK

The model GRASTOCK estimates the amounts of metabolic energy available for herbivore consumption. The total grass production is calculated by using a rainfall-grass production subroutine. The rainfall level used in this calculation is determined from the amount of risk that a farmer is willing to accept, together with the cumulative rainfall probabilities for that particular area.

A flow diagram of the model GRASTOCK is represented in Figure 4.3.

4.2.4 Conceptualization of the problem

Three of the most important stages in engineering a body of knowledge into an expert system include identification, conceptualization and formalization (Waterman, 1986). This section attempts to identify the most important aspects of the problem, and the various sub-problems involved. It examines the concepts involved in the problem, and how the knowledge embodied in these concepts [illegible] formalize and represented within the expert system framewo

4.2.4.1 The concept of 'risk acceptability level' as used in the model

The underlying philosophy of the model GRASTOCK is the belief that ecological advice should be descriptive, and not prescriptive in nature. The inherent complexity of ecosystems and the difficulty in validating ecological models precludes the possibility that 'exact answers' (such as an optimal stocking rate) could ever be found.

Rather than attempt to provide prescriptive advice, the model provides descriptive advice on the likely outcomes of various options. These options concern a farmer's level of 'risk acceptance' (or his ability and willingness to provide supplementary feed in the event of a 'drought').

Donaldson and Kelk (1970) have discussed the implications of a highly

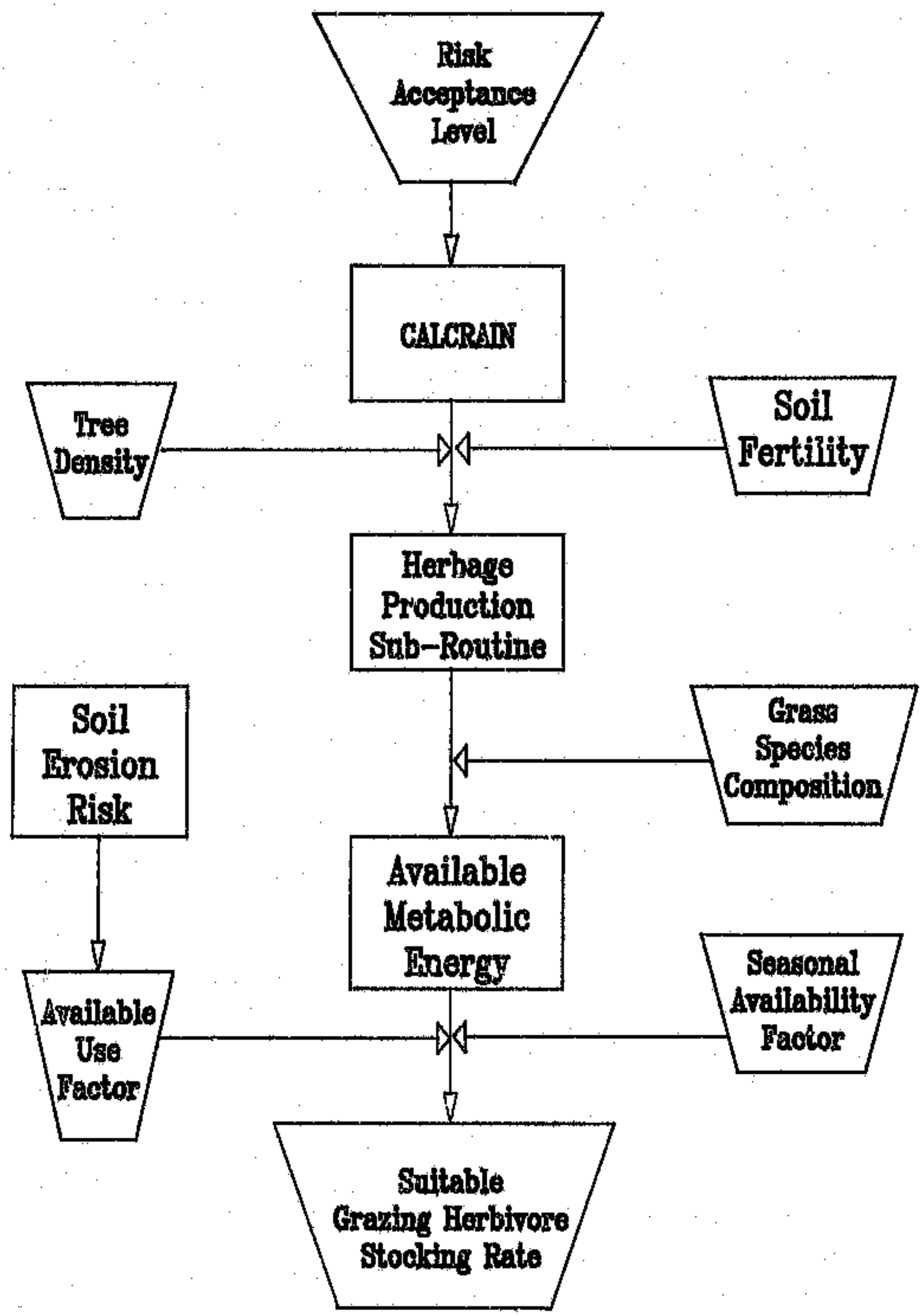

Figure 4.3 Overview of model GRASTOCK (CALCRAIN is the calculated rainfall level which corresponds with the risk acceptance level).

erratic annual rainfall for ranches in semi-arid areas. They have discussed the importance of ensuring that animals are stocked at a rate that leaves them sufficient fodder in dry years. The exact stocking rate chosen will depend on circumstances governing the feasibility of adopting measures to prevent excessive stress on both vegetation and animals in critical years of low veld production. These measures would include the flexibility of changing stocking rates at short notice, and the ability to draw on fodder reserves (Dye & Spear, 1982).

The risk acceptability level is the level of risk that a rancher is willing to accept in experiencing a fodder shortage from the veld, for any given year. The low predictability of rainfall and the inability of most game ranchers to alter stocking rates at short notice imply that, for every given stocking rate, there will be an associated risk of experiencing a fodder shortage. The factors that may influence the risk acceptability level of a farmer are briefly listed below.

(1) Psychological attitude. Does the farmer want to gamble with the weather for bumper crops?

(2) Financial considerations. Is there a minimum stocking rate needed to enable the repayment of debts?

(3) Practical considerations. Can supplementary fodder be produced at short notice?

(4) Ecological considerations, for example the risk of soil erosion.

The risk level referred to here is the probability that the feed requirements of animals will exceed the fodder produced from the veld for any given year. No reference is made to the extent of shortfall in these years.

The cumulative annual rainfall probabilities (i.e. the probabilities of receiving more than a certain amount of rainfall for a particular area) are used to estimate the cumulative annual forage production probabilities. This enables every stocking rate level to be associated with a probability of a fodder shortfall (see figure 4.4).

For example, in a specific area, a stocking rate of say, 0.1 AU/ha, may have a fodder requirement level that can be met only in 50% of all rainfall years. This implies that, over the long term, five out of ten years' grass production will be at or below requirement.

The expert system model does not ask the farmer directly for his level of risk acceptance; rather he is asked to make a choice on a scale of one to ten. The scale increases from a low stocking rate, for which feed requirements will almost always be met by grass production, up to high stocking rates, for which the chances of shortfall years are high. The farmers choice will depend on his willingness to accept risk and his ability to provide supplementary feed.

4.2.4.2 <u>The effects of rainfall and soil fertility on herbaceous production</u>

Herbage production and plant quality in savannas depend on the total

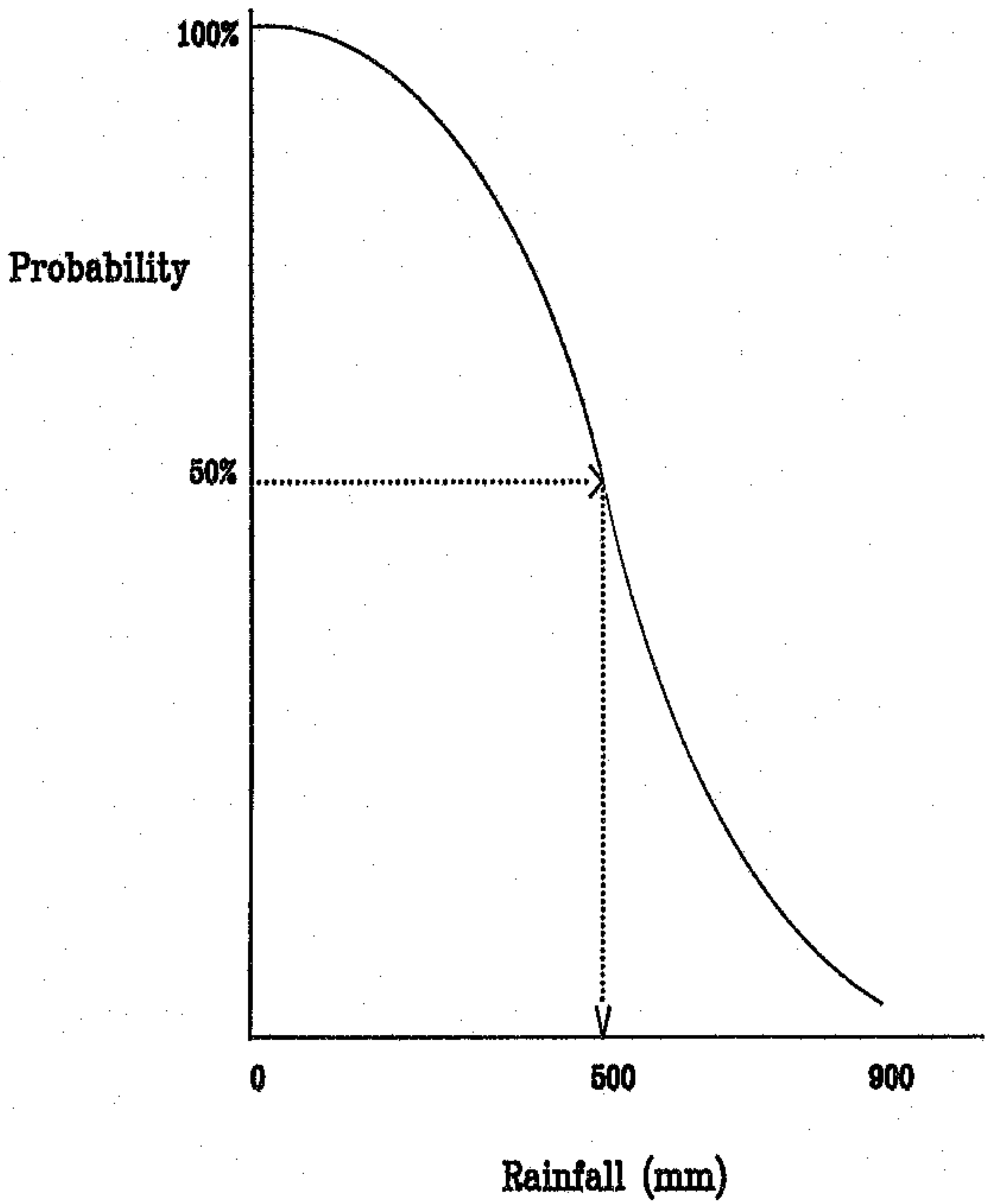

Figure 4.4 Cumulative Rainfall Probabilities as used in GRASTOCK.

amount and seasonal distribution of rainfall, and on the availability of nutrients, particularly nitrogen and phosphorus (Frost _et al_. 1985).

The influence of water availability is most apparent in dry savannas, as indicated by the positive correlations between annual rainfall and herbaceous above-ground biomass (Walter, 1971; San Jose & Medina, 1976; Rutherford, 1980; Deshmukh, 1984). This relationship is only very general and is affected by factors such as the duration of the wet season, soil type and texture, nutrient availability, temperature, fire and species composition (Frost _et al_. 1986).

Dye and Spear (1982) have pointed out some of the effects of soil fertility on the rainfall-grass production relationship. They found that fertile (clayey) soils showed a relatively high correlation between yearly grass yield and annual rainfall, but with large year to year variation in these yields. In contrast, sandy soils of low fertility showed a low correlation between annual grass yield and annual rainfall, but less annual variation in these yields. When rainfall is low, production on clays may be as low as, or even lower, than that on sandy soils under the same rainfall. However, production on clays increases more rapidly with increasing rainfall.

The rainfall-grass production relationship is modified by various other factors such as runoff and seasonal carry over. Runoff is potentially affected by storm, soil, plant, and site characteristics (Dye ,1984).

The inclusion of the modifying factors of soil fertility, runoff and soil surface evaporation into a generalized herbage production-annual precipitation model has been proposed by Scholes (1987) as

$$G = r + sP$$

where P is the annual precipitation (in mm), G the predicted herbage produced, and r and s are constants. The value of r ranges between -20 and -100, the smaller values being associated with sites with high soil surface evaporation and high runoff. The value of s lies between 2 and 5, the higher values occurring on more fertile soils.

Developing a rule base to set the values of r and s in the abovementioned equation was considered, but rejected because of the inherent difficulties associated with the end-user trying to obtain accurate estimations of soil fertility (with five fertility classes), and reliable estimates of evaporation and runoff for each habitat type.

It was felt that the long-term data sets obtained by Dye and Spear (1982) provide a reliable description of rainfall-herbage production relationships. These regression lines obtained for herbage produced on cleared plots on different soil types have been used in the model GRASTOCK. The regression lines were assumed to represent the generalized herbage production for three soil fertility classes (high, medium and low) used in the model GRASTOCK.

The model provides a crude form of calculating the relative contributions made to the overall grass production from different habitat types. The user is asked to input the relative percentages of his farm which are covered by soils of high, medium and low fertility.

It is envisaged that an improved version of the model could calculate the stocking rate of each habitat separately. This will enable habitat differences, such as tree density, grass species composition and soil erosion risk, to be used more effectively in estimating appropriate stocking rates.

4.2.4.3 <u>The influence of the woody component on herbage production</u>

Predictions on the degree to which a given woody density will depress herbage production can be made only if a good understanding exists of the mechanisms involved in determining how the two very different components - grass and woody vegetation - co-exist (Knoop & Walker, 1984).

To account for the balance between woody plants and grasses in dry savannas, Walter (1971) has proposed a model involving a two-layered soil system in which the grasses are the superior competitors for water in the topsoil, and woody plants have exclusive access to a lower (subsoil) water supply. Walter's (1971) model is essentially niche separation on a spatial axis (rooting depth). An alternative model has been put forward by Westoby (1980), which is based on a temporal separation of niches. Unpredictable rainfall o[illegible] series of growth opportunities of variable lengths, which the different growth forms are variously equipped to exploit.

That there is competition between grass and trees is well illustrated by the increase in grass production following the removal of trees. This has been well established by work done in America, Australia and

Africa. What is less clear, is the relation between partial clearing (or tree thinning) and herbage yield. Cᵔnflicting results appear in the literature. Donaldson and Kelk (1970) found an inversely concave dependency of grass production on tree standing crop. Aucamp _et al_. (1980), on the other hand, found an inversely convex relationship between herbaceous production and various degrees of _Acacia karroo_ removal in the Eastern Cape. This work implies that there is an optimal tree density to maximize grass yield (recorded at 300 'tree equivalents' per ha). Work done by Moore and Odendaal (1987) imply a linear relationship between tree density and grass yield. In Australia Walker _et al_. (1972), Beal (1973) and Scanlan (1987) provide support for the inverse concave dependency of grass production on tree density, as observed by Donaldson and Kelk (1970). The implications of these curves for bush clearing policy are large, since the concave curve predicts maximum cost-efficiency with total clearing, while the convex curve implies a non-zero optimum woody density (Scholes, 1987).

The evaluation of these conflicting findings is difficult, since the degree of woodiness is quoted in non-comparable units (i.e. mature trees, tree equivalents, basal area and percentage thinning).

The model, GRASTOCK, uses the inverse concave dependency of grass production on tree density as proposed by Scanlan (1987) and Scanlan and Burrows ('988). This is illustrated in figure 4.5.

Scanlan (1987) and Scanlan and Burrows (1988) have shown how the degree to which tree density depresses grass production is determined, to a large extent, by the pasture production potential of the site. They

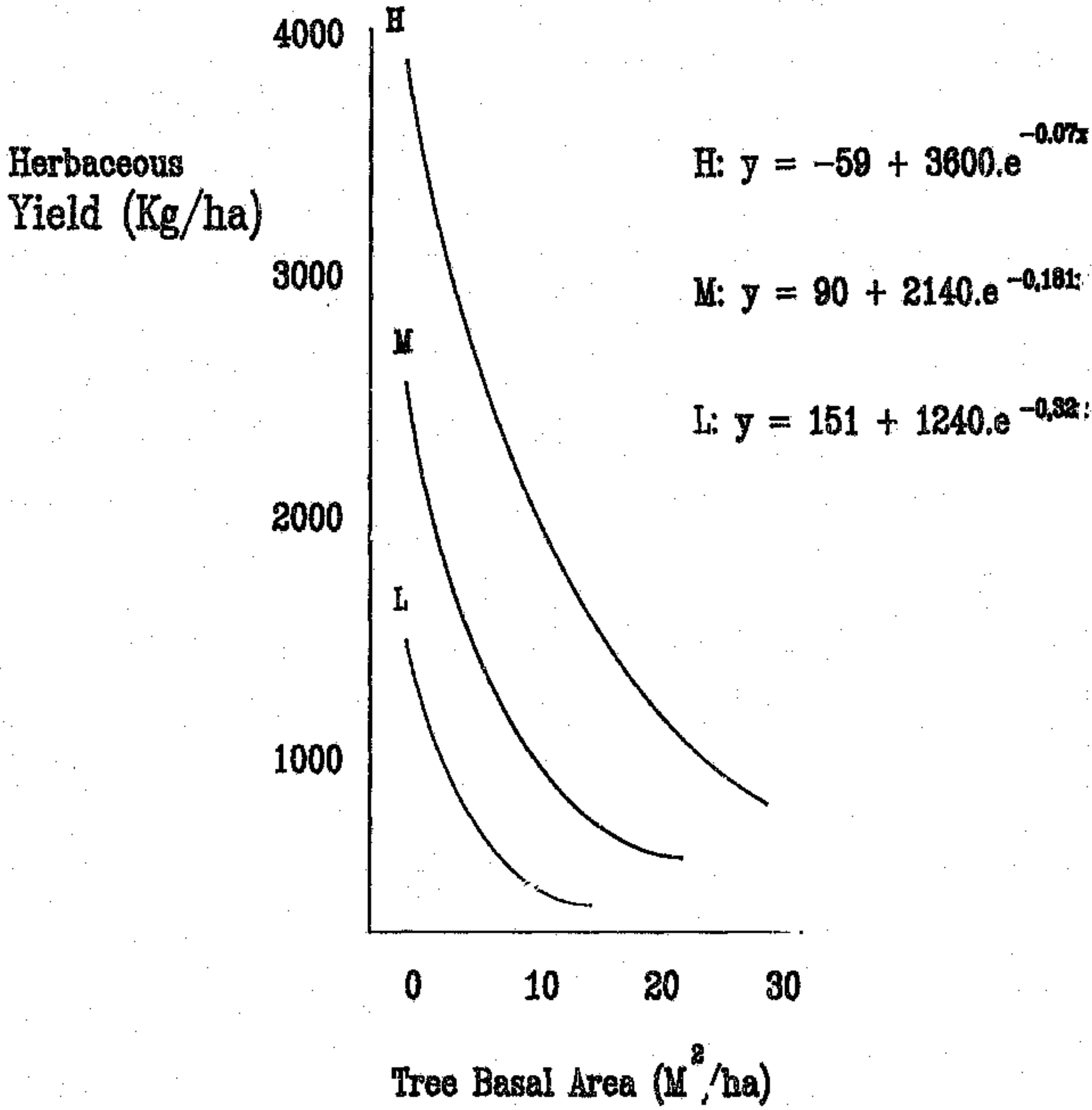

Figure 4.5 Herbaceous yield in relation to tree basal area in Eucalyptus Crebra communities, for areas of High (H), Medium (M) and Low (L) site production potentials (After Scanlan, 1987).

found that, at similar densities, grass production was more severely depressed at sites with low pasture production potential. Although this work was conducted in Australia on various Eucalyptus species, there is good reason to believe that similar relationships would occur in semi-arid African savannas. No literature could be found that addressed this phenomenon for Southern Africa.

The model, GRASTOCK, uses the relationships obtained by Scanlan (1987) and Scanlan and Burrows (1988) to estimate tree correction factors, [TCF] (see rule 7 of GRASTOCK). These TCF indicate the degree to which tree density suppresses grass production. TCF are estimated separately for low, medium and high fertility soils. These TCF are then multiplied to the potential grass production amounts obtained for each of the three soil fertility classes.

4.2.4.4 Herbaceous quality and stocking rate

This section takes a look at the question of herbaceous quality and the problems involved with using it as a determinant in a stocking rate model. The determinants of, and the problems involved in the objective measurement of herbaceous quality are considered. The importance of herbaceous quality in determining animal productivity is also briefly discussed.

Because of the variable tolerance of plant species to grazing, it is usually assumed that grazing intensity must have some effect on the floristic composition of the veld. The degree of this influence is variable. O'Connor (1985) feels that there is enough evidence to suggest that long-term rainfall variability, independent of grazing regime, has an overriding effect on compositional trends. This notion is supported by the observation that the influence of grazing is less pronounced in arid than in mesic savannas (O'Connor, 1985; Snyman, 1989; Peel, 1990).

The composition of herbaceous layers in dry savannas appears to be affected primarily by year-to-year and longer-term variations in rainfall. The effects of grazing or fire becomes more important as mean annual rainfall increases and its variability declines (Frost et al. 1985). Furthermore, the wide variety of phenological responses displayed by herbaceous plants to variable rainfall regimes would support this view. For example, some species are favoured by early summer rains such as redgrass (Themeda triandra), whereas other species such as blue buffalo grass (Cenchrus cilliaris) are favoured by late summer rains (Dye, 1984).

The reverse relationship, that of the degree to which animal performance (and grazing capacity) are determined by the floristic composition of the veld, are less clear. Because plant species vary in palatability, nutritive value and digestibility, it is generally assumed that veld composition will influence the metabolic energy and, hence, the grazing capacity of the veld. Hardy and Mentis (1986) felt that seasonal forage production has an overriding effect over veld composition in the determination of animal performance. Mentis et al. (1989) state that it is dubious that the plant species composition (excluding extremes) has the strong effect on animal performance that conventional wisdom would have us believe. Mentis et al. (1989) go on to say that the outcome of various mathematical models have subordinated the importance of species composition.

Evidence exists (O'Reagain, 1989; Danckwerts, 1989) that the dietary quality of the ingesta of cattle on veld may be poorly correlated with range conditions (i.e. species composition). Danckwerts (1989) feels that for the semi-arid grassveld of the Eastern Cape, forage availability is likely to have a greater influence on animal performance than forage quality.

One of the cornerstones of grazing management philosophy in South Africa has been manipulation of the species composition of the veld (Tainton, 1981). dy and Mentis (1986) felt that, because of the overriding effects of forage production over species composition in the determination of animal performance, a revision of the perception of the problem is needed. They go on to say that management tactics should be directed at maximizing grazable seasonal herbage production as a first priority, rather than managing to create 'good' veld condition.

Barnes <u>et</u> <u>al</u>. (1984) feel that grazing capacity is determined by the amount, as well as the composition, of the herbage on offer. Work done by Barnes <u>et</u> <u>al</u>. (1984) appears to illustrate the crucial importance of veld composition in relation to grazing capacity for cattle in the Eastern Transvaal highveld. They found that in the paddocks studied, grazing capacity varied by more than threefold. The differences were primarily attributed to differences in veld composition.

Most grazing capacity models for cattle are based to a large extent on some form of veld condition assessment (for example, Tainton et al. 1980; Danckwerts, 1982; and Barnes et al. 1984). During the past decade, pasture scientists in South Africa have paid much attention to the development of methods to assess veld condition (Roberts, 1970; Foran, 1976; Tainton & Booysen, 1978; Tainton et al. 1980; Tainton, 1981; Voster, 1982; and Mentis, 1983). A cornerstone of the methods used by these workers is based on the response of species to grazing intensity. This involves the division of species into groups which are judged to have 'ecological affinity'. These groups have been commonly termed 'increasers', 'decreases' and 'invaders'. The differentiation of the groups is based on the estimated position in a successional series, and on their known or supposed reaction to grazing intensity. Mentis (1983) has criticized these methods of veld condition assessment, particularly with respect to the subjectivity of the ecological grouping, the choice of benchmarks, and the assignment of arbitrary values to species or groups, as well as the lack of a quantitative model linking carrying capacity with veld condition.

Mentis (1983) has suggested using formal methods of ordination of data from grazing trials as a means of arranging species along a gradient of grazing intensity. The relative distance between species arranged along a gradient (or axis) is used to produce a multiplier, which is a scalar that will indicate both the direction and degree of departure of any species from a specified point of reference.

Barnes et al. (1984) have put forward a different approach to the weighting of species in terms of grazing capacity. They have proposed a more direct and purely agronomic system, in which the amount of usable forage is estimated from an assessment of the species composition of a community and a knowledge of the relative palatability of each of the component species. Multipliers for species groups have been devised for their value in terms of these contributions to grazing capacity.

The method proposed by Barnes et al. (1984) takes no account of possible long-term effects of the animal on the ecological status of the veld. The method is also, as Tainton (1988) has pointed out, dependent on an accurate measure of relative palatability among species. Tainton (1988) goes on to say that no absolute measure of palatability exists; it varies with season and is, itself, a function of the grass species mix.

The inherent difficulties of attempting to adopt these methods to estimate grazing capacities for mixed herbivore communities are obvious. Mentis (1980) stated that large-sized and small-sized animals select differently for feed, and the carrying capacity for veld would probably be higher for the less selective herbivore. Danckwerts (1982) feels that it is unlikely that his predictive model, developed for determining grazing capacities for cattle, would hold for small grazers such as sheep. Despite the relatively large overlap in dietary preference of wild herbivores (Walker, 1976), palatability ratings of forage species would probably show considerable variation between herbivore species.

Mentis (1980) has pointed out some of the differences between bulk grazers and concentrate grazers; of particular importance is the difference in the degree of selectivity between the feeds groups. Concentrate grazers will practise dietary selection with regard to plant species, plant part and area. The problem of trying to determine an 'average palatability rating' of a plant species for a feeding group would be further confounded by these palatability ratings being dependent on growth stage of plants. For example, the preference displayed by concentrate grazers for grass in its early growth stages, irrespective of the grass species. It is likely that the acceptability of forage to concentrate grazers is determined predominantly by factors other than species composition. Factors such as rainfall, fire, season and bulk grazer stocking rate would all act to influence forage acceptability irrespective of grass species composition.

The overriding influence of factors, other than grass species composition, in determining forage acceptability for concentrate grazers reduces the necessity to take veld composition into consideration when calculating concentrate grazer stocking rates. Of the various factors which influence forage acceptability to concentrate grazers, bulk grazer stocking rate is the most accessible. For this reason it is felt that concentrate grazer stocking rates should be made a function of bulk grazer stocking rates.

Despite the difficulties and the conflicting opinions in the literature, it was decided to adhere to conventional wisdom and include grass species composition as a determinant of herbivore stocking rates. It is assumed that grass species composition directly influences the amount of metabolic energy available through the differential amounts of metabolic energy in high, medium and low palatability grass classes (see rule 3 of GRASTOCK).

4.2.4.5 The effect of seasonal change in herbaceous quality on stocking rate

Veld types have been traditionally expressed in South Africa in terms of sweet, mixed and sour. The terms refer to the degree to which the nutritive value, and hence the palatability, change throughout the year (Tainton, 1981).

Traditionally, paddocks that tend to have sweetveld will be reserved for winter grazing. Stocking rates for cattle on sourveld will be qualified in terms of number of grazing days for which the pasture will be available. With wild herbivores, seasonal grazing of certain areas cannot be controlled. The question is then, should the 'degree of sweetness' of the veld be considered as an additional variable in the stocking rate model?

An important consideration is whether grazing herbivore populations are limited by forage quantity, or forage quality? Sinclair (1975) feels that the herbivore populations in the East African tropical grasslands are limited by nutritive quality (protein), rather than nutritive quantity (energy). The low annual offtake of primary production by herbivores, as low as 10% (Smith and Harrison, 1967, as quoted in Sinclair, 1975), and the rapid decline in nutritive quality of tropical grasslands, are cited as the main reasons for this conclusion (Sinclair, 1975).

In semi-arid savanna areas grasses do not show the same decline in nutritive quality as do those in higher rainfall areas. The erratic nature of rainfall in semi-arid areas also implies that herbivore populations would be limited by sporadic shortages in forage quantity, rather than by limitations imposed by a seasonal decline in forage quality.

However, it is felt that the degree to which grasses are utilized throughout the year depends to a large extent on their inherent palatability. Highly palatable grasses are utilized throughout the year, whereas low palatable grasses are predominantly utilized during their active growth season. For this reason, a seasonal availability factor has been used to correct the metabolic energy contributions made by high, medium and low palatable grasses. Correction factors used were: 1 (utilized throughout the year), 0,75 (utilized for most of the year), and 0,5 (utilized only during growing seasons), for the high, medium and low palatable classes respectively (see rule 3 of GRASTOCK).

4.2.4.6 Estimating metabolic energy

The model asks the user to input the relative proportion of the forage which comprises of high, medium and low palatable grasses. If the user cannot provide a reasonable estimate, default values depending on veld type are used.

The overall metabolic energy available, per ha, from the veld is estimated by assuming that low, medium and high palatable grasses provide an average metabolic energy content of 6, 7,5 and 9 megajoules per kilogram dry matter, respectively. This was obtained from Bredon and Stewart (1978), as quoted by Bransby (1981). They assumed an average digestibility of 40%, 50% and 60% for low, medium and high palatability grasses (see rule 3 of GRASTOCK).

4.2.4.7 Determining allowable use factors

The allowable use factor is an indication of the portion of the above-ground herbage that can be safely consumed annually. In the literature, values vary fr‹ about 0,3 to about 0,7.

It is assumed that the most important deciding factor is the potential soil erosion risk. The models gives a user the option to set the allowable use factor himself, or to let it become a function of the soil erosion risk. The model estimates this risk via an optional subroutine. Data for the subroutine was obtained from Du Toit (1986). If very conservative stocking rate options are chosen (i.e. a low risk acceptance level), the soil erosion risk subroutine will automatically be avoided. The data required for the soil erosion risk subroutine should be obtained from the most sensitive areas (unless these areas are small enough to be considered as 'sacrifice zones').

4.2.4.7 Estimating suitable stocking rates from the net available metabolic energy

The net metabolic energy available at a particular 'risk acceptance level' is estimated by summing the metabolic energy contributions made from high, medium and low palatable grasses, and then multiplying this by the available use factor.

It has been assumed that one animal unit has the metabolic energy requirement of 75 megajoules per day (Meissner, 1982), i.e. 27375 megajoules per year. Meissner (1982) defines an animal unit to be the equivalent of a 450kg steer, with an average daily gain (ADG) of 500g per day on grass pasture with a mean digestive energy concentration of 55%.

The stocking rate that correlates with the 'risk acceptability level' of the farmer (see section 4.2.4.1) is calculated by

$$[SR] = [AUF] \times \frac{[NME]}{27375}$$

where [SR] is the stocking rate in animal units, [AUF] the allowable use factor (see section 4.2.7), and [NME] the net metabolic energy available (see section 4.2.4.6).

Figure 4.4 illustrates how a cumulative rainfall probability function is used to read off the annual rainfall which corresponds with the designated level of risk acceptability.

GRASTOCK assumes animal production to be constant, i.e. an ADG of 500g per day. This is implicit in the 27375 MJ annual requirement of one animal unit. Further improvements to GRASTOCK will consider ADG as a variable.

CHAPTER FIVE

A BUSH CLEARING EXPERT SYSTEM MODEL

5.1 Overview of the problem

An attempt has been made to assimilate the relevant information concerning the problem of bush clearing within an expert system framework. Three aspects of the problem have been addressed in three separate models, namely, generalized information concerning the feasibility of clearing; recommendation of a suitable herbicide, dosage, cost and method of application; and a cost/benefit analysis model.

In this chapter, special emphasis is placed on illustrating the process of knowledge representation.

Bush encroachment is one of the major range management problems in Southern African savannas (Barnes, 1979; Du Toit, 1968). There are a variety of reasons why this has occurred, overgrazing and changes in fire regimes are most commonly cited (Norton & Walker, 1985).

Bush encroachment indirectly reduces the productivity of savannas to grazers through the competitive effects of woody plants on the herbaceous layer (see section 4.2.4.3).

Bush clearing control methods can broadly be grouped into mechanical (brush cutting, bulldozers, ring barking, etc.) and chemical (herbicides) (Scholes, 1986). The bush clearing expert system developed here is primarily concerned with providing advice on the latter strategy. The potential use of fire as a bush control strategy has not been considered in these models.

The economic and ecological consequences of bush control have become increasingly important both to the range manager and to the vendors of commercially available herbicides. Norton and Walker (1985) suggested a decision analysis approach to the problem of bush control. Ludwig (1988) has shown how expert system type modelling can be used to make practical and ecological knowledge available to farmers in Australia faced with bush control problems.

The bush clearing problem is multi-faceted and is characterized by a poorly defined knowledge domain. It is generally accepted that expert system applications are particularly suited to problems that have clearly defined and narrow knowledge domains (Edmunds, 1988; Hart, 1986; and Waterman, 1986).

The bush clearing problem has been simplified by splitting it up into various sub-problems. This serves to reduce the scope of the problem, thereby improving the knowledge domain definition. Six sub-problems have been identified, namely

(1) the suitability of the site to clearing;

(2) when clearing should be avoided;

(3) clearing patterns;

(4) the method of clearing;

(5) the recommended herbicide and dosage; and

(6) a cost/benefit analysis.

The above problems have been dealt with in three separate sub-models, DEBUSH, REGROWTH and HERB.

5.2 The sub-model DEBUSH

5.2.1 Objectives

DEBUSH provides generalized advice on bush clearing and assesses the feasibility of the site for clearing.

DEBUSH has the following objectives; to

(1) estimate the suitability of the site for bush clearing;

(2) advise on situations which do not lend themselves to clearing;

(3) recommend a suitable clearing pattern;

(4) provide advice for specific situations (for example, not to use granular herbicides on seepline clearing sites).

DEBUSH is largely based on information obtained through consultation with Dr. R.J. Scholes.[1]

5.2.2 Ecological concepts and rules used in DEBUSH

5.2.2.1 Site suitability

Essentially, bush clearing should be recommended only if two important criteria can be met. Firstly, the removal of trees must not result in a high soil erosion risk. Secondly, tree removal must lead to a significant improvement in grass production (Scholes pers. comm.)

To assess whether these criteria can be met, DEBUSH requests information concerning

(1) soil type and clay percentage;

(2) landscape position;

(3) distance to nearest stream;

(4) evidence of seasonal flooding;

(5) type of woody vegetation; and

(6) steepness of slope.

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[1]Dr R.J. Scholes. Department of Botany, University of Witwatersrand P.O. Wits 2050

Situations which do not lend themselves to bush clearing can be considered as primary or secondary contraindications. Primary contraindications to bush clearing include all factors that would lead to a high soil erosion risk if the site were to be cleared (Scholes, pers. comm.). These include sites that are

(1) on sodic or duplex soils;

(2) closer than 30 meters to a stream; and

(3) on a slope of greater than 10 percent.

If any one or more of the above conditions are present then DEBUSH will advise against bush clearing.

Secondary contraindications to bush clearing include sites that

(1) contain broad-leafed hardwoods (usually situated on sandy soils, susceptible to erosion);

(2) are situated on ridge tops (exposed to wind erosion);

(3) are on slopes of between 4 and 10 percent, and

(4) are highly rocky (limiting potential grass production).

Secondary contraindications to bush clearing are considered likely to lead to a high soil erosion risk if at least two of these factors occur simultaneously on the site.

The above information is represented in rules 1 to 9 of DEBUSH.

An indication of the likely economic feasibility of the clearing operation is determined by estimating the extra grass produced as a direct consequence of tree removal. This response to tree removal is considered to be a function of site production potential (as measured by soil fertility) and the pre-clearing tree density. Dense pre-clearing tree-stands on highly fertile soils will produce high grass responses to clearing, which improves the likelihood of the operation being economically feasible (Scholes, pers. comm.).

The likely economic feasibility is estimated as being high, medium or low. This has been represented in using rules 13 to 20 of DEBUSH.

5.2.2.2 Clearing pattern

Depending on the wind erosion risk, the importance of cover for wildlife, and the presence of seeplines, DEBUSH will recommend one of four possible clearing patterns, for example, if clearing is to be done on areas that may be exposed to wind erosion, such as ridge tops or open plains on sandy soils. DEBUSH will recommend that clearing be done in patches with spaces that are about ten times the mean vegetation height, the cleared patches being perpendicular to the prevailing wind direction (Scholes, pers. comm.). This information is represented in rules 22 to 25 of DEBUSH.

5.2.2.3 Hydromorphic grasslands and seepline width

Soils which are waterlogged for long periods on a fairly regular basis support grasslands rich in sedge species are known as hydromorphic grasslands. Savanna trees cannot tolerate prolonged seasonal waterlogging. In semi-arid regions such waterlogged areas can only form when they receive extra water from surrounding areas which is prevented from draining away by an impervious layer in the soil. Such sites are referred to as vleis or seeplines (Scholes, 1986).

Seeplines are usually found on the slopes of granite catenas. Seeplines and vleis are prone to invasion by shrubs and saplings if they fail to flood for several consecutive years. This can be caused by prolonged drought, or by drainage of perched water by incision of the seepline by a game trail or road (Scholes, 1986). Tinley (1979) attributed the encroachment of seeplines in the Sabi-sands area to a combination of drought and overgrazing.

Areas which were once hydromorphic grasslands have a high bush clearing potential, since if hydromorphic grasslands can be re-established it becomes self-sustaining. All other areas require an ongoing effort to keep them open. Clearing above the seepline will increase the wetness of the seepline, but is not recommended due to the sandy soils which occur in these regions. Sandy soils are erosion sensitive, and usually have a low grass production potential. Clearing below the seepline can be successful as long as soils are neither sodic nor duplex (see section 5.2.2.1) (Scholes, 1986).

In bush encroached areas the extent of the seepline may be obscure. The width of the seepline can be estimated using relationships developed by Olbrich (1984), quoted in Scholes (1986). These relationships estimate seepline widths from mean annual rainfall and upslope length. This information has been represented in rules 26 to 30 of DEBUSH.

5.3 The sub-model HERB

5.3.1 Overview of the model

HERB has been developed largely from information obtained through consultations with representatives of two major herbicide-producing companies; namely, Gert Coetzee[2] and Johan Krüger.[3]

The six most commonly used herbicides in South Africa are considered. These are USTILAN GG, USTILAN 10G, GRASLAN 20P, TORDON 101, TORDON SUPER and RECLAIM.

Five of the most common herbicide application methods are considered; aerial application, hand application, foliar spray, chop stem and stem spray.

Twenty-nine tree target species were considered, including the common

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[2]Mr Gert Coetzee. AGRICURA. Silverton 0127. PRETORIA.

[3]Mr Johan Krüger. BAYER. P.O. 143, 1600. ISANDO.

encroaching species.

5.3.2 Objectives of HERB

The objectives of HERB are to

(1) recommend suitable herbicide(s) for a bush clearing operation;

(2) determine the most suitable application method;

(3) calculate appropriate herbicide dosages; and

(4) estimate herbicide costs.

5.3.3 Discussion of HERB

HERB consists of 139 rules. There are five distinct rule sets. These are illustrated in Fig. 5.1.

5.3.3.1 Elimination of unsuitable herbicides (Rule set : 1)

The first rule set (rules 1 to 29) perform a similar function to a database. The purpose of this rule set is to eliminate those herbicides which are not officially registered as being effective against the target species in question.

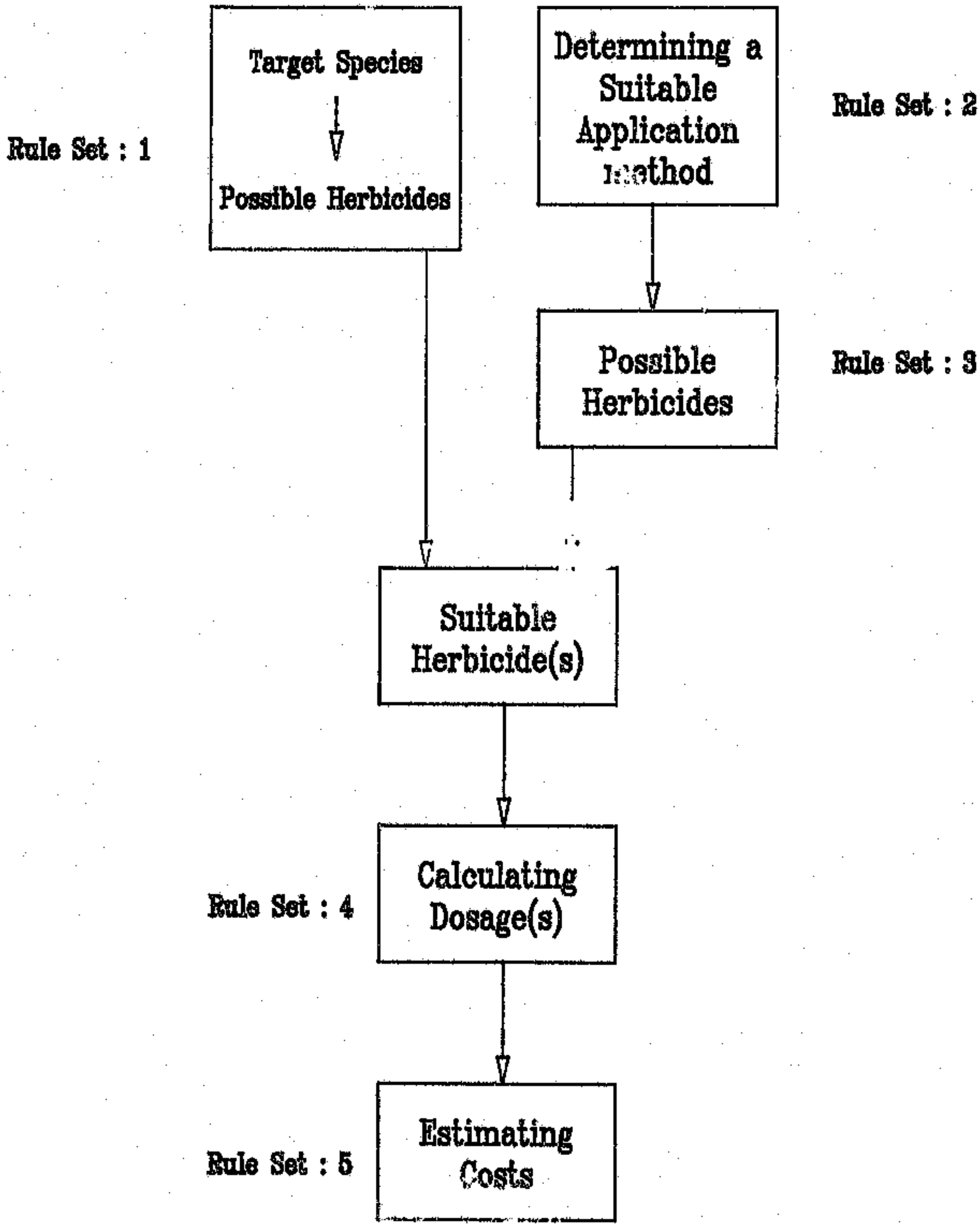

Figure 5.1 Rule sets used in HERB.

5.3.3.2 Determining a suitable herbicide application method (Rule set : 2)

The second rule set (rules 30 to 42) determines a suitable application method.

HERB first tries to determine if aerial application is feasible using the following rule

Rule 31:

If Percentage clay < 21
And Tree density > minimum number of tree equivalents
And Size of target area > 99 ha
And Degree of selectivity = non-selective
And Target species do not consist mainly of seedlings or trees < 1 meter

Then Advised application method = aerial.

Aerial application is usually conducted by the herbicide companies. It is considered feasible only if the application area is relatively large, and the dosage relatively high. The dosage level is primarily determined by the tree density and the percentage clay in the soil (Coetzee pers. comm.).

If the conditions required for aerial application cannot be met, HERB will then use rule 39 to test if the conditions for hand application of herbicides can be met.

Rule 40:

If Aerial application is not suitable
And Percentage clay is < 35
And Degree of selectivity = non-selective or partially selective
And The target species does not consist mainly of seedlings or coppice

Then The advised application method = hand.

If conditions for rule 30 and 39 cannot be met, other rules will be tested to try and determine an alternative application method.

5.3.3.3 Possible herbicides (Rule set : 3)

In the previous rule set a suitable application method was determined. This rule set (rules 43 to 47) contains information concerning the possible herbicides that can be used for each of the application methods. For example

Rule 44 :

If Application = aerial
Then Herbicide = USTILAN GG
And Herbicide = GRASLAN 20P (Aerial)

5.3.3.4 Determining a suitable herbicide, or herbicides

Suitable herbicides must meet the conditions implicit in rule sets one and two. Firstly, the suitable herbicide must be officially registered for use against the target species (rules 1 to 29) and, secondly, the chosen herbicide must be suited to the recommended application method (rules 43 to 47).

5.3.3.5 Calculating dosages (Rule set : 4)

Rule set 4 consists of rules 48 to 134. These rules are based on information obtained from look-up tables in herbicide information pamphlets.

The recommended dosage of a particular herbicide is determined by the target species, the average height of the target species, and the pH and % clay of the soil.

With six different herbicides, 29 different target species, 3 different % clay classes and two pH classes, the calculation of dosages based on each possible permutation would lead to an unmanageably large rule base. For this reason generalized rules were developed.

Two forms of generalizations were used. Firstly, tree species that have similar dosages of a particular herbicide under the same soil conditions, were lumped together. For example

Rule 67 :

If Herbicide = GRASLAN 20P (Aerial)

And Target species = *Acacia melifera* or *A. nebrownii* or *A. reficiens* or *Grewia flava*

And Percentage clay is > 17 and < 21

Then Dosage of GRASLAN 20P (aerial) = 5 g/m^2

The second form of generalization involved detecting and using constant patterns of dosage-changes with changes in soil pH and percentage clay in the soil. For example, with the herbicide USTILAN GG, dosages for a particular species depend on soil pH and percentage clay. The following matrix was used

	% CLAY		
SOIL pH	1-10	11-20	21-30
≤ 7	DIA	DIA + 0,5	DIA + 2,25
≥ 7	DIA + 0,5	DIA + 1,5	DIA + 2,25

The lowest possible dosage of USTILAN GG is represented by the variable DIA (i.e. when soil pH is ≤ 7 and percentage clay ≤ 10). This value will vary, depending on the target species. Target species with similar DIA values are lumped together. For example

Rule 56 :

If Herbicide = USTILAN GG
And Target species = *Acacia karroo* or *A. burkei*

Then DIA = 2,25

Once a DIA value has been determined, the actual dosage under the prevailing soil pH and percentage clay can be calculated. For example

Rule 50 :

If Herbicide = USTILAN GG
And Soil pH > 7
And Percentage clay is > 20 and < 31

Then Recommended dosage of USTILAN GG = DIA + 2,25

For the hand application of herbicides, the average height of the target trees will influence the recommended dosage. For example, a dosage of 6g/m² of GRASLAN 20P (Hand) is recommended for the control of *Dichrostachys cinerea* trees below two meters. If the average tree height is greater than two meters, then for each additional two meters, another 6g/m² must be added. Generalized formulas for each herbicide have been developed to represent these relationships. For example

Rule 96 :

If Herbicide = GRASLAN 20P (Hand)

And The target species is *Dichrostacys cinerea*

And Percentage clay is > 20

And Average tree height is > 2 meters

Then

Dosage of GRASLAN 20P (Hand) = 6 + ([Average tree height] - 2) x 6

2

5.3.3.6 Calculating costs (Rule set : 5)

The cost of a bush clearing operation includes both the application cost and the cost of the herbicides. Because of the inherent difficulty in estimating labour costs, they have been excluded from the calculation of hand applied herbicides.

The current cost of aerial application of herbicides runs at about R12.50 per ha (Gert Coetzee pers. comm.). Total costs are calculated in Rands per ha using 1989 prices. For example

Rule 137 :

If Recommended herbicide = GRASLAN 20P (Aerial)

Then

Total cost = [Recommended dosage, in kg/ha] x [R32/kg] + [R12.50]

The comparison of costs of different aerial applied herbicides are relatively simple because all dosage levels are expressed in kg/ha. However, comparisons of hand applied herbicides are complicated by the fact that dosage levels are calculated in terms of g/average tree. Under high tree densities herbicide concentrations could lead to toxic levels. To avoid this, the herbicide companies have set limits on the number of trees that can be treated within a certain area. For example, GRASLAN 20P (Hand) may only be applied at one calculated tree dose for every 1 m^2 (i.e. a maximum of 10 000 trees can be treated per ha), whereas USTILAN 10G has a upper limit of only one tree dose to every 10 m^2 (i.e. a maximum of 1 000 trees can be treated per ha). This implies that recommended maximum dosage levels per ha for USTILAN 10G are lower than for GRASLAN 20P. If there are more than 1 000 trees per ha treatment with USTILAN 10G can only achieve partial clearing, making direct economic comparison with GRASLAN 20P difficult (Johan Krüger pers. comm.).

5.4 The sub-model REGROWTH

5.4.1 Overview of REGROWTH

The expert system model REGROWTH simulates the regrowth of trees and the annual grass production for 15 years after a bush clearing operation. REGROWTH is a deterministic model that makes use of both qualitative and quantitative data. Figure 5.2 gives an outline of the model.

REGROWTH has been developed predominantly from information obtained

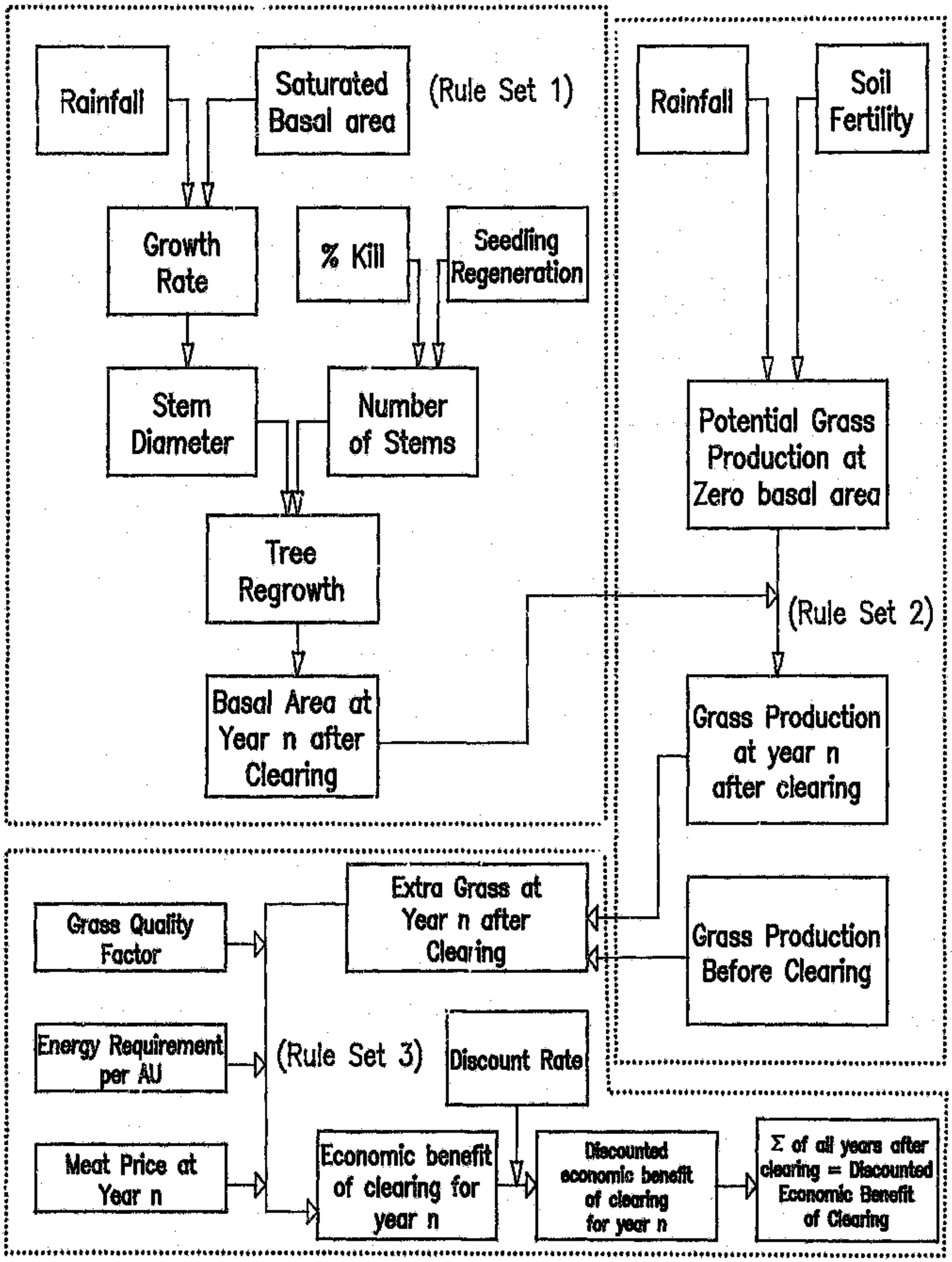

Figure 5.2 Overview of the Model REGROWTH.

from the literature.

5.4.2 Assumptions made in REGROWTH

The following assumptions are implicit in the model.

(1) After a clearing operation, tree regrowth occurs through coppicing and seedling regeneration. Tree removal does not result in a stable grassland, such as may occur on fire-subclimax or hydromorphic grasslands.

(2) Only the first 15 years after clearing are modelled. The effects of possible follow-up operations have been excluded.

(3) The effects of varying rainfall on tree regrowth and grass production are excluded.

(4) The suppressive effects that fire and browsing may have on tree regrowth have been excluded.

(5) Differences between woody species have not been taken into account.

(6) Only the quantitative and not the qualitative effects of tree removal on the herbaceous component are taken into account.

(7) The only economic benefits derived from bush clearing are through improved grass production. Indirect economic benefits of

clearing, such as improved game viewing or habitat improvement, have not been included in the model.

(8) The improved grass production after clearing leads to improved meat production.

(9) Meat production is the only form of livestock utilization.

(10) The method of tree removal has no effect on the tree growth or grass production.

5.4.3 Objectives of REGROWTH

The objectives of REGROWTH are to

(1) determine the economic benefit of a bush clearing operation;

(2) model the regrowth of trees after a bush clearing operation; and

(3) model the competitive interaction between grass and bush after a tree removal operation.

5.4.4 Description of components of REGROWTH

5.4.4.1 Modelling tree REGROWTH (Rule set : 1)

Rule set 1 includes rules 1 to 18 of REGROWTH.

The annual increment of woody basal area after clearing is calculated by using mathematical variables within the rules. Each years' calculations are done using a separate rule. This was necessary due to the inability of EXSYS to update variables after successive iterations.

This section of the model is based on Scholes' (1987) model of coppice regrowth of Colophospermum mopane.

Scholes (1987) measured cross-section ring diameters of coppice stems and related this to seasonal rainfall. The relative stem growth rate [R] was related to annual rainfall [P] by

$$[R] = 0,0012\ [P] - 0,08$$

Resource competition imposes a finite limit on tree regrowth. This can be expressed by using the logistic equation. The annual growth increment at year n, [Rn] is a function of the existing tree basal area at year n, [Bn], in relation to the saturation tree basal area [k], so that

$$[R_n] = 1 + [(0,012[P] + 0,08)\ (([K] - [Bn])/[K])]$$

The basal area per ha at any year n, $[B_n]$, will be given by the total number of stems per ha, multiplied by the average stem cross-sectional area

$$[B_n] = [S_n][D_n]^2.\pi/4$$

where $[S_n]$ is the number of stems at year n and $[D_n]$ the average stem diameter.

The total number of stems per ha after the first year of a bush clearing operation $[S_1]$ will be given by

$$[S_1] = [S_0](100 - [E])/100 + [L]$$

where $[S_0]$ is the number of stems before clearing, [E] is the kill efficiency of the clearing method, and [L] the number of new stems per ha that are added to the population annually.

The average stem diameter at year n after clearing $[D_n]$, will be given by

$$[D_n]^2 = [D_{n-1}]^2 . [R_n]$$

when $[D_{n-1}]$ is the average stem diameter at the start of the preceding year.

Rule 3 of REGROWTH illustrates how the basal area, for the first year after clearing, $[B_1]$, is calculated

<u>Rule 3</u> :

If Information on bush clearing is required

Then $[S_1] = [S_0]\ (100 - [E])/100 + [L]$

And $[B_0] = [S_0].[D_0]^2.\pi/4$

And $[R_1] = 1 + [(0{,}012\ [P] + 0{,}08)([K] - [B_1]/[K])$

And $[D_1] = \text{SQRT}\ ([D_0]^2.[R_1])$

And $[B_1] = [S_1].[D_1]^2.\pi/4$

where $[S_0]$, $[D_0]$ and $[B_0]$ are the number of stems, average stem diameter and the basal area per ha directly after the clearing operation, respectively.

There are a few important assumptions made in this section of the model. Firstly, it is assumed that the growth rate of the broad-leafed C. mopane is representative of all bushveld species. Secondly, the model does not allow for intra-specific competition. Thirdly, the assumption is made that the cleared area will ultimately end up with the same basal area (K) that it had before clearing.

5.4.4.2 Modelling annual grass production (Rule set : 2)

The effects of rainfall and soil fertility on grass production were discussed under section 5.2.4.2 of this thesis.

Relations calculating the annual grass productions for fifteen successive years after a bush clearing operation are represented in rules 19 to 21 of REGROWTH. The rainfall-herbage production relationships were obtained by adapting data from Scholes (1986) and Dye and Spear (1982). Three separate regression lines are used for soils of high, medium and low fertility. These functions represent the annual potential grass production, (i.e. at tree basal area equal to zero) for any given annual rainfall.

A tree correction factor has been introduced to take into account the suppressive interaction of tree basal area on grass production. Work done by Scanlan (1987), and Scanlan and Burrows (1988), provide information on the interactions between tree basal area, site production potential and herbage production.

Scanlan (1987) found that the site production potential has a marked influence on the shape of the basal area/grass production curve. At a given level of tree basal area, grass production is reduced (relative to grass production in the absence of trees) by a greater percentage as the site potential decreases (see figure 4.5).

Tree correction factors are obtained by adapting Scanlan's (1987) tree basal area/grass yield relationships. For example, Scanlan found that under high site production potential, grass yield (Y) was related to tree basal area (X) by

$$Y = - 59 + 3600.e^{-0,072\ x}$$

The tree correction factor for year n, [TCF_n] under a high site production potential will be obtained by

$$[TCF_n] = \frac{\text{grass yield at basal area, [Bn]}}{\text{grass yield at zero basal area}}$$

or using Scanlan's (1987) data by

$$[TCF_n] = \frac{-59 + 3600.e^{-0,072[Bn]}}{3541}$$

The actual annual grass production for any year, n after the clearing operation can be obtained by multiplying the $[TCF_n]$ by the potential grass production. The above relations have been represented in the following rule

Rule 19 :

If Site production potential = High

Then [APGP] = 2,5 x [P] + 500

And $[GP_n]$ = (-59 + 3600.EXP (-0,072.$[B_n]$))/3600.[APGP]

where [APGP] is the average annual potential grass production per ha, [P] the average annual rainfall, $[GP_n]$ is the actual grass production at year n after clearing, and $[B_n]$ is the basal area at year n after clearing.

It is assumed that it takes 3 years for grass production to reach its potential maximum after clearing. The first year after clearing, grass production is only half of its potential maximum, and three quarters of its potential maximum at year 2.

5.4.4.3 Modelling the economic benefit of bush clearing (Rule set: 3)

The economic benefit of bush clearing is essentially measured by the improvement in grass production after clearing.

Rules 22 to 36 calculate the annual improvement in grass production and the economic benefit derived.

Improvement in grass production for year n after clearing is given by

$$[EGP_n] = [GP_n] - [GP_k]$$

where $[EGP_n]$ is the improvement or 'extra' grass produced, $[GP_n]$ is the actual grass production at year n after clearing and $[GP_k]$ is the grass production before clearing.

The benefits of bush clearing could be expressed in terms of an improved stocking rate potential. However, because we are interested in the economic feasibility of clearing, it is necessary to express benefit as an economic value.

The proportion of the [EGP] actually consumed is determined by a grass quality factor, [QF]. [QF] can take on the values of 0,7; 0,5 or 0,3 depending on whether the quality of the extra grass is considered to be high, medium or low, respectively. It is assumed that each AU requires 3650kg dry material per year (i.e. 10kg per day).

The economic benefit for any given year, n after clearing, $[BF_n]$ is obtained by

$$[BF_n] = ([EGP_n] \times [QF])/3650 \times [MP_n] \times ((100 - [PCOSTS])/100)$$

where $[MP_n]$ is the meat price at year n that the farmer gets in Rands per Kg live weight. [PCosts] are the production costs, expressed as a percentage of net income derived from grazing animals.

It is assumed that the proportion of production cost to net income remains constant between years. However, an inflation adjustment factor has been included in the meat price value, so that

$$[MP_n] = [MP_{n-1}] + ([MP_{n-1}] \times [IR]/100)$$

where [IR] is the inflation rate at the time of bush clearing. In future versions of REGROWTH a subroutine could be included, which would provide more reliable estimations of projected meat price values. Various trends, such as the apparent cyclic variation in meat prices, could be included (Groenewald pers. comm.[4]).

Because income obtained at some future date has less current value than money owned at present, a discount value has been included to estimate present values of future income. The following formula, after Bishop and Toussaint (1958), has been used to estimate the discounted economic benefit, $[DBF_n]$, for any year n after clearing

$$[DBF_n] = \frac{[BFn]}{(1+[I])^n}$$

where [I] is the discount rate, or the rate of interest received over a

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[4]Professor W.H. Groenewald. Department of Agricultural Economics. University of Pretoria.

period of n years.

Each year's calculations are done separately in one rule so that, for example, rule 23 of REGROWTH provides the calculations for the second year after clearing, i.e.

<u>Rule 23</u>

If Information on bush clearing is required

Then

$[EGP_2] = [GP_2] - [GPK]$

And $[MP_2] = [MP_1] + [MP_1] + ([MP_1] X [IR]/100)$

And $[Bf_2] = ([EGP_2] x [QF])/3650 x [MP_2] x ((100 - [PCOST])/100$

And $[DBf_2] = [Bf_2]/EXP (2x LOG(1 +[1])$

Note that the condition in the 'IF' section of the rule ensures that this rule always fires.

The net discounted economic benefit of clearing is calculated by the sum of each year's [DBF] values, i.e.

$$[DBF TOT] = \sum_{n = 1}^{15} [DBf_n]$$

SECTION 3 : DISCUSSION AND CONCLUSIONS

CHAPTER SIX

DISCUSSION AND EVALUATION OF MODELS

This section evaluates the models in terms of their objectives. The evaluation is the subjective opinion of the author. No attempt has been made to evaluate or validate these models under real time use. This is justified, considering the original objectives of developing these models, namely to evaluate the modelling approach.

6.1 Discussion of the model POLICY

POLICY was primarily concerned with collating and assimilating the relevant information concerning stocking rate policies.

The model is highly simplistic, but does manage to isolate the essential criteria which should be considered before settling on a stocking rate policy.

The model provided a useful conceptual framework in which the question of rainfall predictability was investigated.

POLICY provides an example of how the process of expert system modelling may be more valuable than its end product.

6.2 Discussion of the model GRASTOCK

Although it is well-known that South Africa has distinct periods of above and below average rainfall, and that most of the country receives less than 500mm of rainfall per annum, dry spells are traditionally described as 'droughts'. Substantial drought aid is paid to farmers in so-called 'drought-stricken areas'. During the 30-year period to 1985, 27% of the country was 'drought-stricken' for more than 50% of the time. It is, therefore, a moot point whether such areas are suitable for farming at all (Huntley et al. 1989).

The underlying philosophy of GRASTOCK is that stocking rate advice should be descriptive, as opposed to prescriptive. By taking this approach, it is emphasized that there can be no single 'magical' stocking rate level, but that for each stocking rate there will be an associated level of risk.

The prime determinant in stocking rate decision making is rainfall. Rainfall is unpredictable, but can be expressed in terms of probabilities. GRASTOCK can provide reasonable estimates as to the likely consequences of various stocking rate levels. These consequences are expressed in terms of the 'number of years in every ten in which a fodder shortage can be expected'. The amount of risk that a farmer is willing to take in this respect is a personal decision, and cannot be prescribed.

GRASTOCK has provided a framework in which a large body of research data has been assimilated and distilled into relevant concepts. Expert systems provide an ideal environment in which this knowledge becomes accessible to field managers.

The success of models like GRASTOCK depend, to a large extent, on the user interface. The graphical representation of information, pop-up screens and display windows become vital links in making research accumulated knowledge both accessible and comprehensible to field managers. Furthermore, the general impressions and degree of confidence installed in the model will largely be determined by this user-interface.

The user-interface provided by EXSYS was found to be extremely limiting. Improvements were made on GRASTOCK by calling up external programs written in TURBO PASCAL. These programs allowed for the graphical representation of data, pop-up help files and easy access to rainfall database files.

GRASTOCK contains relatively deep knowledge structures. This is important in expert systems that have a functional emphasis on knowledge transfer, rather than just end point decision making.

If the objective of GRASTOCK was purely one of providing an educated guess at suitable stocking rates. The model could have been built out of a set of heuristic rules. These rules would have been derived from empirical observations of what appeared to be suitable stocking rates for given areas.

The fact that reliable heuristics are difficult to find in ecology, and considering the underlying philosophy behind the model (i.e. that ecological advice should be descriptive as opposed to prescriptive), it was necessary to build GRASTOCK from relatively deep knowledge structures. This implies that the fundamental relationships determining stocking rates had to be included in the model.

Models built out of deep knowledge structures have greater explanatory depth than models built purely from heuristics. In short, if a model is to have an educational function, the user needs to know the 'how and why' of the decision.

6.3 Discussion of the bush clearing models

The bush clearing models were, at the outset, ambitious projects.

Most successful expert systems have confined their problem-solving activities to a narrow and clearly defined domain of knowledge (Edmunds, 1988). The bush clearing problem is complex and multi-faceted, involving many different areas of expertise.

In the bush clearing models an attempt was made to absorb the collective expertise of a number of people, and to present this as a coherent unit.

The bush clearing problem was narrowed down by splitting the problem into three distinct sub-problems which were modelled separately. In spite of this, the problems were not well defined and could have been split up further. For instance, a distinction could have been made between the regrowth of trees after chemical or mechanical clearing. This implied that the relevance of the bush clearing models were heavily dependent on the assumptions made.

Further improvements of BUSHCLEAR would require what Waterman (1986) describes as an 'expert system paradigm shift'. This is necessary when prototype models become unmanageable in size, unwieldy, slow, and when the system resembles a patchwork of sub-routines and unintegrated constructs. At this stage a complete re-examination of the problem and a reassessment of the initial representation scheme is called for.

6.3.1 DEBUSH

DEBUSH provides generalized advice on the suitability of a site to bush clearing.

DEBUSH considers a site feasible for clearing only if there is not a high soil erosion risk, and if the removal of trees will lead to a significant improvement in grass production. DEBUSH is inadequate at handling situations in which these two criteria may not be important in determining the feasibility of clearing. For example, bush clearing may be feasible in situations which lead to habitat improvement, or improved game viewing, irrespective of whether grass production is improved.

Similarly, various management practices may reduce the risk of erosion, for example, covering the exposed area with some of the removed bush.

DEBUSH is a simple model which provides realistic answers only in typical situations. It undergoes what Waterman (1986) describes as a 'catastrophic degradation in performance' (as opposed to a 'gradual degradation') under atypical situations.

The robustness of an expert system is described by Waterman (1986) as the ability to degrade gradually in performance when it is pushed to its limits. The robustness of models such as DEBUSH could be improved by adding rules which recognize unusual situations. However, expert systems, typically, have difficulty in recognizing the limits of their ability (Waterman, 1986). The lack of 'self-knowledge' displayed by models such as DEBUSH is typical of expert systems written in shells, such as EXSYS, which have difficulty in representing meta-knowledge. Meta-knowledge simply implies knowledge about knowledge (Waterman, 1986). EXSYS is unable to contain rules which represent information about when and how to use other rule sets, or the ability to organize rules into frames.

6.3.2 HERB

HERB comprises mostly of heuristic (rules of thumb) type rules and database-type information.

Edmunds (1988) feels that one of the more challenging aspects of knowledge engineering is to try and uncover heuristic rules about a knowledge domain and then code them into a knowledge base.

Consultations with representatives of two major herbicide companies revealed that there were a few basic rules which were applied to determine what herbicide application methods should be used. These rules were built from knowledge gained through experience, and could not be reasoned back to first principles. This is typical of heuristic knowledge.

Much of the information in HERB could have been represented in the form of a database. However, by using rules to store information the problems involved in calling up external database programs were avoided. In addition, this enabled much of the data to be represented in the form of generalized rules.

HERB appears to be relatively successful in determining which herbicide and which application method would best be suited to a particular situation. Other than for aerially applied herbicides, HERB is unable to give reliable estimations of costs.

6.3.3 REGROWTH

REGROWTH involves dynamic simulation modelling. The model is deterministic and no attempt has been made to reflect the inherent variability of ecological systems.

REGROWTH is predominantly a quantitative model. It goes through successive iterations to simulate fifteen years of data. The ability of EXSYS to handle mathematical variables within rules, and the ability to 'backward chain' calculated results from one year to the next enabled the problem to be successfully modelled within the expert system framework.

One of the disadvantages of dynamic models is the uncertainty of being able to estimate the values of basic parameters (Jeffers, 1982). This is true for REGROWTH, which requires input data on variables, such as average basal area or average stem diameter, which may be time consuming to estimate with any certainty. Future versions of REGROWTH could include sub-routines and help-screens which could provide information on how reasonable estimates of some of these variables could be obtained.

The relevance of REGROWTH is heavily dependent on the assumptions made. For example, in the economic analysis it is assumed that the only economic benefits of bush clearing are through improved grass production.

For REGROWTH to be used as a decision-aid for bush clearing projects, it would have to expand its domain of applicability. For instance, sub-routines could be built which simulate the effects of bush clearing on browser populations. The economic analysis should also be expanded to include other economic consequences of bush clearing, such as the benefits accrued through the sale of wood resulting from tree removal.

REGROWTH displays how expert system modelling can extract information from different sources in the literature, bringing it together into a functional unit.

CHAPTER SEVEN

CONCLUSIONS OF AIMS OF THESIS

7.1 The potential uses of expert systems modelling for savanna management

7.1.1 Potential advantages

The following is a list of some of the potential uses which expert systems modelling holds for savanna management. It must be stressed that this information is based only on experience gained during the development of the models, and not from the real-time implementation of these models.

Most of the conclusions reached here are not novel in the sense that they have been (implicitly or explicitly) stated in other expert system literature. Where possible, indication is given of observations that corroborate those found in the literature.

(1) Expert systems provide useful mediums of knowledge transfer from researcher to field manager (Starfield & Bleloch, 1983; Ferrar, 1986; Davis et al. 1986). This will help narrow the existing gap between ecological research and its practical implementation in the field.

(2) The process of building and using expert systems is a useful educational tool for students, field managers and researchers

(Starfield et al. 1983; Ferrar, 1986).

(3) Expert systems provide a medium to integrate existing knowledge. This will facilitate effective and efficient use of available information (Starfield & Louw, 1986; Waterman, 1986; Davis et al. 1986; Coulson et al. 1987; Murphy & Fuggle, 1989).

(4) In resource management decision making, links between data and the final decision are often implicit. Expert system modelling will encourage these links to become explicit (Starfield, 1983). Furthermore, in many poorly understood ecological systems, management decisions must be based on implicit hypothetical assumptions. By developing an expert system these assumptions are explicitly stated, and hence can be criticized and constructively defended.

(5) Expert system shells provide useful ecological modelling environments in which both qualitative and quantitative information can be used (Starfield & Louw, 1986; Ferrar, 1986; Nobel, 1987; Davis et al. 1987). Further, they do not require a high level of computer literacy before they can be used. This will result in a general increase in the use of modelling.

(6) Expert system modelling may highlight particular areas of knowledge that may be important to decision making. This would be useful in prioritizing research projects (Ferrar, 1986).

(7) Expert systems will change the way we approach and solve problems

and make decisions (Starfield & Louw, 1986). This could lead to new insights in, and perspectives on, ecological issues.

(8) Expert systems provide a potential marketable end-product for agricultural and ecological research.

7.1.2 Why are expert systems suitable for ecological modelling?

The expert system approach is suitable for ecological modelling because

(1) use can be made of both qualitative and quantitative information (Starfield & Bleloch, 1983; Starfield & Louw, 1986; Ferrar, 1986);

(2) uncertain information can be used (Davis & Nanninga, 1985; Waterman, 1986; Hart, 1986);

(3) it provides a flexible environment in which information processed in different models can be integrated and co-ordinated (Lemmon, 1986; Coulson et al. 1987; Murphy & Fuggle, 1989);

(4) shells that contain frame based knowledge representation are ideal for representing the more contextual type of ecological knowledge, i.e. a certain group of facts (or 'chunk of knowledge') may be considered true only in a specific circumstance [For example

IF it can be ascertained that vegetation change occurs according to the successional theory

THEN let frame A become valid for species x

ELSE let frame B become valid for species x

(Frame A may contain a group of facts and rules about how species x may behave in a successional paradigm)];

(5) it provides a suitable environment for modelling event-driven systems (Mentis, 1988; Grossman, 1988) [The implications of the 'event-driven philosophy have been discussed by Westoby (1979), Walker et al. (1986), and Walker (1988). If ecological system-states are changing episodically and frequently, then it would be more appropriate that management practices be dictated by current circumstances, rather than as fixed policies. The event orientated approach would seem to lend itself to qualitative expert system type modelling rather than deterministic mathematical modelling];

(6) it provides a suitable environment for predicting vegetation changes based on species' life histories and population dynamics (Silva & Mentis, 1988) [Noble & Slatyer (1980) described an expert system that incorporates the vital attribute scheme to predict vegetation change. These models are useful for predicting the consequences of various management practices on the vegetation. For example (after Silva & Mentis, 1988)

IF fire regime = late wet or early dry

and species x = member of group (a) (i.e. short-lived, obligate reseeders which flower during the late wet season)

THEN effect on population of species x = decline]

(7) it could provide a suitable environment for representing knowledge in the 'state-and-transition models' as proposed by Westoby et al. (1989) [In this management-orientated model, rangelands are described by means of catalogues of alternative states and catalogues of possible transition between states. Circumstances which allow favourable transitions represent opportunities. Circumstance which threaten unfavourable transitions represent hazards. It is suggested here that knowledge describing the various vegetation states be represented using frames (see section 2.5.2.1), and rules used to describe the possible transitions. For example, two vegetation states are described using two frames (after Westoby et al. 1989).

(a)

```
frame name = vegetation state II
veld type = tall grassveld
description of vegetation = predominantly palatable
                            Perennials, e.g. Themeda
agricultural potential = high
hazards = 'over-resting' may lead to vegetation state I
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(b)

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frame name = vegetation state I
veld type = tall grassveld
description of vegetation = dominated by large course
                            perennials, e.g. Cymbopogon,
                            Apochaete
agricultural potential = medium
opportunities = moderate grazing and burning will return
                vegetation to state II
```

Rules can then be used to describe the transitions. For example

IF vegetation is in state II

and management policy results in over-resting

THEN a transition shift will occur towards vegetation state I.

Similarly, rules can be used to describe potential hazards and opportunities.].

7.1.3 Reasons why expert system modelling may not be suitable for ecological problems

(1) Ecological knowledge domains are usually not well defined. Ecological knowledge is difficult to consider as isolated units. Knowledge about one particular problem may be derived from many different, but inter-related disciplines. Edmunds (1988) feels that the more precisely the domain can be enclosed, the more focused the expert system will be, and the greater its chance of success.

(2) Ecological knowledge tends to be of a contextual nature (see section 3.4.3). This implies that generalized ecological problem solving models will be difficult to build. For ecological theories to be predictive, they become highly dependent on auxiliary assumptions. Certain hypothesis are valid only in certain situations, i.e. there is a 'situational falsifiability' (Mentis, 1988).

(3) There is a shortage of suitably trained experts. Experts tend to

be over-specialized, which could result in a limited scope of expertise. One of science's most serious problems is its fragmentary approach to nature. Scientific and, in particular, ecological problems depend on contexts that extend into many different disciplines. Clearly, such problems cannot be adequately solved within the limited contexts in which they are normally formulated (Bohm & Peat, 1987). Post-graduate training typically involves specialization within a particular direction. This has led to a fragmented approach. Boam and Peat (1987) describe fragmentation as arising when attempts are made to impose divisions in an arbitrary fashion without any regard for a wider context. This has resulted in a specialization of ecological expertise. The very notion of ecological unuerstanding appears to be incompatible with a fragmentary attitude to reality.

(4) Ecologists have usually gained their experience through theoretical research. They may lack the experience obtained through practical implementation of their knowledge.

(5) Waterman (1986) describes expert systems as unsuccessful at capturing intuition and common sense aspects of decision making. Much ecological decision making is done through intuition or gut-feeling. This kind of knowledge is difficult to capture in a decision model.

7.2 The challenge of artificial intelligence to ecology and agriculture

7.2.1 Second-generation ecological modelling

The ideas and technology of artificial intelligence have encouraged the development of a second-generation of ecological models.

Artificial intelligence, and more specifically expert system technology, have introduced new and exciting concepts into ecological modelling. Importantly, there has been a shift in emphasis concerning the basic medium from which models are built. First-generation models were built essentially from quantitative data, while second-generation models are built from knowledge (which may include both quantitative and qualitative information).

The use of knowledge as the basic modelling medium enables the development of powerful and useful management decision models. This is due to a number of reasons. Firstly, most management decisions in ecology and agriculture are largely based on heuristics (i.e. if situation x and y, then take management action z). Secondly, expert systems have the ability to handle uncertainty. This is particularly useful, as much information in ecology is 'noisy' and uncertain. Thirdly, expert system modelling forces hypotheses and concepts to be expressed as explicit statements. This facilitates conceptualization of the problem, and forces management decisions to be based on rational deductions.

A third generation of natural resource modelling has already begun. This includes large integrated expert system models. Essentially, these expert systems act as a type of 'central nervous system', co-ordinating and linking the input and output of information. Typically, integrated expert systems will have the ability to co-ordinate the workings of numerous different process models. These may be interfaced with large geographical information system-type databases, which may receive direct on-line information from sensors in the field, or at weather stations (for example, Coulson et al. 1987, and Lemmon, 1986).

7.2.2 Expert systems : providing a new and marketable end product for agricultural and ecological research

There is currently an unprecedented interest taken by administrators, managers, politicians and general public in the changes taking place in the environment. There is a demand for concise, well packaged ecological information. Irrespective of whether ecology has achieved its maturity, it is already having to bear adult responsibility (Jeffers, 1976).

The publication of scientific papers can no longer be regarded as the satisfactory end-product of research. Governments, managers, politicians and the taxpayer will demand that research results be presented in a form of direct use to them. User friendly expert system models would meet this requirement.

The idea that research results be presented in a tangible, concise and usable form, such as in expert system models, introduces the possibility that these models could become marketable end-products.

In Australia, the Queensland Department of Primary Industries are developing a series of computer decision-aids, which will be sold to farmers (Scanlan, pers. comm.[1])

Currently, large burdens are placed on the South African taxpayer to support large non-profit making organizations. The services provided by these organizations are not always apparent. Agricultural research has often been so criticized. Assuming that this criticism is justified, one may postulate that the fault lies either in the type of research being conducted, or in the manner in which results are transferred to the end users (i.e. the mechanisms of knowledge transfer).

With increased attention being paid to privatization and the concept of a free market economy, pressure is being placed on government research organizations to show the fruits of their labour. Scientists are living in the age of 'publish or perish'. It is being suggested here that not only will expert system models be a more appropriate end point for research, but that agricultural research should, to some extent, become subjected to free market economic forces. If knowledge is required, then it must be paid for by whoever needs it. If the demand for knowledge exceeds that which is currently available, then more

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[1]Dr J. Scanlan. Queensland Department of Primary Industries, Pasture Management Branch.

research is indicated.

In the light of the above remarks, it is felt that for many long-term agricultural research projects, and most pure ecological research, a special case is presented. These kinds of research cannot justify themselves on purely economic grounds, and should rather be evaluated on their scientific and ethical importance.

7.2.3 Attitudes for the knowledge age

The important changes that new technologies have brought about in society have historically been referred to as the agricultural, the industrial and the information age. With each age has come radical technological innovations. For example, the computer was said to precipitate the information age. It is now being claimed (for example, Parsaye & Chignell, 1988) that expert systems are the technology for use in the knowledge age.

Toffler (1981) has stressed the need for adapting social structure to new technologies.

It is envisaged that expert system technology will revolutionize the process of technology transfer. In particular, organizations involved with knowledge transfer, such as agricultural extension services, will require major conceptual changes.

Attitudes of farmers in South Africa are changing. Farmers can no longer consider farming as a 'comfortable lifestyle', but rather a scientifically run business. More business-minded attitudes imply keeping up with technological innovations. Increasing numbers of farmers employ computers for record keeping and data processing. South African farmers are moving into the information age.

From the number of expert systems currently being developed in America and Australia, it would appear that farmers in those countries have indicated their willingness to enter the knowledge age.

Society's response to new technology inevitably lags behind their development. It is common for old organizational structures and ideas to be inappropriately applied to new technologies (Toffler, 1981). The challenge in employing new technologies such as expert systems is to determine what organizational changes need to be made to accommodate the new technology, and what organization structures are simply hangovers from earlier technologies or methodologies.

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APPENDIX A : Floppy Discs

See floppy discs in pockets of back cover.

APPENDIX B : Instructions on running models

NOTE: Because of copyright restrictions, the programs are run using the EXSYS shell editor (EDITXS) instead of the more appropriate and user-friendly run time version.

(1) Hardware. The models will run on any IBM/PC compatible computer using MS-DOS 2.1 or higher. A hard disc drive is needed. As the programs have graphics as well as text, a Hercules mono graphics cards or a CGA, EGA or VGA colour graphic card is required. A monochrome monitor is adequate, but the display is improved with colour.

(2) Installation: Copy floppy discs on to your hard disk, under a separate directory or subdirectory. For example, use the following commands:

(Note: '☻' denotes 'enter')

```
C:\>MD EXSYS ☻
C:\>CD EXSYS ☻
C:\EXSYS>COPY A:*.* ☻
[Repeat this for each floppy disc]
```

(3) <u>To access the programmes</u>

Type in

C:\>CD EXSYS ⊛

C:\EXSYS>EDITXS ⊛

this will take you into the EXSYS shell editor.

The programme will now request the expert system file name. Type in POLICY, GRASTOCK, DEBUSH, REGROWTH or HERB, depending on which model you would like to run, and enter.

A blank screen with a menu at the bottom will appear (this is the EXSYS editing menu). Press 'R' for run.

The programme then asks two questions:

'Do you wish to have the rules displayed as they are used? (Y/N)(default = N)'

'Recover previously saved input? (Y/N)(default = N)'

Accept both defaults by entering twice.

The consultation can now begin.

(4) Information is inputted either as a text, a value, or as a number corresponding to an option for a particular question.

(5) Some questions have been provided with additional information in the form of help screens. Press '?' and enter to access.

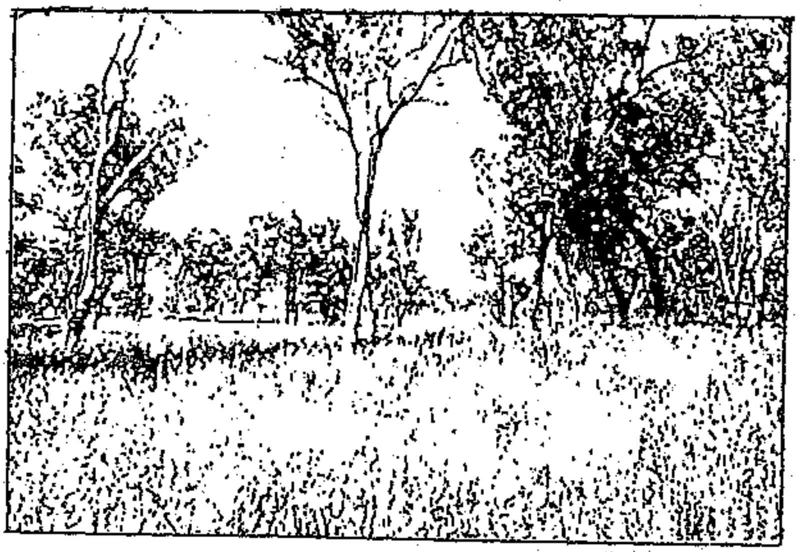
(6) If at any time during the consultation you may wish to know why the question is being asked, type in 'WHY' and enter. This will immediately take you into the rule base showing you the rule in which the requested information is used. Some rules have been provided with explanatory information and source references.

(7) To return to D^S after a consultation, press 'D' for done. This takes you back into the editor main menu. Press 'S' for store/exit. Because you are only using the editor to run the programme and not using the editor specifically, there is no need to store any information (you have already copied the rules onto your hard disc).

(8) The EXSYS shell has been provided with a competent on-line help facility. Press 'H' to access help at any time during the consultation. This will provide all the necessary information on using the shell editor menus. For example, after a consultation you may wish to use the 'trace', or 'change and rerun' facilities (consult the help line after a consultation for further information on this).

APPENDIX C : Tree density estimations
(after Scanlan & Mckeon, 1989)

Basal area
4
sq.m/ha



Basal area
8
sq.m/ha

Basal area
13
sq.m/ha

Basal area
15
sq.m/ha

Basal area
19
sq.m/ha

Basal area
27
sq.m/ha