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# Development and evaluation of an expert system approach to uneven-aged management of loblolly-shortleaf pine stands in the west Gulf region

Lorenzo, Alfredo Baptista, Ph.D.

The Louisiana State University and Agricultural and Mechanical Col., 1993

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# DEVELOPMENT AND EVALUATION OF AN EXPERT SYSTEM APPROACH TO UNEVEN-AGED MANAGEMENT OF LOBLOLLY-SHORTLEAF PINE STANDS IN THE WEST GULF REGION

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The School of Forestry, Wildlife, and Fisheries

by
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December 1993

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Finally, to my wife, Asun, I dedicate this research for hanging-in there with me for too long.



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## ABSTRACT

Forest managers expend significant time and effort seeking, organizing, and synthesizing information relevant to making effective forestry decisions. Oftentimes, they must rely on the knowledge and experience of human experts, a resource that is in short supply, requires many years to acquire, and is concentrated in a few individuals. This research task suggests expert systems as one viable solution to the problems of technology transfer and automating and maintaining expertise in consistent and usable form.

Expert systems are practical computer programs which solve problems that were previously considered only solvable by human expertise. The expert system developed in this research, named FOREX, was written in ProLog. FOREX is primarily a second-generation expert system for prescribing silvicultural systems. Aside from human expertise stored in its knowledge base, FOREX is linked with growth and yield and optimization models to complement the search for optimal recommendation.

A methodology was developed for transforming available literature/research knowledge and the private knowledge of human experts into decision rules. Factors pertinent to prescribing silvicultural systems were identified. English-like decision rules were developed, and human experts were then asked to verify and confirm these rules. The process of encoding these rules into ProLog format was an important phase of the development process.



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In a modified Turing test, nine human evaluators rated prescriptions from four other human experts, FOREX, and another computer-based model. FOREX's scores were found comparable to the research foresters and superior to the industrial foresters and the other computer model. These results indicate that human expertise, in uneven-aged management of loblolly-shortleaf pine stands, has been captured by an expert system. Success in this project should encourage other researchers to apply this approach for other forestry problems.



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# Chapter 1

# INTRODUCTION

Loblolly-shortleaf pine forests are currently the dominant forest cover type in the Southeastern and the West Gulf regions of the United States, covering approximately 58 million acres (McWilliams 1990, Birdsey 1991). Its natural range extends from Delaware along the Atlantic and Gulf Coastal Plains to Texas and Oklahoma, including most of the Piedmont region and parts of the Ouachita Mountains of Arkansas. The important timber species and principal components of this forest type are loblolly pine (*Pinus taeda* L.) and shortleaf pine (*Pinus echinata* Mill.). Frequent hardwood components of this forest type include red maple (*Acer rubrum* L.), dogwood (*Cornus florida* L.), post (*Quercus stellata* Wagenh.), red (*Q. falcata* Michx.), white (*Q. alba* L.), water (*Q. nigra* L.), and willow (*Q. phellos* L.) oaks. Also associated are commercially important but less common hardwood timber species including sweetgum (*Liquidambar styraciflua* L.), persimmon (*Diospyros virginiana* L.), and hickory (*Carya* spp.) (Baker 1989). The volume of growing stock of the primary species surpasses that of any other southern yellow pine. In addition, the economic importance of both pine species is apparent from the variety of roundwood uses. Loblolly and shortleaf pines rank first and second in both sawlog and pulpwood production. As old growth forests in the Northwest become more protected, forests in the South will become more important. Consequently, reliance on the loblolly-shortleaf pine type for softwood



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timber will likely remain strong in the future. This further implies that good timber management practices are essential to guarantee the continuous flow of valuable products from these stands.

Critical to the successful management of loblolly-shortleaf pine stands is the proper implementation of uneven-aged silvicultural system. In the South today, a million acres of industrial and over a million acres of non-industrial private lands are being successfully managed using the selection system of uneven-aged management (Baker 1985). But as uneven-aged silviculture becomes more widespread in the South, there is concern that stands may be managed by uninformed, mistaken, or wishful intent rather than by strict adherence to established uneven-aged standards (Guldin et al., 1990). Secondly, there is the obvious need to augment existing management guidelines developed from years of research with up-to-date practical experiences and information. Thirdly, there is the need for a flexible system to facilitate transfer of research knowledge and exchange of information. Lastly, there is the need for a framework for saving existing knowledge and updating such a framework as new knowledge becomes available.

## Scope and Objectives

This research was inspired by recent developments in the field of artificial intelligence (AI) research, in particular expert systems. Expert systems are computer programs that exhibit, within a specific, very restricted, but non-trivial subject, a degree of expertise in problem solving that is comparable to human

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experts (Ignizio 1990). Unlike conventional computer programs, knowledge about a particular problem domain is encoded and symbolically manipulated to assist in the selection of one of several alternative courses of action given a specific problem.

Influenced by the many successful applications of expert systems in the fields of medicine, geography, computer science, psychology, business and management, to name a few, prescribing silvicultural systems was perceived as a suitable forestry application of this technology. In the expert system developed in this project, information existing in the literature and research findings were combined with the subjective judgement of experts to build sets of decision rules. With this approach, landowners, forest managers, and practicing foresters will likely be able to deal more effectively with the implementation of uneven-aged management.

The focus of this research has been loblolly-shortleaf pine stands in the West Gulf region. But the approach is flexible enough to be used in other areas by adjusting the threshold values of critical variables to suit any potential user's requirements.

The objectives of this research were:

1) to investigate the use of an expert system for decision making in forestry;
2) to develop a stand diagnostic aid for prescribing uneven-aged management system; and

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3) to evaluate the performance of the expert system with that of human experts.

## Decision Making in Forestry

Forest- or stand-level management can be classified as either even-aged or uneven-aged. The major difference between these two strategies is that an even-aged stand has a definite end, which is also the beginning of a new stand; an uneven-aged stand is continuously regenerating itself and a harvest never removes more than a portion of the stand. Although even-aged management has been traditionally associated with shade-intolerant species and uneven-aged with more shade-tolerant ones, moderately shade-tolerant loblolly-shortleaf stands have been successfully managed with uneven-aged techniques.

Under either management philosophy, effective decisions are made from appropriate quality information and expertise. Many forest management decisions and recommendations are made by subjective judgment with reliance on past experiences and professional intuition. For instance, in recommending a silvicultural prescription, a change in the landowner's management objectives or a change in local product markets might cause the advising forester to suggest leaving the stand alone rather than harvesting it. Such decisions are made by transforming a set of information (data in the form of observations and facts) representing the problem into a subset of the possible set of alternative actions (decisions). When the data are numerical and the transformation equation is described by a precise mathematical relationship, the resultant decisions can be

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obtained by using familiar numerical methods. In circumstances where either the data are qualitative (descriptive) or the transformation equation is less precisely described, human expertise has widely been employed to reach decisions.

Expertise gained through experience is highly regarded. With experience comes an intuitive feel for the subject, a type of knowledge that oftentimes can not be easily expressed. It augments subjective judgement, providing one the ability to identify diverse factors, evaluate alternatives, and make intelligent decisions. There are many benefits to be gained from use of experiential type of knowledge. One, it provides an explicit record of expertise which affords the decision maker a means for justifying decisions and which guarantees some protection from loss. Two, current strategies used in solving problems and making decisions become more concrete and less mysterious. Three, human expertise provides a focus for upgrading and improving management strategies over time. Four, decisions will be consistent, unaffected by day-to-day bias. Five, human expertise makes the most current knowledge available for many users rather than just the few individuals that are acquainted with the human expert.

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## Chapter 2

## LITERATURE REVIEW

Hann and Bare (1979) identified the basic stand-level questions for uneven-aged management as determining (1) the optimal sustainable diameter distribution including maximum tree size, level and structure of growing stock, (2) the optimal species mix, (3) the optimal cutting cycle, (4) the optimal conversion strategy and length, and (5) the optimal schedule of treatments for all stands to best meet forest-wide objectives and constraints. Uneven-aged management has been perceived as fundamentally more difficult to implement than even-aged management. Consequently, models for uneven-aged management appear more problematic and complex than even-aged management.

Nevertheless, Willett and Baker (1990) point out that the basic principles of uneven-aged management are straightforward and fairly easy to understand. Specifically for loblolly-shortleaf pine stands, effective uneven-aged management requires (1) periodic control of midstory and overstory hardwoods, (2) a cutting cycle of 3 to 10 years depending on the growth rate, operable cut and structure of residual stand, and (3) a maximum density of 75 $ft^2$ per acre of merchantable basal area.

During the last 20 years, research interests in uneven-aged management have focused on designing computationally efficient methods for optimizing these



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management decisions at the stand level. These techniques, traditional and non-traditional, are the subject of this chapter.

**Quantitative Approaches**

By most accounts, modern approaches to the management of uneven-aged forests began with the work of Meyer (1952) who validated and extended observations and conclusions made by deLiocurt about the structure of uneven-aged stands. At about the same time, Duerr and Bond (1952) formulated the problem of determining the optimal level of growing stock as a financial-maturity problem. Interests in uneven-aged research within the subsequent twenty years has concentrated on the optimization of residual stock structure and cutting cycle length. Controlling stand structure is critical to successful implementation of uneven-aged management. The series of selection cuts undertaken are designed (1) to remove mature and high-risk trees, (2) to create space for new regeneration, (3) to concentrate growth on the best trees while maintaining sufficient stocking across a range of diameter classes (Leak and Gottsacker 1985), and (4) to regulate yields from uneven-aged stands. Decisions related with diameter distributions for uneven-aged stands are complex as they vary with management objectives and stumpage values (Adams and Ek 1974), product objectives and tree values (Haight et al., 1985), site quality, alternative rate of return and cutting cycle length (Martin 1982). Compared to poorer sites, diameter distributions on better sites had lower proportion of small trees and lower stand basal area. In addition, as the alternative rate of return increased, the proportion of small trees increased,

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whereas basal area decreased. Cutting cycle had the least impact on sustainable distributions (Martin 1982).

Results from these previous studies demonstrate the interrelationship of stand structure and management objectives and subsequently the need to match the two. Selected published diameter distributions could be applied to real stands provided that the growth models and management assumptions are appropriate for the local conditions.

Many of the methods used and proposed to solve for the optimal decision variables have their origins in the field of operations research/management science (OR/MP). OR/MP includes a family of techniques for representing problems mathematically and determining the optimal solution. The OR/MP methods heavily used in forest management include linear programming and non-linear programming within the context of static and dynamic formulation. OR/MP-based methods have been greatly enhanced by growth and yield simulators. The success of OR/MP techniques depends upon the degree to which growth and yield models portray stand dynamics. Consequently, the methods to be used depend largely on the complexity of the stand growth and yield model used. Depending on management objectives, whole-stand growth simulators provide a means to update forest inventory and estimate yield, needed to determine when the objective is optimal. Familiar objectives are maximization of board-foot or cubic-foot yield, present net worth, soil expectation value, internal rate of return, or forest value.

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Possibly the most straightforward methods are those used when a differentiable growth function is available. The objective function is maximized over time by solving for the value of t (the optimal cutting cycle length) and g (the optimal growing stock) which results in the first derivative of the function being zero and the second derivatives being negative. The problem can be stated as,

$$Max\ Z = f(t,g)$$

subject to

$$t,\ g > 0$$

and the solution is where

$$\delta f(t,g)/\delta t = 0$$

$$\delta f(t,g)/\delta g = 0$$

$$\delta^2 f(t,g)/\delta t^2 < 0$$

$$\delta^2 f(t,g)/\delta g^2 < 0$$

When Z is not easily differentiable or is discontinuous, numerical techniques are used. If Z requires little calculation, complete enumeration is possible. If a large number of calculations is required for Z, a nonlinear search technique can be used.

Adams (1974) and Adams and Ek (1974) derived sustainable equilibrium diameter distributions utilizing diameter classes and formulating the maximization problem as nonlinear problem using a variation of the steepest ascent algorithm. The use of the stand table projection method in these studies was a bold attempt

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to capture the dynamic characteristics of uneven-aged stands. In an effort to determine the optimal diameter distribution associated with the best economic stocking in a uneven-aged forest, Adams (1976) defined optimal distributions as those which yield maximum value growth over the cutting cycle for a given initial stocking level. He developed optimal sustainable diameter distributions that maximized the marginal value growth criterion which is equivalent to land expectation value.

Comparative static optimization has been proposed and applied to the same problem. Chang (1981) showed that maximizing land expectation value is equivalent to maximizing forest value. He then used static optimization to simultaneously determine the optimal growing stock and cutting cycle given the stand before harvest as the initial stand. Hall (1983) used a similar concept in which the stand after harvest was considered as the initial stand. In both studies, diameter class dynamics were not accounted for as in Adams and Ek's (1974) model. Hotvedt and Ward (1990) pointed out certain problems associated with static analysis. The structures of existing stands do not usually correspond to the optimal structures derived from static models and static models do not provide for optimal conversion strategy.

Mathematical programming techniques have been applied to a number of uneven-aged management problems but have met only limited acceptance and operational application. Linear programming has been used to simultaneously determine the optimal level of residual growing stock, diameter distribution, and

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cutting cycle length (Bosch 1971, Rorres 1978). Buongiorno and Michie (1980) used the linear programming technique to generate sustainable diameter distributions that maximize net present value. While mathematical programming models are an elegant approach to decision making, there are non-trivial difficulties with formulating these forest management problems in mathematical terms. Oftentimes, mathematical programming approaches require over-simplification of the problem in order to find a solution. In addition, except in very simple cases, mathematical programming techniques do not provide forest managers with readily understandable solutions.

Simulation approaches, including random and Monte Carlo simulations, have also been used rather heavily to manage forest operations. Simulation techniques traditionally require a large amount of time, luck, and human expertise before an acceptable solution to a problem can be found. Hansen and Nyland (1986) demonstrated that the combination of q value, maximum DBH and basal area varied depending on management objectives and cutting-cycle length. Problems associated with static models are overcome through the use of dynamic programming except that it does not guarantee global optimum. In addition, growth simulators cannot be readily incorporated into the dynamic programming framework because the prohibitively large number of decision variables involved requires long computation time and massive computer storage. Consequently, Haight et al. (1985) and Haight (1987) introduced the gradient optimization technique based on optimal control theory for finding the optimal sequences of

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diameter-class harvesting rates, cutting cycle and species composition that maximized the present value of the existing stand over an infinite time horizon.

Several nonlinear programming approaches including Hooke and Jeeves (Haight and Monserud 1990), Box's complex algorithm (Bare and Opalach 1987), and gradient projection method (Adams and Ek 1974) have also been successfully applied in determining optimal equilibrium diameter distribution for uneven-aged forest stands.

Bare and Opalach (1987) used a direct search, derivative-free, constrained nonlinear programming algorithm to determine the optimal sustainable equilibrium diameter distribution and species composition for a mixed-species forest stand. Using a distance-independent individual tree growth model, they assumed that the sustainable equilibrium diameter distribution can be adequately represented by a Weibull distribution. Consequently, the maximization problem was formulated in terms of three decision variables per species: the scale and shape parameters of a Weibull probability density function and the total number of trees per acre. Like other earlier studies, their results indicate that optimal sustainable diameter distributions are a function of management objectives. Optimal stand structures associated with the maximization of economic or financial objectives (e.g., land expectation value and managed forest value) dramatically differ from those associated with maximization of physical volume (e.g., board-foot or cubic-foot volume harvest). Because of the inter-relationships of management objectives and stand structures maximum tree size and price

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assumptions should be carefully selected as they are critical in describing the diameter distribution of uneven-aged stands.

Martin (1982) also determined sustainable equilibrium diameter distributions for northern hardwoods by maximizing the land expectation value. Martin used a Weibull function to characterize diameter distributions. With the shape parameter set to one, the optimization problem is reduced to a two-variable decision space.

In practice, distributions are based on a fixed q value (ratio of number of trees per acre between successive DBH classes) because it is simple and computational procedures are well documented. Existing management guides, however, do not show the impacts of adjusting maximum tree size, basal area, and q ratio on different management objectives and cutting cycles.

Computer-based decision tools will continue to provide information to forest managers to help them make better decisions. These include management information systems (MIS), geographic information systems (GIS), simulation models, and operations research/mathematical programming (OR/MP) techniques. Whereas the common goal of these tools is to improve decision making, they differ in their approach and in what they offer the user. With the exception of OR/MP, these decision aids are by design not problem solvers. MIS and GIS are primarily information storage and retrieval systems. They are designed to allow easy access to a variety of information relevant to solving a problem. Likewise, simulations of reality are very informative and useful in

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making a decision. These tools turn into problem solvers when integrated with an expert system or a reasoning system.

## Qualitative Approaches

Quantitative approaches, while theoretically attractive, face serious practical shortcomings. An alternative approach to OR/MP techniques and simulation is knowledge-based modelling using artificial intelligence (AI) techniques. AI, particularly expert systems, allows forest managers to use their knowledge and expertise earned through years of real life experiences and thus rendering the decision-making process more intuitive and more closely related to their chosen actions. Knowledge gained from other sources, including simulations and OR/MP models, can be readily incorporated into the knowledge base in usable form.

Several qualitative techniques which appear promising for applications to forestry problems include heuristic optimization, knowledge-based systems, and a combination of both. These techniques are described next.

### Heuristic Optimization

Heuristic is from the Greek word *heurskein* meaning "to discover". With respect to OR/MP, heuristics are procedures to reduce a search in problem-solving activities (Tonge 1961) or a means to obtain acceptable solutions within a limited computing time (Lin 1975). For practical purposes, heuristics are simple procedures, often guided by common sense, that are meant to provide good but not necessarily optimal solutions to difficult problems easily and quickly (Zanakis and Evans 1981). In forestry, simple examples of heuristics include rules of thumb

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like *"thinning to basal area equal to the site index"* or *"harvesting the oldest trees first"*. Heuristic optimization has been used where exact OR/MP methods such as linear and dynamic programming are either inapplicable or impractical. Moreover, heuristics may be used in uneven-aged management to estimate the optimal number of trees to harvest by diameter classes after each cutting cycle.

Knowledge-based Systems

The knowledge-based systems (KBS) approach, unlike those OR/MP methods described above, are relatively new to forest management and are very promising. KBS provide new ways to record information and build models of systems. KBS can capture and manipulate non-numeric information -- heuristic knowledge, rules of thumb, experience, and qualitative information, that no traditional OR/MP approach like those described earlier can. Further, since KBS mimic one way humans store, retrieve and manipulate knowledge, KBS provide users with the capability to deal with complex problems.

Despite the relative infancy of KBS, the amount of interest and work in developing an expert system for any likely application has been remarkable. The progress of expert system applications in forestry can be traced in three phases just like any technological breakthrough. Phase 1 was the "initial excitement" stage, with small applications of AI, often purely academic, designed to see what could be done. In the second phase, there was a proliferation of stand-alone systems mainly used for consultation by field foresters. The third phase was the

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obsolescence phase when AI ceased to be something other than an additional set of tools to expand the range of the problem type amenable to computer solution.

Hybrid Systems

Quantitative techniques described at the beginning of this Chapter can be interfaced with an expert system, making them more user-friendly and more robust. The level of integration is such that an optimization model component supplements the KBS's reasoning element (Turban and Watson 1986). Following this framework, the expert system is to serve as a means for assessing the initial stand condition and applying an appropriate management prescription. At the back end, it interprets the results of the optimization model and reconciles the differences in characteristics between the target stand identified using the knowledge base and the optimum found by the optimization model.

**Evaluation of Expert Systems**

Evaluation of expert systems is oftentimes confined mainly to testing the quality of decisions or recommendations generated. In practice, evaluation involves verification, validation, and sensitivity analysis (Harrison 1991). Procedures that have been employed to evaluate expert systems can be classified as either subjective methods or statistical tests.

The subjective methods include assessment comparison against performance standards (Plant 1989), the Turing test (Boggess et al., 1989; Schmoldt and Martin 1989), and assessment of field performance (Geissman and Schultz 1988).

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Statistical tests consist of parametric and non-parametric methods. Parametric procedures include establishing tests and confidence intervals for means and differences between means (O'Keefe et al., 1987; Boggess et al., 1989). Non-parametric methods such as the Spearman rank correlation test was used to compare judgments of rankings of scenarios by human experts and expert systems (Harrison 1990).

**Use of Expert Systems in Forestry**

Not all qualitative problems lend themselves to the expert system approach. Stefik et al. (1984) categorized problem areas that encompass the range of expert system development as either classification or creation types. Classification types includes diagnosis, interpretation, and monitoring; while the creation type includes prediction, planning, and design. Several problems in forestry are currently being researched, or seem promising for future applications of expert systems.

Rauscher and Cooney (1986) described a silvicultural prescription system called CHAMPS (Computerized Habitat Analysis and Multiple-Use Prescription System) that was developed by the USDA Forest Service, North Central Forest Experiment Station. It was designed for individual stands in Itasca County, Minnesota. The system contains management rules based on timber, wildlife, and watershed research results.

A similar system, NE Decision Model, is also being developed by the USDA Forest Service, Northeastern Forest Experiment Station, for the northeastern United States (Solomon and Marquis 1990). The system will

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incorporate available scientific information on silviculture, wildlife habitat management, aesthetics, watershed management, timber management and harvesting, growth and yield, economics, and pest and disease management.

Subsequent models span the range of potential applications of expert systems from as mundane as selecting herbicides (Zedaker 1990), disease diagnosis and identification (Schmoldt and Martin 1990), and forest fire suppression (Kourts 1991) to distinctive applications such as harvesting and forest operations scheduling (Brack and Marshall 1992).

In a recent survey of AI projects in natural resources management, Rauscher and Hacker (1990) described over 70 projects in various stages of development. In an earlier survey, from mid-eighties to the late eighties, Rauscher (1987) and Lambert and Wood (1989) reported nearly 100 expert systems in various stages of development. Davis and Clark (1989) also reported more than 200 publications on the subject of expert systems in natural resource management between 1976 and 1989. If these figures are any indication of the ground gained by use of expert systems, more are likely to come and at a faster rate. On the basis of the above surveys, specific applications of expert systems in forestry can be grouped into operations planning and scheduling, silvicultural prescriptions, pest and disease identification and diagnosis, and forest fire prediction and suppression.

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## Chapter 3

## KNOWLEDGE-BASED SYSTEMS: AN OVERVIEW

Expert systems have been called different names, e.g., knowledge-based systems, inference systems, rule-based systems, advisory systems, and consultation systems. In most cases, the particular name used reflects the type, presentation, and structure of the knowledge in the system. Although, this project combines frames and production rules to formalize the knowledge base, it can still be more appropriately called a knowledge-based system.

Definitions of expert systems and their characteristics have been presented by many authors (Feigenbaum 1979, Buchanan and Duda 1983, Ignizio 1990, Plant and Stone 1991). Knowledge-based expert systems are practical computer programs that are capable of solving complex problems within a very clearly defined and limited subject comparable to a human expert. The solution process attempts to mimic human reasoning, relying on logic, belief, rules of thumb (heuristics), opinion and experience. Like human experts, expert systems tend to be specialists with expertise focused on a narrow set of problems and use both theoretical and practical knowledge perfected through experience in the subject. However, unlike humans, expert systems cannot learn from their own experiences; their knowledge must be extracted from humans and encoded in a formal language.



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## The History of Expert Systems

Knowledge-based expert systems have evolved from approaches developed in artificial intelligence (AI) research. The basic goals of AI research are (1) to develop more intelligent machines, particularly computers, (2) to study the concepts and develop models of human cognition and thought processes, and (3) to find new ways of reproducing human intelligence. Expert systems are the most successful branch of AI application. The fact that the problem-solving knowledge is separated from algorithms results in great flexibility. Moreover, this feature increases the portability of the system and usage of expertise from one application to another.

During the past twenty years many expert systems have been constructed. The earliest and more notable expert systems built include MYCIN (Davis et al., 1977), PROSPECTOR (Duda et al., 1979), DENDRAL (Lindsay et al., 1980), and XCON (McDermott 1982). MYCIN provided diagnosis and treatment recommendations for bacterial infections in human blood, PROSPECTOR selected sites for mineral exploration, DENDRAL inferred the molecular structure of unknown compounds from mass spectral and nuclear magnetic response data, and XCON (originally R1) customized configurations of VAX computers according to user specifications. Recent years have witnessed the widespread applications of expert systems in electronics, engineering, law, manufacturing, business and economics, meteorology, physics, and space exploration (Hayes-Roth 1986).

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Applications in agriculture and forestry were reported as early as 1986. Over 70 knowledge-based systems have been constructed for prototype, commercial, research, and teaching uses (Rauscher and Hacker 1990).

**Basic Components of Expert Systems**

A typical expert system consists of four essential components. The facts base, knowledge base, and inference engine are data structures; whereas the user interface contains algorithms to operate on the data structures.

Facts Base

The facts base contains assertions about the problem area. These assertions may be known facts obtained by asking the user, or invoking external programs or read from existing data files. Assertions may also be inferred from facts established *a priori*. In expert systems terminology, facts may be represented as simple statements like "*the stand is overstocked*", numeric relationships like "*merchantable basal area > 60 $ft^2$ per acre*." Associated with each fact is a certainty factor value indicating confidence and belief on that fact in the context of the current problem.

Knowledge Base

The subject-specific knowledge base contains information about how to solve problems within the problem area in general. The types of knowledge may include scientific knowledge and experience specific to the area of expertise. Three of the most widely used types of knowledge representations, rule-based, frame-based and logic-based representations, are discussed next.

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Rule-based Knowledge Representation

In this representation, knowledge is encoded as a set of "*IF condition THEN action*" statements. The specific action is performed if the antecedent condition(s) are matched in the facts base. An action might involve modifying certain facts, inferring a hypothesis, executing some external program or evaluating another set of rules. The following example illustrates the IF-THEN logic.

*IF: 1) Merchantable basal area is between 45 and 75 $ft^2$ per acre, and*
*2) Ratio of sawtimber to merchantable basal area is between 65 and 75 percent*
*THEN: The stand is considered "well stocked".*

Frame-based Knowledge Representation

In this representation, knowledge is encoded as objects. Objects are entities about which it is important to reason, e.g., stand, individual tree. A frame contains slots which can be properties, pointers to other frames, pointers to procedures for calculating values, and pointers to inference rules. Unlike rules, frames allows the user to express more complex relationships between entities and for deep reasoning models.

Logic-based Knowledge Representation

Logic-based representations commonly use first-order predicate logic to represent assertions and inferences. The inference procedure is a method of theorem proving. ProLog is a logic-based programming language is widely used for this purpose.

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Inference Engine

At the heart of an expert system is the subject-invariant inference engine which contains the reasoning capability to draw conclusions from the knowledge base. The inference engine specifically controls the search mechanism of the knowledge base by using either a forward- or backward-chaining strategy, or a combination of both, in an attempt to find a solution.

Unlike the passive knowledge base, the active inference engine performs many functions which make up the control strategy of the system. The inference engine selects and orders the rules to be applied, specifies the criteria for instantiating knowledge base conditions and facts base conditions, determines the operation and order of actions on the facts base, and terminates the inference process under predefined conditions.

The discussion that follows is a general description of the three basic inference strategies used by current knowledge-based expert systems.

Forward Chaining

In forward chaining, sometimes called data-driven approach, rules are selected for application if and when all their necessary conditions are satisfied by the data in the facts base. Conflict resolution instructions are applied to the rules already selected to select the rule with the highest priority. Search begins by giving the rules with the most recently modified facts base condition priority for evaluation. After the first rule is applied and the facts base is modified, the data-driven process is continued until a goal is reached. When no rules are selected,

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then the user is asked to provide information that may allow some rules to be selected.

Since rules for application are selected on the basis of the current available information, the facts base must be searched more frequently. Consequently, when the facts base is large, this searching can result in a great deal of processing time for each iteration. This strategy corresponds to a breadth-first search of the state space. That is, all states possible from the current state are completely examined before proceeding to states on the next level. If none of these states is a solution state, then all potential rules are applied from one of these states. This is repeated until the necessary termination conditions are satisfied. This can provide the user of the expert system the impression of random questioning with little sense of direction toward finding a solution.

Backward Chaining

The backward chaining or goal-driven strategy starts from a given goal (hypothesis), then investigates only those rules which pertain to the particular goal. If a rule has the goal currently being considered in its conclusion and the premise of that same rule is satisfied, then the goal is established. If the conditions are not satisfied, then these conditions become subgoals and the process continues recursively. When a subgoal cannot be established using the available rules, the user may be asked to confirm that subgoal and/or other subgoals may be investigated. This control strategy has been used very effectively in the landmark expert system MYCIN.

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Backward chaining is similar to depth-first search of the state space. Each rule to a new goal moves farther from the initial goal. The process seeks the deepest possible node until the current goal is satisfied or a dead end is reached (i.e., no rules are applicable to the current goal). When a dead-end state is discovered, the process backtracks and then proceeds to seek down again until one of the above conditions are met. This process involves much more direct questioning and an inordinate amount of effort may be expended on goals that cannot be satisfied; however, it guarantees a solution.

Forward-Backward Combination

With a combined forward and backward chaining approach, intermediate subgoals in the data-driven phase are used to select a goal for investigation in the goal-driven phase. When the goal-driven phase reaches a large number of alternative paths, the data-driven phase is invoked again to select additional goals for investigation.

User Interface

As the name implies, the user interface serves as the input/output link between the user and the system. The interaction is implemented through menu-driven, graphical, or question-answer mechanism.

The way in which the consultation is presented to the user is key to the successful implementation of the system. Without good user-interface facilities, systems are likely to end up in shelves. Most existing systems require end-users to supply some information via queries. Some more sophisticated systems are

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equipped with natural language front ends and can process English-like responses. In most systems, the user is presented with a query in the form of a menu from which answers may be selected or line input where the user fills in the missing information. Menus restrict the values that may be specified and are more helpful for users less familiar with the subject.

Reports of results can be displayed using textual descriptions or graphical presentations. These results may be displayed on the monitor, printed, or sent to a file for later use. The contents of the current session may also be stored for later use; this, along with the results, will constitute a record of the current decision-making strategies. Current strategies can be reviewed and updated as necessary.

It may be desirable to provide the user with an experimentation facility which would make possible a sensitivity analysis on the solution. For example, at the end of a session, one or more answers to investigative questions could be changed; the session would be run again and the results compared with those previously obtained. In this way, the user will be aware of how sensitive the solution is to uncertain information.

**Optional Components**

In addition to the basic components, certain enhancements can be included to improve the design and acceptance of expert systems. Three possible enhancements, namely explanation and justification, uncertainty, and the use of demons are briefly described next.

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Explanation and Justification

The manner in which an expert system interacts with the user is very important. An expert system should not appear like a black box, the reasoning, actions, and recommendations of which are hidden from view. If the user is able to ask the system why certain information is required, or how a particular recommendation was reached, results are more acceptable. These features are accomplished by means of stored text and execution tracing. For small applications, text, describing why and how goals are selected or inferences made, may be sufficient to provide a surface-level explanation of system performance. Other systems employ some form of tracing back through the rules that led to a conclusion in response to user requests.

Uncertainty

When dealing with qualitative problems, human experts are often faced with inexact information and must rely on imprecise knowledge (or heuristics). Data may be incomplete as a result from poor observation or unavailability of the data. In addition, not all of the available data may be known with certainty; more often it is believed true with some subjective level of confidence. Furthermore, heuristic knowledge applied to the problem are often subjective judgments or "educated guesses" and do not usually lead to conclusions which are absolutely certain. Imperfect information is compounded by the combined rules of thumb and inexact pieces of knowledge relied upon for inferences.

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Some expert systems have incorporated certain technique for coping with uncertainty. Users may be allowed to specify values indicating the levels of confidence in their data, and inferences in the knowledge base may contain values to indicate the relative strength of their conclusions. Various approaches determine how the measures of uncertainty are combined during the logical inference process. Widely-used techniques include Bayesian methods, two-value certainty factor used in MYCIN, and fuzzy logic which uses the mathematical theory of fuzzy sets (Zadeh 1965).

Demons

Demons are programs not directly related to the reasoning process but which perform useful functions including evaluation of mathematical relationships. Demons serve as information sources, providing meaningful output usable by the inference engine in making recommendations. Turban and Watkins (1986) described various ways of configuring the relationship between demons and knowledge-based systems. In forestry applications, demons might include growth and yield simulators and optimization models. The expert system could serve as a user-friendly front end that calls efficient simulation and/or optimization programs and then interprets their results in an intelligent manner.

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## Chapter 4

## DESIGN AND DEVELOPMENT OF FOREX

FOREX stands for FORest EXpert. It is a "second generation" knowledge-based system for prescribing a silvicultural system. FOREX performs similar tasks already accomplished by other systems, but does so by using a combination of rules and frames to represent knowledge and control structure. FOREX was written using PDC ProLog, an implementation of ProLog. Other components of the system were written in Turbo Pascal.

Development of a working prototype of FOREX required several distinct phases for completion. This chapter presents details of the various phases in the development of FOREX and a complete description of the components of FOREX, highlighting their rationale, structure, and function(s).

### The Prescription Process

"Silvicultural system" refers to a planned program of silvicultural treatments during the entire life of a stand, including tending operations, intermediate and reproduction cuttings (Smith 1986). The process of prescribing and evaluating silvicultural systems consists of two phases, namely, diagnosis and prescription. The diagnosis phase involves determining the current state of the stand, in particular the condition of the growing stock, stand structure, size and species distribution and abundance, site quality and diversity, species requirements and regeneration needs. The prescription phase, on the other hand, involves



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determining an appropriate action or response to the consequences of the diagnosis phase.

In practice, the process requires site specific information on stand conditions, management objective(s), economic variables and other information necessary in making effective decisions. Through the diagnosis phase, a target stand is identified by comparing the existing stand described by the stand table and the desired stand. Consequently, potential prescriptions are identified, evaluated and compared. Generally, alternatives include (1) clearcut the stand and replace by either seed-in place or seedling-in-place, (2) manage the stand by shelterwood, (3) manage stand as seed tree, (4) modify the stand to guarantee achieving the desired target stand, (5) leave the stand without applying any treatment.

## Knowledge Acquisition

As previously noted, knowledge acquisition involves collecting and organizing information necessary for decision making. It also includes the process of encoding these condition-action relationships into a set of inference rules. Available resources, both research literature and human experts, were initially investigated for factors taken into consideration when developing specific prescriptions for uneven-aged management of loblolly-shortleaf pine stands. In general, Minckler (1979) suggested stand/site conditions, economic variables, and management objective(s) as major factors to consider among others. Diagnostic strategies frequently used by human experts were closely followed as far as what

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the selected development tool would allow. Rule construction consisted of an initial paraphrasing of the decision rules in an English-like format which were later encoded in formal Prolog syntax.

Knowledge acquisition is widely considered the bottleneck in building expert systems. However, it was not the case in this project. At the first meeting with the experts, not a hint of skepticism of the value and applicability of the technique was apparent. This was evident from the time commitment and cooperation made by those involved during the long process of intensive knowledge elicitation, revisions, corrections and enhancements of the final model. The success of this project is a reflection of the interest, cooperation and effort of these experts.

Knowledge Collection

Literature and human expertise are two primary sources of knowledge often exploited. Valuable research publications on uneven-aged management of loblolly-shortleaf pine by the Southern Forest Experiment Station at Monticello, Arkansas, were collected. Human expertise was provided by known experts, in the persons of Drs. James Baker, Paul Murphy, Mike Shelton, and Jim Guldin, all of the USDA Forest Service, Southern Experiment Station, Monticello, Arkansas. Dr. Guldin participated in the initial meeting but was unable to attend subsequent meetings. The remaining experts decided to invite Mr. Louis Rainey, a forester with Deltic Farm and Timber, Inc., to represent the non-academic community. Mr. Rainey was selected for his experience and knowledge in the implementation

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of uneven-aged management. These persons were the group of experts who helped built the model.

After a general procedure used to arrive at a prescription was agreed upon, the next major function of the experts was to identify the various factors important to making silvicultural prescriptions. These factors were designated as stand and site conditions, management and product size desired, market factors, and financial resources and needs of the landowner.

Information on stand and site conditions is essential for the type, timing, and intensity of silvicultural prescription. This information includes stand location, site quality, stand structure, stocking, availability of seed source, distribution of basal area among product classes, overall quality of the trees present, and species composition.

Management and product class objectives refer to the type of product the landowner wants to produce from the area. This may include pulpwood, small to large sawtimber, and non-timber products including recreation opportunities, wildlife opportunities, and other non-timber related amenities. The group, discouraged by the enormity of the job ahead and many grey areas with respect to the non-timber products, decided to concentrate on the timber objectives.

The willingness of a landowner to invest and resources available were also mentioned above as another factor. This influenced the type of vegetation competition which could be recommended as well as the potential frequency of harvest.

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The experts established descriptive categories for specific aspects of each of these factors that could be used to describe the state of the stand. Numerical responses by the user to FOREX's queries as well as derived stand values were transformed into their corresponding qualitative equivalents defined by these categories.

Stand and State Descriptors

States are representations or configurations of the problem on hand. Two states of particular importance are: the initial state and target state. Both states are defined by the distribution of trees among the DBH classes, also known as the stand structure. The target state is one that satisfies pre-specified conditions, namely residual basal area, maximum DBH class to leave in the residual stand, and the ratio of the number of trees between adjacent size classes.

Site quality. A stand is assigned to a site class of either good, medium, or poor on the basis of threshold values of site index (at base age 50 years) established by the experts. Site quality in turn is the sole determinant of the appropriate basal area (BA) and diameter growth rates. Consequently,

| Site Class | Site Index (SI) (ft) | BA Growth Rate ($ft^2$/acre/year) | DBH Growth Rate (inches/year) |
|---|---|---|---|
| Good | $SI \geq 80$ | 3 | 0.4 |
| Medium | $70 \leq SI < 8$ | 2 | 0.2 |
| Poor | $SI < 70$ | 1 | 0.1 |

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Stand Characteristics. State descriptors previously noted refer exclusively to variables pertaining to the stand including the following:

1. Stand structure refers to the distribution of the number of trees per acre among DBH (size) classes. The number of trees per acre and the corresponding basal area in each class size are drivers for inferring the management type to use, i.e., either even-aged or uneven-aged. Both number of trees and basal area should meet threshold levels set in inference rules.

2. Percent stocking and basal area per acre. Both variables are simultaneously used in the inference rules. Percent stocking (S) is calculated using a tree-area ratio equation for southern pine species (Murphy and Farrar 1982):

$$S\ (\text{percent}) = 0.16667(N) + 0.045098(\Sigma DBH) + 0.043356(\Sigma DBH^2)$$

S is used as an indicator of whether the stand is adequately stocked ($S \geq 20\%$) or understocked ($S < 20\%$). Additionally, experts defined basal area stocking (B) classifications shown below. Variables S and B used simultaneously would indicate stand stocking level.

| Basal area (B) ($ft^2$/acre) | Category |
|---|---|
| $B < 5$ | Inadequate |
| $5 \leq B < 45$ | Understocked |
| $45 \leq B < 75$ | Well stocked |
| $B > 75$ | Overstocked |

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3. Stand quality. This variable is an indicator of the overall quality of trees in the stand. It is primarily a function of the number of trees in each of the following tree quality classes:

Growers -- good to excellent quality trees that will provide rapid and high quality growth; these are crop trees.

Thinners -- fair quality trees that can be cut now or left for the future. They currently are not contributing greatly to stand growth but may do so in the future if released.

Cutters -- poor quality trees unlikely to survive to the next cutting cycle, or slow growing trees that are competing with growers. Stand growth would be increased by their removal.

Growers and thinners are considered acceptable growing stock while cutters are unacceptable. Stand quality categories were defined by the experts based on P, percent of merchantable basal area in growers and thinners:

| Value of P (%) | Category |
| --- | --- |
| $P \geq 75$ | High |
| $66 \leq P < 75$ | Medium |
| $P < 66$ | Low |

4. Sawtimber basal area to merchantable basal area ratio. This ratio is essential to guarantee periodic harvest. The ideal before-cut ratio is about 80%, and a good after-cut ratio would be about 60%.

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5. Availability of seed trees/source. This variable dictates the maximum DBH class in the residual stand and is a function of site quality, cutting-cycle length, and product-class objective. Trees large enough to provide sufficient seed for natural regeneration of the stand must be retained. The experts estimated that dominant trees having a 12-inch diameter were the smallest trees to meet this criterion.

Rule Construction

Four groups of rules were constructed to (a) check user provided data, (b) infer category/class of stand with respect to decision criteria, (c) search knowledge base for the appropriate prescription and stand type, and (d) summarize results.

From the rules, ultimate decisions, intermediate decisions, and specific facts were distinguished. Ultimate decisions are the components of the prescription and their corresponding values. Many of the assertions in the rules are intermediate decisions, i.e., assertions which are combinations of simpler, more obvious facts. Because of the number of rules, a structure was imposed to facilitate easier organization and comprehension. Rules with similar purposes were grouped into blocks. Within each sub-block, the rules are organized sequentially and in decreasing order of diagnostic content. This was done to minimize questioning. The conditions within each rule are organized from basic facts to more specific facts to avoid specific facts from being investigated if the preceding basic conditions are not true.

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Logic and completeness rules were added to minimize questioning and supplement information omitted by the user. In the example below, the antecedent conditions are asked in almost every session so they represent information already known to the system. From it, the system can deduce "the stand is an old stand" without specifically requesting that fact.

*IF: 1) Only one size class is represented, and*
*2) That size class is large sawlog.*
*THEN: The stand is an old stand.*

Finally, instructions to the user indicate that all applicable values of a fact should be supplied when requested. However, the user may not always reliably follow the instructions, so rules have been added to ensure that the information the system uses is as complete as possible.

Knowledge Representation

Knowledge is represented in FOREX using both frame-like structures and production rules. A frame-like structure ties together knowledge about a given situation and provides expectations about what objects and events should be present in the situation. The frame is composed of a set of slots which provide explicit place for information or values corresponding to the expected objects and events. Frames, therefore, offer the benefit of assuring complete information prior to solving a problem, something production rules do not provide. Each frame slot is associated with IF-THEN production rules. The IF part states a set of conditions in which the rule is applicable. The THEN part of the production

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rule states the appropriate conclusions to make when the premises are satisfied. The decision to combine rules with frames was primarily to offset the limitations often associated with use of production rules and to avail the respective advantages of rules and frames in a joint structure.

Frame-like structures were implemented in ProLog using list; they are used to represent a management type and the treatment or prescription appropriate for a particular stand given its current conditions.

The threshold values established by the experts were used to define descriptive variables to classify a given stand condition. These values are stored in the knowledge base as IF-THEN rules. For instance,

*IF: Merchantable basal area is between 45 and 60 $ft^2$/acre*
*THEN: Stand is well stocked.*

Distribution of Stocking

Rules were also constructed by combining percent stocking and amount of merchantable basal area to infer the distribution of the basal area among the size classes and species into qualitative categories, namely, understocked and adequate. Consequently, a current stand is a candidate for uneven-aged management if percent stocking is at least 20% of merchantable basal area or at least 5 $ft^2$ per acre.

The state of the stand at decision time is defined by merchantable basal area, submerchantable basal area, number of trees per acre, overstory/midstory

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hardwood stocking, percent of ground covered with herbaceous vegetation, and overall quality of trees in the stand classes.

Stand Regeneration Needs

Another prime consideration are rules to determine the capability of the stand to regenerate naturally. Rules were developed to recognize regeneration needs in terms of availability of sound, vigorous seed trees and their quality and quantity available.

Example of the rules to accomplish this are:

*IF the number of small sawlog trees > 0,*
*and their corresponding basal area is at least 6 $ft^2$ per acre*
*THEN seed source is available; or*

*IF the number of medium sawlog trees > 0,*
*and their corresponding basal area is at least 6 $ft^2$ per acre*
*THEN seed source is available; or*

*IF the number of large sawlog trees > 0,*
*and their corresponding basal area is at least 6 $ft^2$ per acre*
*THEN seed source is available.*

These rules are mutually exclusive, i.e., only one needs to be satisfied to probe the hypothesis that seed source exists.

Hardwood Control

As noted earlier, hardwood control is critical to successful implementation of uneven-aged management of loblolly-shortleaf pine stands. Control is accomplished through mechanical, chemical, or manual means. The user selects

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the method. The specific rules used to infer if overstory and/or midstory hardwood control is needed are as follows:

| Condition | Category | Action |
| --- | --- | --- |
| IF Hardwood merchantable basal area is: | THEN Hardwood level is: | THEN: |
| Greater than or equal 20 $ft^2$/acre | Heavy | Immediate control |
| Greater than 5 but less than 20 $ft^2$/acre | Moderate | Postpone control |
| Less than 5 $ft^2$/acre | Light | No control needed |

Understory Vegetation Control Required

Rules to determine the need of vegetation control and also type, amount, and expediency of carrying out vegetation control were constructed. Studies show that hardwood removal hastens pine growth. In fact, it is one of the frequently-cited keys to success of uneven-aged management. The rules were constructed such that recommendations were made taking into account the dynamic relationship between pine and hardwood stands.

| Condition | Category |
| --- | --- |
| IF Pine Stems per acre (SPA) is: | THEN Pine understory level is: |
| Greater than or equal 250 | Heavy |
| Between 100 and 250 | Moderate |
| Less than 100 | Light |

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Similarly for understory hardwood,

| Condition | Category |
|---|---|
| IF Hardwood Stems per acre (SPA) is: | THEN Hardwood understory level is: |
| Greater than or equal 7000 | Heavy |
| Between 1000 and 7000 | Moderate |
| Less than 1000 | Light |

Consequently, inference rules for understory vegetation competition control are shown below.

| Condition | | Category |
|---|---|---|
| IF level of understory Pine/Hardwood is: | | THEN: |
| *Pine* | *Hardwood* | |
| light | light | No control |
| light | moderate | postpone control |
| light | heavy | immediate control |
| moderate | light | no control |
| moderate | moderate | no control |
| moderate | heavy | immediate control |
| heavy | light | no control |
| heavy | moderate | no control |
| heavy | heavy | no control |

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The second half of the recommendation, i.e., the method of control could have been chemical or manual depending on the financial status of the owner as well as his/her environmental convictions. The system does not recommend any particular method, but it does list some of the alternatives.

Understory Non-woody Vegetation Control

Control of vegetation other than hardwood, e.g., vines, grasses, honeysuckle, and other herbaceous vegetation, is also of prime importance. Control recommendation was based on the percent of ground covered with herbaceous vegetation. The rules are as follows:

| Conditions | Action |
|---|---|
| IF Percent of ground covered is: | THEN: |
| Greater than 75% | Immediate control |
| Between 25 and 75% | Postpone control |
| Less than 25 % | No control |

Economic Factors

Silvicultural decisions are intricately linked to economic considerations. While a number of them in reality influence decisions, only interest rates and stumpage prices were included in FOREX for their obvious direction and degree of influence. Other factors could readily be added.

There were no specific rules pertaining to these variables that were directly used as inference rules. They were asked from the user for completeness and to

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adjust prices and interest rates. Default values for both variables were provided in the system.

**Testing and Refinement**

For testing, refining, and evaluating a completed expert system, test cases provide examples of real-world problems. Weiss and Kulikowski (1984) proposed an empirical framework for refining knowledge-base rules using test cases. This framework assumes that there is a single, best answer for each case, a situation which is inconsistent with the view of stand diagnosis taken here.

Test Cases

Actual case records were obtained from Dr. James Baker of the USDA Forest Service, Southern Forest Experiment Station, at Monticello, Arkansas. These test cases were recorded in an arbitrary format. Data were often supplemented by follow-up interviews (via telephone) with the consultant/forester and/or actual visit to the property with the clientele. Such follow-up activities provided additional descriptive information about the stand.

The lack of many case studies necessitated the use of hypothetical cases. To minimize the possibility of using too unrealistic cases in the evaluation phase, these cases were created by Drs. Baker and Shelton and were used for testing and refinement as well as for system evaluation.

Test and Refine Cycle

Where a single, best answer to each test case is realistic and available, Weiss and Kulikowski's (1988) empirical approach to model revision may be

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appropriate. In their approach, a large number of test cases are evaluated by the expert system. The number of correct evaluations for each conclusion and the number of false positives (conclusion reached, but incorrect) for each conclusion are summarized. Generalizations are performed for incorrect evaluations, and specializations are performed for false positives. After generalizing, a conclusion becomes inferred more highly than previously, and therefore evaluated correctly in more cases. Specialization results in the inference of a conclusion less highly than previously, thereby reducing the number of cases where it has been inferred and should not be. Generalization and specialization were used in the system's refinement.

During the design of the expert system, a determination was made as to what constituted an appropriate prescription for stand problems. It seemed reasonable that, given a particular stand, single prescriptions, multiple prescriptions, or no prescriptions might be appropriate. This made the distinction between a correct prescription and a false positive uncertain. Due to the lack of test cases and their non-definitive prescription, this empirical technique was not considered a viable approach.

After using early versions of the expert system, Dr. Baker and Dr. Shelton provided useful comments and suggestions on the silvicultural realism of the prescriptions. It became necessary to make revisions to the rules used in the knowledge base as the results of their comments.

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**Design of FOREX**

This section provides a description of all the modules and demons in FOREX that make up the entire system. A conceptual design of FOREX is given in Figure 1.

Modules

Data Acquisition Module.

This module prompts the user for a description of the site, stand, objectives and relevant economic values. Through a data-input screen, the user could enter the standard stand descriptors asked for by the system, e.g., stand ID, location, site index, area, and year of last cut. The module also allows the user to interactively input stand table by combinations of DBH, species, and tree quality. Management and product-size objectives are also sought at this stage of the consultation. All information are asked of the user at the start of the session to avoid repetitive querying which might make user tiresome and the system unfriendly. Also in this module is a data-checking routine invoked after every user response is read. The purpose of the routine is to screen unwanted entries before they become part of the database or fact base so as to minimize errors. The data-input checker also estimates missing values where possible or asked the user for qualitative input rather than the previously requested quantitative input. For example, if site index is unknown, the system will ask the user to select from a menu [good, medium, poor]. Once data entry is complete, a procedure coded in Turbo Pascal is called to calculate the derived variables such as basal area by species and product class,

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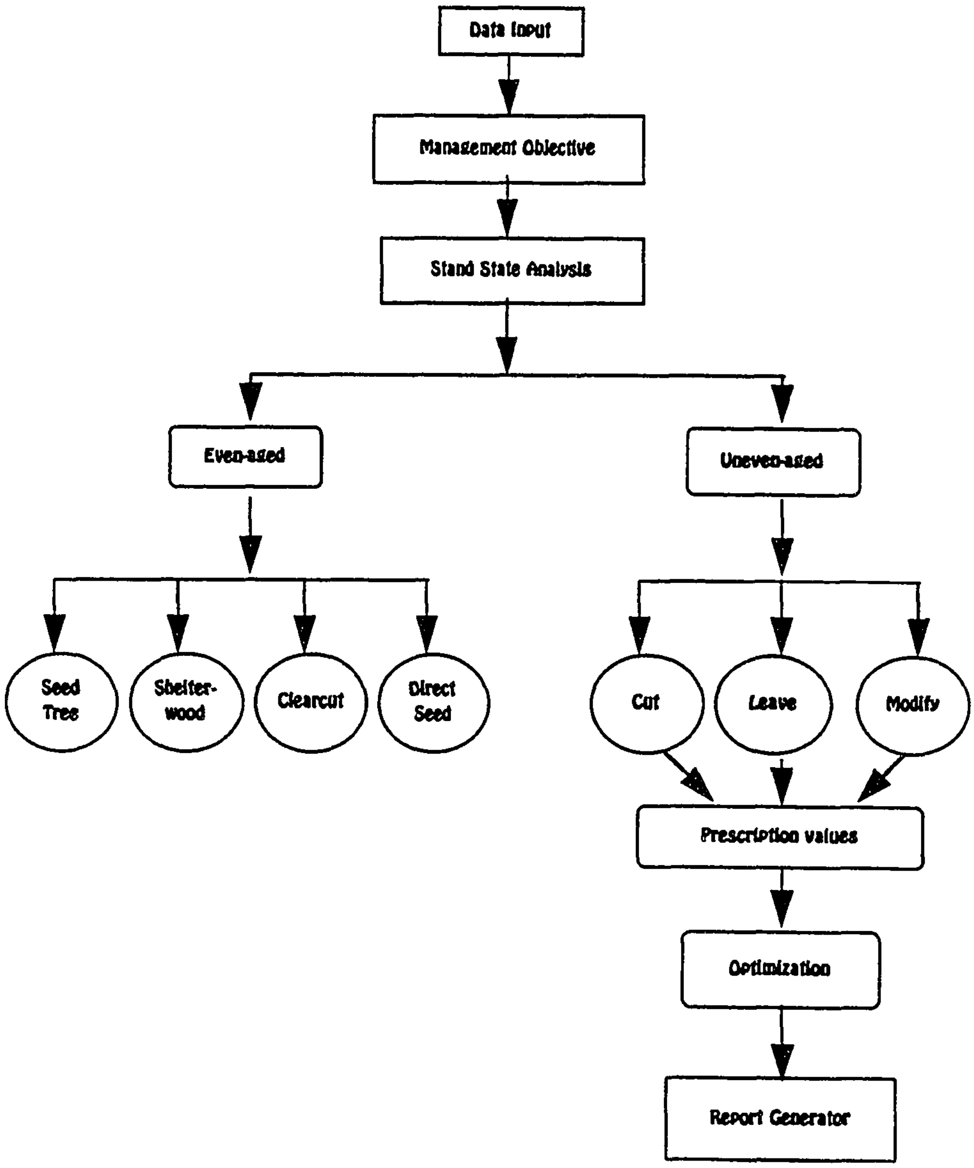


Figure 1. Conceptual design of FOREX

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percent stocking, volume, trees per acre, and others. All primary and derived variables are stored in an internal file to be available to other modules in the system.

Diagnostics Module

This module is responsible for classifying the stand attributes into qualitative categories which will influence the recommended prescription. Based on these classes, the overall condition of the stand is inferred. It is also the responsibility of this module to generate and present the user all possible alternative prescriptions from which the user makes a choice. This module consists of the following three types of rules.

Condition Rules. The purpose of these rules is to determine the current state of the site and stand. A list of these rules is given in Appendix A.

Management Rules. These rules help the user select the management type appropriate for the stand under present conditions. Appendix B contains the rules for selecting even-aged or uneven-aged management.

Treatment Rules. These rules serve to help the user select specific silvicultural treatment. Options include seed tree, shelterwood, clearcutting, harvest, leave or modify stand. Appendix C contains the list of these rules.

Optimization Module

This module had imbedded in it a growth and yield model (Murphy and Farrar 1988) to optimize the economic objective indicated by the user in the data acquisition module. The optimization problem is formulated as a nonlinear

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problem that is solved by a numerical technique combining Hooke and Jeeves' direct search and adaptive search methods to locate optimal values for decision variables.

Report Generator Module

This module reads the output of the optimization module and allows the user to display the output on screen, print it on a printer or file it. Outputs can also be graphically displayed on the screen.

Sensitivity Analysis Module

This module allows the user to determine the impact of varying product objective, residual growing stock, maximum DBH, cutting cycle length, stumpage values, and interest rates on the optimal solution.

Demons

Demons are external programs invoked by the KBS. Outputs of demons are used by the KBS to match values to any variable.

In this study, three kinds of demons were encoded, namely: one calculates and summarizes relevant stand values needed by the KBS (INIT), a growth and yield model which is embedded in an optimization routine (OPTIM), and one calculates a marking goal for both the current stand and projected stands (ALLOC). The link between the demons and the KBS is through internal files created by the demons and/or KBS as the case may be. A blackboard (a working memory shared by all demons and other system components) structure would have served the purpose more efficiently than the crude handling done in this study.

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PDC Prolog has no provision for the development of such a structure, and it would have required more time and money to develop or acquire one.

INIT. INIT accepts the stand table as input and calculates summary values for the stand, e.g., basal area, number of trees per acre, cubic-foot volume, board-foot volume, percent stocking, and average DBH by species, tree quality classes, and product/size classes. The output generated is stored in an internal file accessible to ProLog functions.

OPTIM. The primary purpose of OPTIM is to optimize a physical or an economic objective indicated by the user. The growth and yield model is a diameter distribution model based on the equations derived by Murphy and Farrar (1988). The model uses a doubly-truncated Weibull distribution to describe the stand structure. The optimization seeks for the values of trees per acre, and Weibull's scale and shape parameters, b and c, respectively, that optimize a physical or economic objective. The parameters b and c are determined using an algorithm combining the Hooke and Jeeves method (Hooke and Jeeves 1961) and a random search method. Both methods are derivative-free search algorithms. The subprograms in OPTIM are linked by either a physical or economic objective function. Low resolution flow charts for the combined search algorithms and OPTIM are given in Figures 2 and 3.

ALLOC. Embedded in OPTIM is a subroutine which implements harvest by allocating the allowable cut among tree quality classes according to the following cutting priorities:

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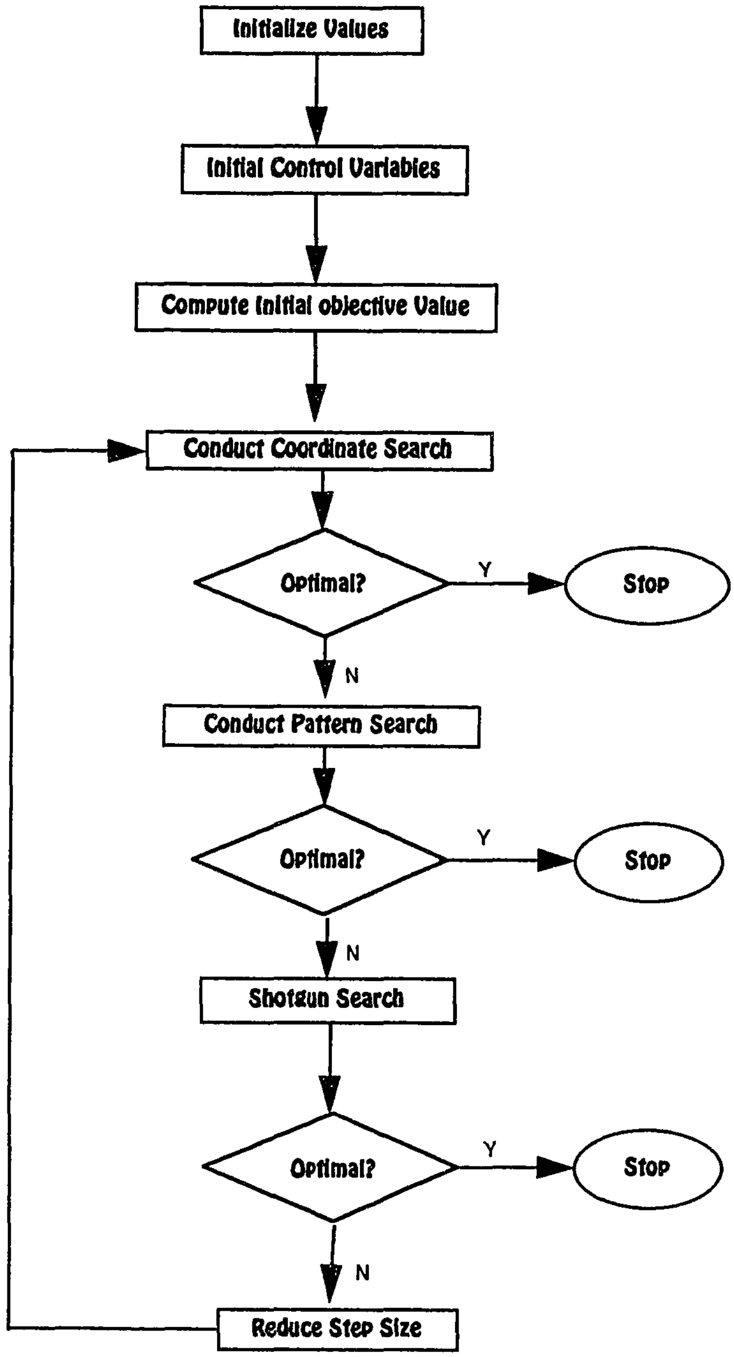


Figure 2. Low resolution flow chart for the combined Hooke and Jeeves and random search optimization methods

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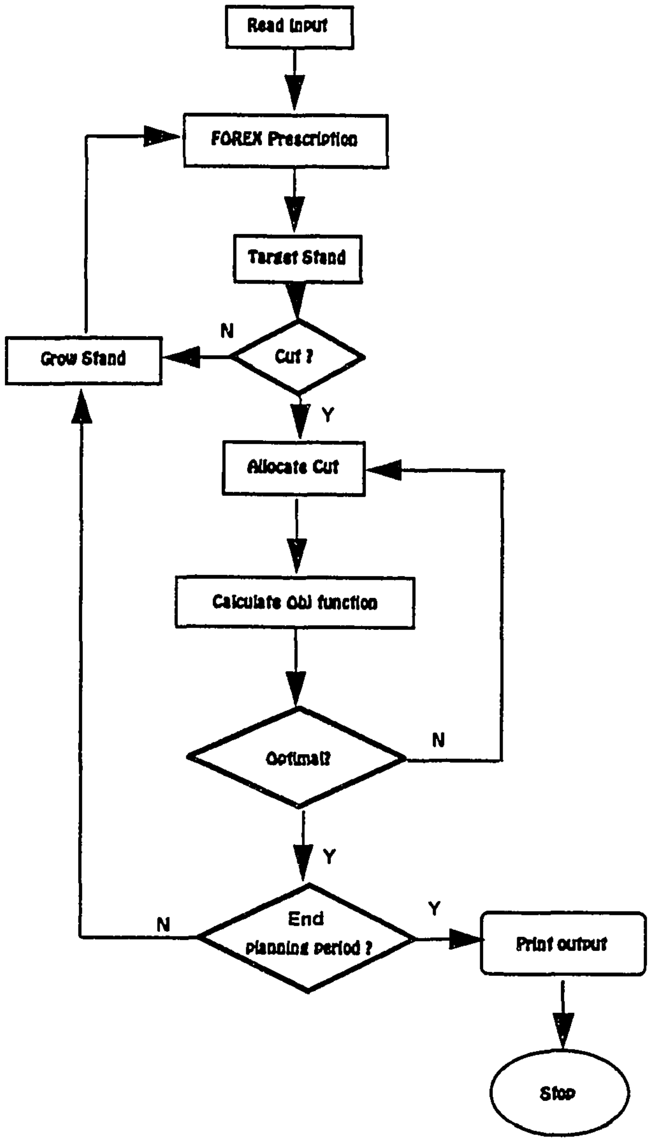


Figure 3. Flow chart illustrating the general structure of OPTIM

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| | |
|---|---|
| *First priority* | *Cutters* |
| *Second priority* | *Thinners* |
| *Third priority* | *Growers* |

## Hybrid FOREX (HFOREX)

Stand diagnosis and a silvicultural prescription based on heuristics were the major effort of this project. It seemed meaningful to see how each prescription would compare with an optimal solution obtained from a more complete search of the prescription space. To accomplish this, an optimization model was developed whose final output is stated in the same format as FOREX's output is provided.

HFOREX uses the same rules and knowledge base to provide values that define the solution space from which to search for the optimum. It also utilizes FOREX's data base from which to draw an equivalent prescription. The main difference between HFOREX and FOREX is that in HFOREX the recommendation is optimum after a complete search of the solution space defined by minimum and maximum values for residual growing stock, maximum DBH, and cutting cycle. These values are generated after searching the knowledge base.

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# Chapter 5

# CASE STUDIES

The basic components of guidelines for the management of uneven-aged stands include (1) specification of residual stocking levels appropriate for a range of management conditions, (2) identification of appropriate stand structure, i.e., the distribution of trees by DBH classes, (3) specification of largest residual DBH class, (4) specification of cutting cycle, and (5) specification of species composition. The few published management guides for uneven-aged management of loblolly-shortleaf pine stands have been developed by subjective extrapolation from years of limited field research. Part of this chapter is devoted to comparing the KBS's recommendations with those from published management guides proposed by Reynolds (1969). Several advantages of the KBS over printed guides in general are discussed. For illustrative purposes, prescriptions for two typical loblolly-shortleaf pine stands reflecting well-stocked and overstocked stands produced by the KBS are presented and described and subsequently compared with prescriptions recommended by Dr. Baker for similar stands.

## The Reynolds Management Guide

The stocking levels and size-class distribution recommended by Reynolds (1959) is summarized in Table 1. This stand structure and stocking guide were derived by Reynolds from almost three decades of field experimentation on the



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Table 1. Diameter distribution of an ideal uneven-aged stand before the cutting cycle, according to Reynolds (1959)

| DBH Class (inches) | Number of Trees (per acre) | Basal area ($ft^2$/acre) |
|---|---|---|
| 2 | 20 | 0.44 |
| 3 | 18 | 0.88 |
| 4 | 16 | 1.39 |
| 5 | 14 | 1.90 |
| 6 | 12 | 2.35 |
| 7 | 11 | 2.94 |
| 8 | 9 | 3.14 |
| 9 | 8 | 3.54 |
| 10 | 7 | 3.82 |
| 11 | 7 | 4.62 |
| 12 | 6 | 4.71 |
| 13 | 5 | 4.61 |
| 14 | 4 | 4.28 |
| 15 | 4 | 4.91 |
| 16 | 3 | 4.19 |
| 17 | 3 | 4.73 |
| 18 | 2 | 3.53 |
| 19 | 2 | 3.94 |
| 20 | 2 | 4.36 |
| 21 | 1 | 2.40 |
| 22 | 1 | 2.64 |
| 23 | 1 | 2.88 |
| 24 | 1 | 3.14 |
| Total | 157 | 75.34 |

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Crossett Experimental Forest in south Arkansas. The empirical distribution depicts the characteristic reversed J-shaped curve, with the number of trees diminishing in successive DBH classes.

The proposed guide requires 38 trees per acre (24%) of submerchantable sizes (DBH < 4 inches), 70 trees per acre (45%) of pulpwood sizes (DBH 4 to 9 inches), and 49 trees per acre (31%) of sawlog sizes (DBH ≥ 10 inches). Basal area stocking is distributed as follows:

| Product size | Basal area ($ft^2$/ac) | Percent |
|---|---|---|
| Sapling | 1.32 | 2 |
| Pulpwood | 15.26 | 20 |
| Sawlog | 58.76 | 78 |
| Total | 75.34 | 100 |

Moreover, the average ratio of number of trees per acre between successive 1-inch DBH classes is 1.2 (or 1.44 for 2-inch classes). In addition, Reynolds recommended the use of guiding diameter limit (GDL) regulation to implement uneven-aged management. Implementation of GDL regulation basically requires cutting single trees or groups all stems above a pre-determined diameter class which must be within about 20 inches.

**Other Management Guides**

Brender (1973) suggested a q factor of 1.3 applied to 2-inch diameter classes for Georgia Piedmont sites with an average site index of 77 feet. A theoretically ideal stand structure for an average stocking of 62.8 $ft^2$ per acre of

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basal area and a maximum diameter of 18 inches is given in Table 2. Diameter distributions should only serve as guidelines since they vary with product-class objective and stocking levels.

## Case Studies

The rest of this chapter is exclusively about two actual cases. One of the alternative prescriptions recommended by Dr. Baker (one of the experts for this project) is compared with the expert system's prescription.

Case 1: Optimal Management of a Well-stocked Even-aged Stand

The current stand table for an even-aged stand is summarized in Table 3.

Baker's recommendations

Dr. Baker identified and recommended for this stand the following alternative prescriptions:

1. An immediate reduction to 60 $ft^2$ per acre of basal area, or
2. A 2-stage reduction of basal area to 60 $ft^2$ per acre, i.e., immediately reduce to 75 $ft^2$ per acre; then make another cut to 60 $ft^2$ per acre in 2-3 years before the next cyclic cut.

For both prescriptions, a q-ratio of 1.44 (for 2-inch diameter classes) and maximum diameter of 22 inches were recommended.

System recommendations

Similarly, the expert system produced the following alternative prescriptions:

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Table 2. Diameter distribution of an ideal before-cut uneven-aged stand, according to Brender (1973)

| DBH Class (inches) | Number of Trees (per acre) | Basal area ($ft^2$/acre) |
|---|---|---|
| 6 | 27.80 | 5.46 |
| 8 | 21.39 | 7.47 |
| 10 | 16.45 | 8.97 |
| 12 | 12.65 | 9.94 |
| 14 | 9.73 | 10.41 |
| 16 | 7.49 | 10.45 |
| 18 | 5.76 | 10.18 |
| Total | 101.28 | 62.87 |

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Table 3. Stand table for Case 1: A well-stocked even-aged stand

| DBH Class (inches) | Number of Trees (per acre) | Basal area ($ft^2$/acre) |
|---|---|---|
| 2 | 0.20 | 0.00 |
| 4 | 1.50 | 0.13 |
| 6 | 6.40 | 1.26 |
| 8 | 9.20 | 3.21 |
| 10 | 10.40 | 5.67 |
| 12 | 11.20 | 8.80 |
| 14 | 13.20 | 14.11 |
| 16 | 10.80 | 15.08 |
| 18 | 9.20 | 16.26 |
| 20 | 6.40 | 13.96 |
| 22 | 3.00 | 7.92 |
| 24 | 2.80 | 8.80 |
| 26 | 0.50 | 1.84 |
| Total | 84.80 | 97.04 |

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1. Harvest and leave from 45 to 60 $ft^2$ per acre of basal area, or

2. Harvest in 2 steps to leave 60 $ft^2$ per acre.

For both prescriptions, a maximum diameter of 16 inches was recommended. Q-ratio was not a direct output of the expert system; however, it could be calculated from the target stand found optimal by the expert system under existing circumstances. For this case, q-ratio was 1.3 if the objective is to maximize PNV or 1.7 if the objective is to maximize cubic-foot harvest.

Comparisons

Compared in this section are the efficiencies of alternative prescriptions that are computed with two maximization criteria: present net value and merchantable cubic-foot volume harvest. The problem formulations were the same for all management objectives. The objective was to find the best sequence of selection harvests on a 5-year cycle during a 25-year horizon.

Maximizing Cubic-foot Volume

With the cubic-foot volume objective, there were no production costs, stumpage price was effectively $1 per cubic-foot, and the discount rate was zero. The minimum merchantable tree size was 4 inches in DBH, and merchantable tree volumes were measured with a 3.5 inch minimum top diameter.

Figure 4 illustrates graphically Dr. Baker's and the system's initial prescription (at year 0). Both prescriptions recommended immediate reduction of basal area to 60 $ft^2$ per acre. However, Dr. Baker recommended a 22-inch Dmax and a q-ratio of 1.44 whereas the expert system recommended 18-inch

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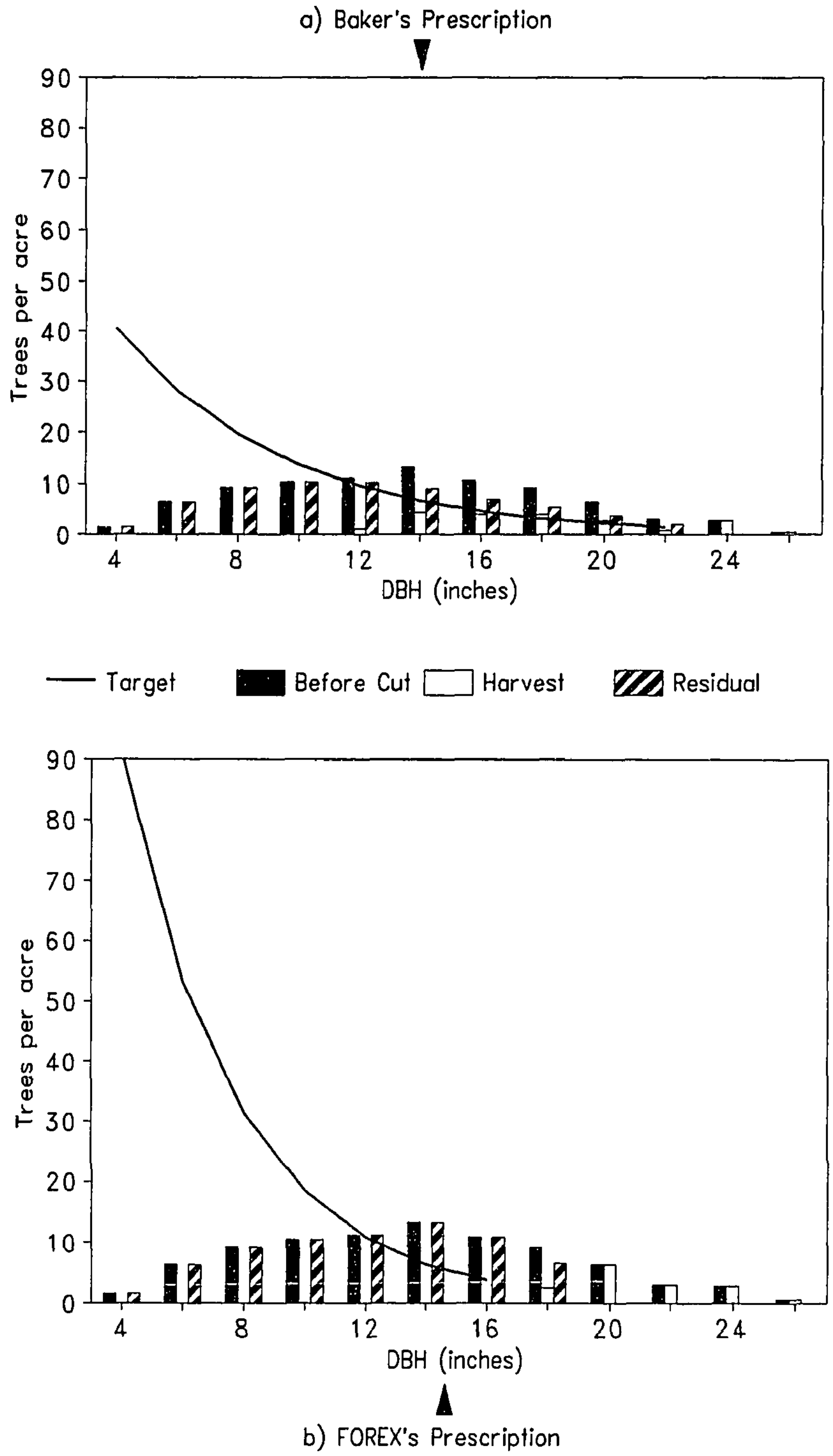


Figure 4. Initial stand conditions and harvest for Case 1

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Dmax and 1.70 q-ratio. Although both prescriptions involved the same amount of cut, the former left more of the bigger trees (i.e., less board-foot harvest), the latter left more of the smaller trees (i.e., higher board-foot harvest). Moreover, both prescriptions gave rise to a typical even-aged stand.

Maximizing Present Net Value (PNV)

With a PNV objective, optimal regime was computed using economic parameters that represented the 10-year average market conditions -- $170 per MBF, $15 per cord of pine sawlog and pulpwood, respectively. Costs involved $5/acre/year for administrative cost, $17/acre for costs of marking trees for harvesting, and $4.11/acre for timber cruising. Additional assumptions included a real discount rate of 7%, and that the discount rate, prices and costs were assumed to be constant over the planning horizon. Finally, the same merchantability limits indicated above apply here.

Dr. Baker's prescription produced an initial harvest of over 5.7 MBF/acre and an equivalent PNV of $944. In contrast, with the system's prescription, harvest volumes could range between 1.6 and 2.1 MBF/acre. The PNV per cutting cycle of the 25-year regime ranged from $1307.32 per acre at year 0 to $24.43 per acre at year 25. The management strategy involved an immediate harvest of trees above 18 inches dbh. During the first 10 years, the management strategy was to cut a portion of trees between 12 and 14 inches in diameter. In years 15 and beyond, optimal harvesting approached a steady state with harvesting from above removing all trees above 18 inches in diameter and a portion of trees

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between 12 and 16 inches in diameter, thereby controlling the number of younger trees.

Case 2: Optimal Management of an Overstocked Uneven-aged Stand

The current stand table for an overstocked uneven-aged stand is summarized in Table 4.

Baker's recommendations

Dr. Baker recommended for this stand the following alternative prescriptions:

1. An immediate reduction to 60 $ft^2$ per acre of basal area, or
2. A 2-stage reduction of basal area to 60 $ft^2$ per acre, i.e., immediately reduce to 75 $ft^2$ per acre then make another cut to 60 $ft^2$ per acre before the next cyclic cut (2-3 years).

For both prescriptions, a q-ratio of 1.2 and a maximum diameter of 22 inches were recommended.

System recommendations

The expert system produced the following alternative prescriptions:

1. Harvest and leave from 45 to 60 $ft^2$ per acre of basal area, or
2. Harvest in 2 steps to leave 60 $ft^2$ per acre.

For both prescriptions, a maximum diameter of 16 inches was recommended and a q-ratio between 1.3 (to maximize PNV) and 1.5 (to maximize cubic-foot harvest).

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Table 4. Stand table for Case 2: An overstocked uneven-aged stand.

| DBH Class (inches) | Number of Trees (per acre) | Basal area ($ft^2$/acre) |
|---|---|---|
| 5 | 5.40 | 0.74 |
| 6 | 33.50 | 6.58 |
| 7 | 34.20 | 9.14 |
| 8 | 30.40 | 10.61 |
| 9 | 23.50 | 10.38 |
| 10 | 13.10 | 7.14 |
| 11 | 14.20 | 9.37 |
| 12 | 6.20 | 4.87 |
| 13 | 7.70 | 7.10 |
| 14 | 5.00 | 5.35 |
| 15 | 4.60 | 5.65 |
| 16 | 4.60 | 6.42 |
| 17 | 3.50 | 5.52 |
| 18 | 1.90 | 3.36 |
| 19 | 0.80 | 1.58 |
| 20 | 0.40 | 0.87 |
| Total | 189.00 | 94.67 |

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Comparisons

As in case 1, efficiencies of prescriptions computed with the present net value criterion and the merchantable volume criterion were compared. The problem formulations were the same for all management objectives. Again, the objective was to find the best sequence of selection harvests on a 5-year cycle during a 25-year horizon. Assumptions pertaining to merchantability limits, stumpage prices, costs, and other economic variables were as defined in case 1.

Maximizing Cubic-foot Volume

Figure 5 illustrates Dr. Baker's and the system's initial prescription (at year 0). Both prescriptions recommended immediate reduction of basal area to 60 $ft^2$ per acre. However, Dr. Baker recommended a 24-inch maximum DBH and a q-ratio of 1.20 whereas FOREX recommended a 20-inch maximum DBH and a 1.50 q-ratio. Although both prescriptions involved the same amount of cut, the former involved cutting more from the smaller size classes and leaving more bigger trees in the residual stand.

Maximizing Present Net Value

Dr. Baker's prescription generated an initial harvest of 1.5 MBF/acre, about 5 cords of pulpwood, and an equivalent PNV of $302. In contrast, with the system's prescription, harvest volumes could range between 1.9 and 2.2 MBF/acre. The PNV per cutting cycle of the 25-year regime ranged from $1307.32 per acre at year 0 to $24.43 per acre at year 25. The management strategy involved an immediate harvest of trees above 20 inches dbh. During the first cut, the

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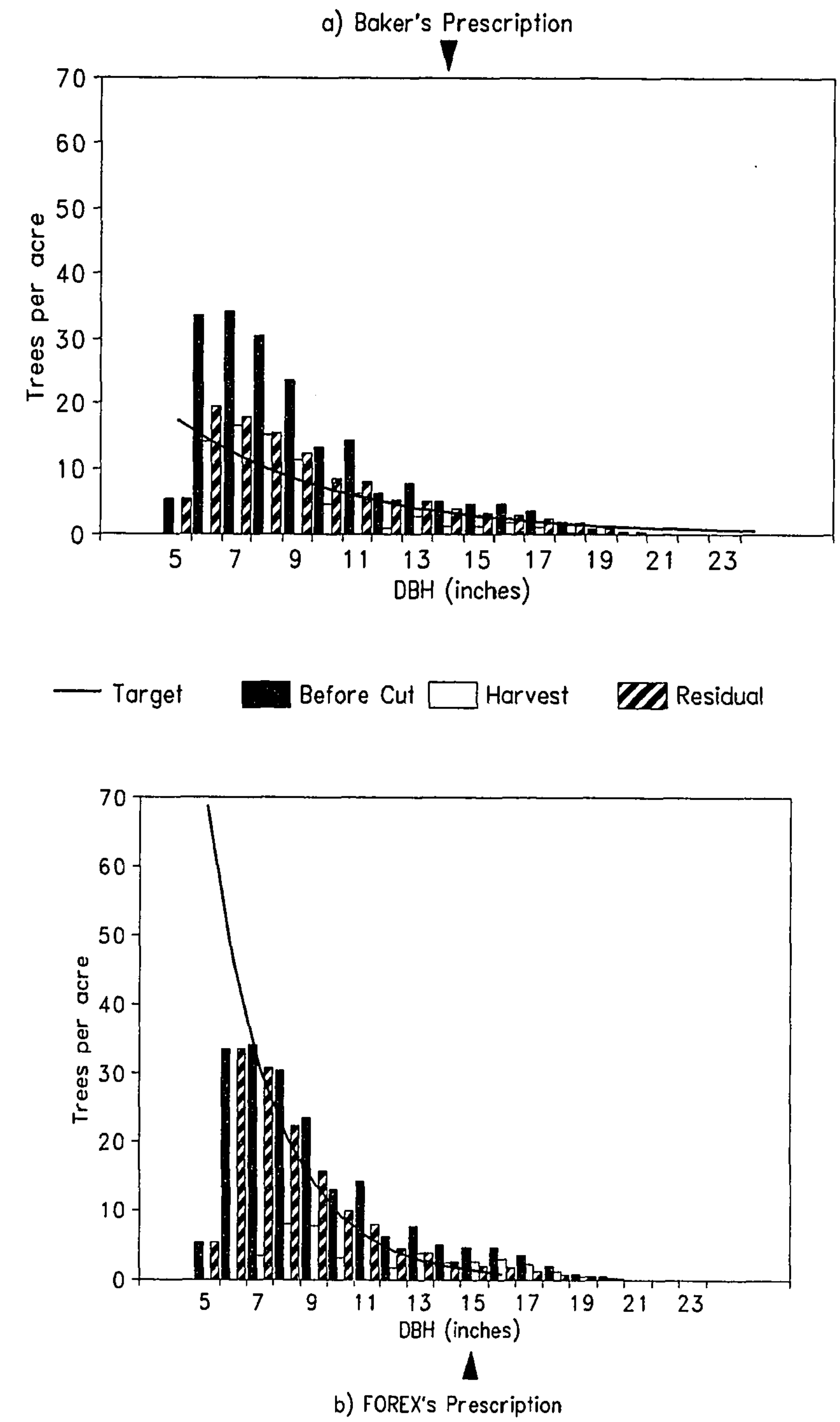


Figure 5. Initial stand conditions and harvest for Case 2

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management strategy was to cut a portion of trees across all DBH classes. After year 5, optimal harvesting approached a steady state by removing all trees above 20 inches in diameter and some of the trees between 7 and 20 inches in diameter, thereby controlling the number of younger trees. This strategy generated harvest volumes ranging from 1.9 to 2.2 MBF per acre. PNV per cutting cycle of the 25-year regime ranged from $42/acre to $471/acre.

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# Chapter 6

# EXPERT SYSTEM EVALUATION

Some method of evaluation was necessary to determine the extent to which the knowledge of the experts had been captured and to determine if one of the prescriptions is preferred over the others. The tests and methods of comparison used in the evaluation of the expert system model are discussed in this chapter.

## Experimental Design

As noted previously, available test cases were scarce and did not have definitive prescriptions. It seemed more appropriate under this circumstance to evaluate the performance of the expert system by means of human evaluators. The method used provided evaluators the opportunity to form their respective opinion concerning each test case, and then assess the prescriptions produced by the expert system.

A drawback of the above design is that evaluator bias might have occurred and the final evaluation scores would not reflect the performance of the expert system in a meaningful way. This shortcoming was avoided by mixing prescriptions from the expert system with those from "testers". Human testers, different from the experts who helped built the system, were asked to examine and produce prescriptions for the test cases just as the expert system. All prescriptions from the testers and the computer models were randomized and presented to the evaluators without revealing the source of each prescription.



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Keeping the evaluators "blind" required making each prescription indistinguishable from any others. To accomplish this, each tester was provided with a list of guidelines for writing prescriptions as well as examples of output produced by the expert system. However, several of the prescriptions did not follow the desired format and thus created inconsistencies. After they were reviewed, these prescriptions were rewritten following the format used in the expert system. The rewritten prescriptions were then sent back to respective testers to confirm that the intent of the original prescriptions was maintained. Finally, prescriptions for each test case then were randomly numbered before being sent to the evaluators.

A total of five testers were selected initially; they represented a broad range of academic background, training and experience in uneven-aged management. A brief description of their backgrounds is presented in Appendix D. Two research foresters, two industrial foresters, and one consulting forester were the testers. For each test case, the testers were provided with information identical to the input needed by the expert system. Each tester was asked to recommend for each test case a prescription indicating (1) the values of primary decision variables (i.e., residual growing stock, largest residual tree size, and cutting cycle), (2) cut or leave decision, (3) hardwood control, (4) understory-vegetation control, and (5) components of the initial cut/marking goal.

After some discussion with the experts and consultation with a statistician, We decided that a maximum of 25 test cases would be reasonable. Because of the

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range of expertise among the testers, the test cases were selected accordingly. Some cases were intentionally easy to diagnose, others were vague and a definitive prescription difficult to identify. Also, an attempt was made to include many of the most common situations. The experimental results would then provide a certain amount of real-world applicability.

The conduct of the experiment was as follows. Ten of the test cases were obtained from Dr. Baker's file. Fifteen were selected from those generated arbitrarily but were not used in the testing and refinement phase. Details of each test case as given to the testers are presented in Appendix F. The testers completed their prescriptions for all 25 cases without any consultation among them. After their responses were returned and reviewed, all responses from one of the five testers were incomplete and therefore not included in the evaluation.

Prescriptions from the remaining four testers were coded as H1, H2, H3, and H4; prescriptions from the expert system (FOREX) were called E1a, E1b, and E1c; and the prescription from the hybrid model (HFOREX) was labeled E2. The expert system generated and reported all possible prescriptions for each test case. As a result, each test case had at least two prescriptions. The first prescription (E1a) corresponded with the range of possible values for the decision variables of a prescription. The second prescription (E1b) was the prescription which the experts were likely to recommend under normal circumstances. To illustrate the difference between E1a and E1b, consider the following examples:

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1. A well-stocked stand with 45 $ft^2$ per acre of basal area.

   E1a: *"To leave the stand from 5 to 10 years"*,

   E1b: *"To leave the stand for 10 years"*.

2. A well-stocked stand with 60 $ft^2$ per acre of basal area.

   E1a: *"To harvest and leave residual stand 45 $ft^2$ per acre of basal area"*.

   E1b: *"To leave the stand for 5 years"*.

The third prescription (E1c), in contrast, was only produced under extreme circumstances, such as when the current stand was heavily overstocked (i.e., greater than 90 $ft^2$ per acre of basal area) or when the stand was well-stocked so that both cut and leave options were possible. Only six of the test cases had E1c prescription options.

Each prescription explicitly indicated the following values and/or treatments, namely, (1) cut or leave decision; (2) recommended residual growing stock; (3) maximum DBH class in the residual stand; (4) cutting-cycle length; (5) hardwood control treatment; and (6) treatment for understory vegetation control. All prescriptions were then randomly numbered (from 1 to 8) before they were sent to the nine evaluators who were asked to examine each test case before reviewing the prescriptions. A brief description of the background training and experience of each of these evaluators is presented in Appendix E. The evaluators then rated each prescription for each test case. A 5-point scale ( 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree) evaluation was used to assign numeric scores to each prescription for each test

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case. The scores were expected to reflect the agreement or disagreement of the evaluators with the completeness, appropriateness, and reasonableness of the decision variables and activities contained in each prescription.

Appendix F contains the information about the 25 test cases given to the testers. Highlights of the prescriptions provided by each tester and computer-based experts for each test case are recorded in Appendix G. Results of the evaluations (score cards) by each evaluator are recorded in Appendix H. These results are summarized in Table 5 which contains the mean score for each prescription in each test case. In addition, Figure 6 illustrates graphically the overall relative performance of the prescriptions. The box plot represents the $25^{th}$ and $75^{th}$ percentiles. The horizontal broken and solid lines in the box represent the mean and median, respectively. The vertical lines represent 1.5 of the distance between the $25^{th}$ and $75^{th}$ percentiles. Any value more extreme than this is marked with a filled circle. Preliminary analysis of the scores indicated violation of normality assumption. However, since the sample size was "sufficiently large" (with 9 evaluators dealing with 8 prescriptions for each of the 25 cases, totaling 1629 observations), the Central Limit Theorem states that the mean is normally distributed (Hogg and Tanis 1987). In addition, the variable of interest was discrete and each possible score (1 to 5) is relatively well represented. For these reasons, there is strong justification for the use of analysis of variance. Furthermore, it appeared that evaluator number six could not agree with any

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Table 5. Mean scores of each prescription (1 = Strongly Disagree; 5 = Strongly Agree). H1 - H4 are from testers, E1a - E1c from FOREX, E2 from HFOREX.

| | Prescription | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Case# | H1 | H2 | H3 | H4 | E1a | E1b | E1c | E2 |
| 1 | 3.11 | 4.11 | 3.33 | 3.11 | 3.11 | 3.11 | - | 2.78 |
| 2 | 3.33 | 3.33 | 3.89 | 1.22 | 2.89 | 2.89 | - | 2.67 |
| 3 | 1.78 | 2.78 | 2.11 | 2.11 | 2.78 | 2.11 | - | 2.89 |
| 4 | 3.22 | 1.22 | 2.89 | 3.11 | 3.44 | 2.44 | - | 2.56 |
| 5 | 4.67 | 1.22 | 3.56 | 2.89 | 2.56 | 3.00 | 3.44 | 2.44 |
| 6 | 2.89 | 3.00 | 2.00 | 2.78 | 1.67 | 1.67 | - | 1.67 |
| 7 | 2.56 | 1.44 | 1.78 | 2.33 | 3.22 | 2.33 | - | 2.56 |
| 8 | 2.33 | 1.33 | 2.00 | 2.89 | 2.56 | 2.22 | - | 1.89 |
| 9 | 3.11 | 1.33 | 2.78 | 1.78 | 3.22 | 3.11 | - | 2.67 |
| 10 | 3.56 | 2.00 | 3.11 | 3.67 | 3.22 | 3.33 | 3.22 | 3.00 |
| 11 | 3.78 | 1.67 | 3.78 | 3.44 | 3.11 | 2.78 | - | 2.56 |
| 12 | 3.33 | 2.00 | 4.11 | 3.22 | 2.44 | 2.89 | 3.11 | 2.44 |
| 13 | 3.67 | 1.67 | 3.67 | 2.67 | 3.22 | 3.56 | - | 3.11 |
| 14 | 2.11 | 1.11 | 2.67 | 1.67 | 2.44 | 2.44 | - | 2.44 |
| 15 | 3.33 | 1.22 | 4.00 | 2.89 | 3.33 | 2.89 | - | 3.00 |
| 16 | 3.22 | 2.33 | 3.11 | 4.56 | 3.22 | 3.44 | - | 2.56 |
| 17 | 3.33 | 2.56 | 3.67 | 1.56 | 3.11 | 2.78 | - | 2.22 |
| 18 | 3.67 | 1.89 | 3.56 | 2.89 | 3.11 | 3.22 | - | 3.11 |
| 19 | 3.22 | 1.89 | 4.44 | 1.89 | 3.00 | 3.00 | - | 1.78 |
| 20 | 3.22 | 1.56 | 3.89 | 3.44 | 2.67 | 2.56 | - | 3.56 |
| 21 | 4.00 | 2.00 | 4.67 | 1.56 | 3.11 | 3.89 | 4.22 | 3.11 |
| 22 | 3.78 | 1.78 | 3.78 | 3.44 | 3.56 | 3.22 | 2.89 | 3.33 |
| 23 | 3.89 | 2.11 | 3.22 | 3.33 | 3.56 | 4.00 | - | 2.56 |
| 24 | 3.56 | 2.22 | 4.11 | 2.44 | 3.11 | 4.22 | - | 2.44 |
| 25 | 4.00 | 1.56 | 4.11 | 2.44 | 3.11 | 4.00 | 3.11 | 2.33 |
| Mean | 3.31 | 1.97 | 3.37 | 2.69 | 2.99 | 3.00 | 3.33 | 2.63 |

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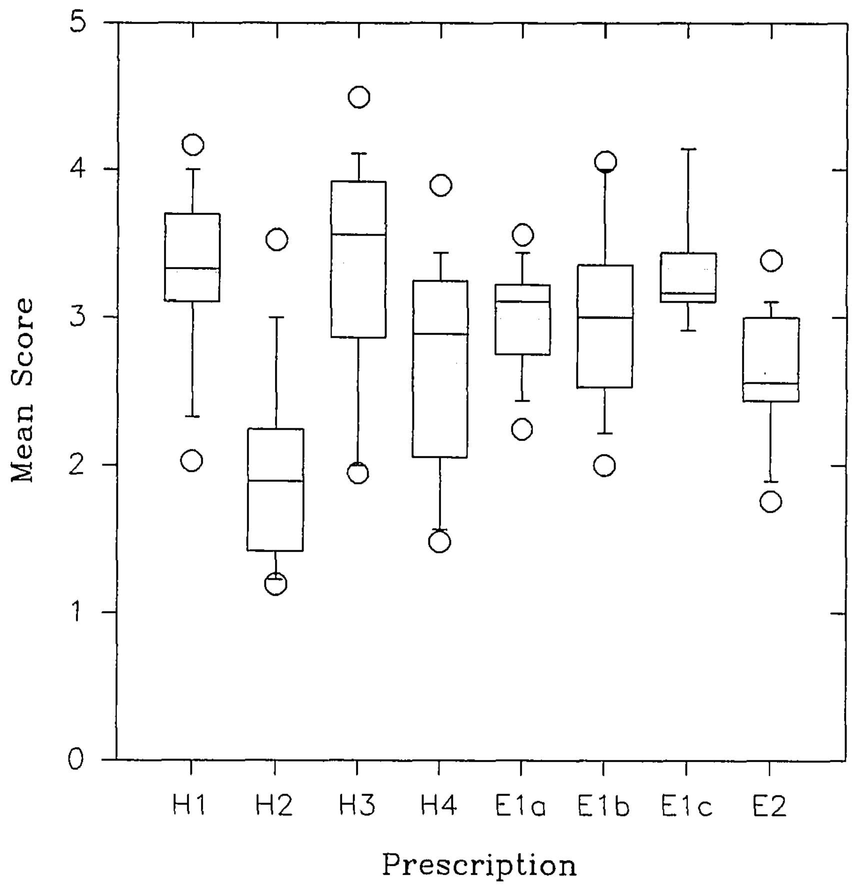


Figure 6. Mean scores by prescription ( The horizontal broken and solid lines in the box represent the mean and median, respectively. The vertical lines represent 1.5 of the distance between the 25th and 75th percentiles. Values more extreme than this are marked with circles).

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of the prescriptions for most of the test cases and his scores were consistently lower than the rest. Since excluding this evaluator did not significantly influence the outcome of the analysis, his evaluation was still included in all hypothesis testing. Also, because prescription E1c was present in only six test cases, overall test did not include this prescription. It was however, included in testing hypothesis 4.

## Hypothesis Testing

The following hypotheses of the experiment described were tested:

Hypothesis 1: All means are equal.

Hypothesis 2: Computer-based prescriptions are as equally preferred as human prescriptions.

Hypothesis 3: All means of the human prescriptions are equal.

Hypothesis 4: All means of FOREX prescriptions are equal.

Hypothesis 5: All means of computer-based prescriptions are equal.

All tests were made at the 0.05 level. In addition, the REGWQ (Ryan) test of multiple comparison was used because it was shown to be more powerful than Tukey's Honestly Significant Difference (HSD) test (Toothaker 1993; Ji and Wozniak 1993).

Hypothesis 1: All means are equal.

The 25 test cases were allocated among stand types as follows: 11 understocked, 6 fully-stocked, and 8 overstocked.

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| Type of Stands | Prescription | | | | | | | p-level |
|---|---|---|---|---|---|---|---|---|
| Understocked | H3 | H1 | E1a | E2 | E1b | H4 | H2 | 0.22 |
| Mean Scores | 2.91 | 2.86 | 2.82 | 2.66 | 2.60 | 2.46 | 2.10 | |
| Fully-Stocked | H3 | H1 | E1b | E1a | E2 | H4 | H2 | 0.28 |
| Mean Scores | 3.89 | 3.59 | 3.30 | 3.20 | 2.76 | 2.46 | 1.98 | |
| Overstocked | H1 | H3 | E1b | H4 | E1a | E2 | H2 | 0.22 |
| Mean Scores | 3.71 | 3.61 | 3.35 | 3.18 | 3.07 | 2.49 | 1.79 | |
| All stands | H3 | H1 | E1b | E1a | H4 | E2 | H2 | 0.43 |
| Mean Scores | 3.37 | 3.30 | 3.00 | 2.99 | 2.69 | 2.63 | 1.97 | |

There are no significant differences among the prescriptions. However, overall, prescriptions from two human testers (H1 and H3) scored high in all cases. Prescriptions from FOREX, on the other hand, were consistently in the middle with scores higher than the remaining two human testers (H2 and H4) in all cases and higher than HFOREX in fully-stocked and overstocked stands.

Paired comparisons in each stand type showed the following results. In the understocked stands, H2 was significantly different from H3, H1, E1a, and E2. In fully-stocked stands, significant differences were detected between H2 and other prescriptions except H4, and between H3 and other prescriptions except H1. Furthermore, H1 was significantly different from E2, H4, and H2. In overstocked stands, H2 and E2 were significantly different from all other prescriptions.

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Hypothesis 2: Computer-based prescriptions are as equally preferred as human prescriptions.

| Type of Stands | Expert System | Human Testers | p-level |
|---|---|---|---|
| | ------------ Mean Score ----------- | | |
| Understocked | 2.71 | 2.58 | 0.2056 |
| Fully-stocked | 3.25 | 2.98 | 0.0153 |
| Overstocked | 3.21 | 3.07 | 0.1610 |
| All stands | 3.00 | 2.84 | 0.0034 |

Prescriptions provided by the testers and those generated from the FOREX were significantly different. Overall, prescriptions from the expert system were preferred by evaluators to those from the testers.

This result was reflected differently among the stand types. Prescriptions from testers scored significantly lower than those from the expert system's in fully-stocked stands. In both understocked and overstocked stands, the mean scores of prescriptions from FOREX were also higher than those from human testers, even though the difference was not significant at the 0.05 level.

Hypothesis 3: All means of the human prescriptions are equal.

Prescriptions provided by the four testers were significantly different (p = 0.0001). Prescription 3 (H3) was most favored, while prescription 2 (H2) was least favored. Ryan's multiple comparison test showed the following results:

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| | | | | |
|---|---|---|---|---|
| Prescription: | H3 | H1 | H4 | H2 |
| Mean score : | 3.37 | 3.31 | 2.70 | 1.97 |
| RegWq : | ———— | | —— | —— |

Mean scores of prescriptions from the research foresters (H1 and H3) were close and were significantly higher than those of prescriptions from the industrial foresters (H2 and H4). This result was expected since both research foresters have substantial experience in uneven-aged management as compared to the two industrial foresters.

Hypothesis 4: All means of FOREX prescriptions are equal.

The three prescriptions generated from the expert system were not statistically different ($p = 0.69$). However, in stands where all three prescriptions were generated, prescription 7 (E1c) was most favored with a least-squared mean score of 3.14 and prescription 6 (E1b) was least favored with a least-squared mean score of 2.99. Paired comparisons of least-squared means of the prescriptions showed that all means were not significantly different. In stands where only two prescriptions exist, prescriptions 5 (E1a) and 6 (E1b) were not significantly different.

Hypothesis 5: All means of computer-based prescriptions are equal.

Prescriptions generated from both computer models were statistically different ($p = 0.001$). FOREX with an overall mean score of 3.00 was more favored than HFOREX with a mean score of 2.63. Prescriptions from both

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models were significantly different in well-stocked stands ($p = 0.0018$) and in overstocked stands ($p = 0.0001$) but not in understocked stands ( $p = 0.70$).

The effect of stocking level reflects the type of solution generated by both models. FOREX tends to prescribe at the higher end of the spectrum, such as higher residual basal area. In contrast, it is not uncommon for optimization models like HFOREX to find optimal solution at the lower end of the range. The difference is particularly pronounced in well-stocked and overstocked stands. For example, consider a well-stocked stand with at least 60 $ft^2$/acre of basal area. FOREX will recommend growing the stand to 75 $ft^2$/acre stocking whereas HFOREX will likely recommend cutting the stand to at least 45 $ft^2$/acre of residual basal area. Prescriptions from FOREX and HFOREX tend to be more similar with understocked stands because both will likely recommend leaving the stand to grow to a more desirable stocking.

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# Chapter 7

# DISCUSSIONS

This chapter is separated into discussions of certain aspects of the design and development of the expert system, of the results of the case studies, and of the results of the evaluation process.

## Design and Development of the Expert System

The decision to design and program a customized expert system involved certain trade-offs. In addition to the time and effort required to develop the knowledge base, substantial programming effort was also required to develop a knowledge representation scheme, a knowledge acquisition program, user interface, and the inference engine. In contrast, use of an "expert system shell" would have allowed more time spent on constructing the knowledge base and testing and refining the completed expert system. This advantage, however, would be possible at the expense of reduced system flexibility. Most development tools allow little or no choice for knowledge representation, control strategy, uncertainty handling, and explanation facilities. The developer is locked into the methods selected by the development tool designers.

The performance of the expert system reflected in the results of the evaluation tests does not only indicate the extent to which the knowledge of human experts had been captured but also the effectiveness of combining frame-like and rules structures in representing knowledge. Because of the lack of direct



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frame implementation in PDC ProLog, use of ProLog's list structures appears to have served the purpose despite drawbacks associated with ProLog's inadequate provision for list-surgery operations noted by Cuadrado and Cuadrado (1991).

Since the power of expert systems is in the knowledge, building one with multiple experts resulted in a more comprehensive system than what might have been developed with just one expert like most expert systems are developed. An unstructured interview coupled with brain-storming sessions with carefully selected experts seems to be an effective technique for extracting expert knowledge, particularly when several experts are involved.

**Case Studies**

The two case studies presented in Chapter 5 are included to show how prescriptions produced by the expert system compare with those of a human expert's. All alternative prescriptions identified by both the expert system and human expert were essentially similar. However, they differed in the specific values of decision variables -- q ratio and maximum tree size to leave in the residual stand. Dr. Baker's recommended values for these variables are driven more by biological and silvicultural considerations and seem more conservative. The expert system, in contrast, is more objective and values found are more sensitive to the economic objective selected by the user. This is particularly true with the q ratio. A lower q value results in a flatter curve, indicating a more even distribution of trees among diameter classes. With respect to maximum residual diameter class, Dr. Baker prescribed leaving bigger trees than the expert system

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in both cases. The difference is that with the expert system, product size objective is not only defined but also explicitly selected by the user. Dr. Baker in contrast assigned a more conservative size on the higher end of the range.

**Evaluation Process**

The evaluators' inability to distinguish the prescriptions generated by the expert system from the prescriptions provided by the test experts served as a cursory Turing test of the expert system. Despite apparent weaknesses of the expert system, prescriptions generated by the system were rated significantly better than those of either industrial foresters and were preferred as well as the prescriptions from the research foresters. Differences between the research foresters and industrial foresters were also striking. The expert system's poor performance in understocked stands indicates that some revisions need to be made. Several of the rules should probably be reconstructed to make them more generalized.

One of the primary concerns during development of the expert system was minimization of errors. This partly explains the listing of all potential alternative prescriptions. It is the end-user who will make that final decision, and the role of the consultant is to provide complete and comprehensive information for that decision. Consequently, a single best answer would not suffice in most circumstances.

Based on the limited set of test cases used in the experiment, the expert system's performance is comparable to that of human experts. Relevant statistics

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also suggest that the system might be more capable than a forester trained in forest management. The consistent results produced by the evaluators suggest the existence of heuristic knowledge, and it has been successfully captured in a computer program.

For the first two test cases, the expert system recognized and prescribed even-aged management like all testers; however, testers preferred irregular shelterwood to seed tree or regular shelterwood favored by FOREX. Prescriptions from the human testers obtained higher scores than those from either computer-based model. For the remaining 23 cases, prescriptions produced by the expert system had a poorer showing than those by either research forester, but were consistently preferred to those by industrial foresters and the other computer-based model (HFOREX).

HFOREX spends more computer processing time in a complete search of the solution space, but still produced prescriptions that scored lower than those from FOREX. The consistent poorer performance of HFOREX compared with FOREX in all cases might be attributed to the growth and yield model and/or the search algorithm used. The growth and yield model has inherent shortcomings such as the lack of explicit mortality and regeneration functions. On the other hand, the combined Hooke and Jeeves and random search algorithms do not always guarantee an optimal solution. These observations imply that components of hybrid systems like HFOREX should be as effective as the knowledge base they complement for the system to function well.

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## Benefit-Costs Issues

The completed system offers the following benefits: (1) provides timely, reliable, and consistent silvicultural recommendations with reduced potential error rate, (2) increases the quality of recommendations since the system integrates the knowledge and expertise of several carefully selected experts, and (3) serves as a stable repository of relevant information. The current information contained in the knowledge base reflects a collection of relatively stable information which has been used for years and has stood the test of time. However, as new knowledge/information becomes available from the continuing research in uneven-aged management, the system provides a flexible conduit for storing, updating, and disseminating such information to a wider and diversified audience.

The cost of building a system such as FOREX is largely attributed to the time and effort expended in building the knowledge base. Other initial costs include acquiring the appropriate computer hardware to house the system, cost of training potential users, and maintenance costs. Because there are not enough foresters well-trained in uneven-aged management, human experts and consulting foresters command a high price. FOREX provides a low-cost means for capturing scarce expertise that would otherwise be lost or become obsolete.

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## Chapter 8

## SUMMARY AND CONCLUSIONS

Expert system technology has been applied to evaluate and prescribe silvicultural alternatives. This study has demonstrated that the approach can be used for forestry applications. The expert system was designed and developed with non-industrial private landowners in mind; however, exactly how this expert system will be used and by whom remains unclear.

Performance evaluations were made between the expert system and four human testers. The expert system compared reasonably well with the research foresters and was ranked better than the industrial foresters.

From the results obtained, the methodology used in this study seems to have worked quite well. Building the knowledge base was dependent on time and availability of human experts.

The knowledge base is a valuable product of this research. It contains information from published documents and also knowledge that has not been previously documented in any form. This may prove an effective avenue of technology transfer, i.e., it serves as a link between researchers and practitioners. The threshold values in the knowledge base can be readily modified, making the expert system general enough to use in a variety of management situations. Finding an optimal solution is not the end. The next step of performing sensitivity analysis on the parameters of the model is readily made available when using the



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expert system. Moreover, the system allows the user a choice from the range of objective functions. This is a key decision in uneven-aged management implementation.

The current version of FOREX is still considered a prototype. Development has consisted of construction, revision, refinement, and evaluation. Some user-friendly attributes need to be added for the system to be beneficial to end-users. Realistically, a distribution copy is still months away.

## Future Works

### Embellishments

Some embellishments noted previously should occur in the final version. First, the revisions implied by the poor performance in understocked stands should be included. Second, technical terms used in the system should have a corresponding on-line definition available to the user on demand. Third, the future system could allow users to make changes and/or adjustments by using graphic displays and descriptive and numeric outputs.

### Explanation Facility

An explanation facility capable of providing answers for why and how questions posed by user should be provided. The explanation facility in FOREX can serve a dual purpose, namely (1) as a teaching and training device and (2) as a means for increasing understanding of the concepts and implementation of uneven-aged management.

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Why Explanation. The why explanation will be invoked to provide information when the user wants to know why a particular question is asked. FOREX will respond by displaying the rule being tested.

How Explanation. The how explanation will be invoked when the user wants to know how the system arrived at its recommendation. FOREX will respond by tracing back and reconstructing the rules fired in order to reach the conclusion.

Uncertainty

Incorporation of uncertainty into each alternative prescription generated should also be added to increase user confidence and acceptance of prescriptions generated by FOREX.

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## APPENDIX A

## CONDITION RULES

*Rule Format: stand(C,[A(Min,Max)])*

*Each rule indicates that a stand is described as C if the value of attribute A is {=, >, <, ≥, ≤} {Min or Max}*

Midstory/Overstory Pine stocking:

stand(understocked,[merchantable_basal_area( ≥ 5 $ft^2$/ac, < 45 $ft^2$/ac)])
stand(full_stocked,[merchantable_basal_area( ≥ 45 $ft^2$/ac, ≤ 75 $ft^2$/ac)])
stand(overstocked,[merchantable_basal_area( > 75 $ft^2$/ac)]).

Midstory/Overstory Hardwood stocking:

stand(understocked,[merchantable_basal_area( < 5 $ft^2$/ac)])
stand(full_stocked,[merchantable_basal_area( ≥ 5 $ft^2$/ac, ≤ 20 $ft^2$/ac)])
stand(overstocked,[merchantable_basal_area( > 20 $ft^2$/ac)])

Understory Pine stocking:

stand(heavy,[sub_merchantable_basal_area( ≥ 200 stems/ac)])
stand(moderate,[sub_merchantable_basal_area( ≥ 100, < 200 stem/ac)])
stand(light,[sub_merchantable_basal_area( < 100 stems/ac)])

Understory Hardwood stocking:

stand(heavy,[sub_merchantable_basal_area( > 7000 stems/ac)])
stand(moderate,[sub_merchantable_basal_area( ≥ 1000, ≤ 7000 stems/ac)])
stand(light,[sub_merchantable_basal_area( < 1000 stems/ac)])

Understory Non-woody Vegetation:

stand(heavy,[percent_ground_covered_non_woody( ≥ 75%)])
stand(moderate,[percent_ground_covered_non_woody( ≥ 20%, < 75%)])
stand(light,[percent_ground_covered_non_woody( < 20%)])

Pine Operability:

stand(operable_cut,[board_foot_cut( ≥ 1.2 MBF),residual_basal_area( ≥ 45 $ft^2$/ac)])
stand(operable_cut,[cords_cut( ≥ 5 cords),residual_basal_area( ≥ 45 $ft^2$/ac)])
stand(non_operable_cut,[board_foot_cut( < 1.2 MBF)])
stand(non_operable_cut,[cords_cut( < 5 cords)])

Hardwood Operability:

stand(operable_cut,[cut( ≥ 4 cords)])
stand(non_operable_cut,[cut( < 4 cords)])



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Stand quality:

stand(high,[percent_acceptable_basal_area( ≥ 75%)])
stand(medium,[percent_acceptable_basal_area( ≥ 66%, < 75%)])
stand(low,[percent_acceptable_basal_area( < 66%)])

Bs/Bm ratio:

stand(heavy,[sawtimber_merchantable_basal_area_ratio( ≥ 75%)])
stand(medium,[sawtimber_merchantable_basal_area_ratio( ≥ 65%, < 75%)])
stand(light,[sawtimber_merchantable_basal_area_ratio( < 65%)])

Site quality:

stand(good,[site_index( ≥ 80 ft @ year = 50)])
stand(medium,[site_index( ≥ 70 ft @ year = 50, < 80 ft @ year = 50)])
stand(poor,[site_index( < 70 ft @ year = 50)])

Stand age:

stand(old,[average_product_class(medium sawlog)])
stand(young,[average_product_class(pulpwood)])

Volume:

stand(high,[cubic_foot_volume( ≥ 2000 )])
stand(medium,[cubic_foot_volume( ≥ 1800, < 2000)])
stand(light,[cubic_foot_volume( < 1800)])

stand(high,[board_foot_volume( ≥ 7000 )])
stand(medium,[board_foot_volume( ≥ 1500, < 7000)])
stand(light,[board_foot_volume( < 1500)])

Percent stocking:

stand(inadequate,[percent_stocking( < 20)])
stand(adequate,[percent_stocking( ≥ 20)])

Availability of Seed source:

stand(available_seed_source,[basal_area_trees_12_up( ≥ 6 $ft^2$/ac)])
stand(no_available_seed_source,[basal_area_trees_12_up( < 6 $ft^2$/ac)])

Stand Structure:

stand(none,[sapling( = 0.0 stems/ac)])
stand(low,[sapling( < Merchantable trees/ac)])
stand(high,[sapling( ≥ Merchantable trees/ac)])

stand(none,[pulpwood( = 0.0 trees/ac)])
stand(low,[pulpwood( < 10% total basal area)])
stand(high,[pulpwood( ≥ 10% total basal area)])

stand(none,[small_sawlog( = 0.0 trees/ac)])
stand(low,[small_sawlog( < 10% total basal area)])
stand(high,[small_sawlog( ≥ 10% total basal area)])

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stand(none,[medium_sawlog( = 0.0 trees/ac)])
stand(low,[medium_sawlog( < 10% total basal area)])
stand(high,[medium_sawlog( ≥ 10% total basal area)])

stand(none,[large_sawlog( = 0.0 trees/ac)])
stand(low,[large_sawlog( < 10% total basal area)])
stand(high,[large_sawlog( ≥ 10% total basal area)])

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## APPENDIX B

## MANAGEMENT TYPE RULES

Rule format: management_type(M,[stand(sapling,pulpwood,small sawlog,medium sawlog,large sawlog)]).

Each rule indicates that: *IF stand has low sapling*
*and low pulpwood,*
*and low small sawlog,*
*and none medium sawlog,*
*and none large sawlog,*
*THEN M management_type is appropriate.*

```
management_type(even_aged,stand([none,none,none,none,low]).
management_type(even_aged,stand([none,none,none,none,high]).
management_type(even_aged,stand([none,none,none,low,none]).
management_type(even_aged,stand([none,none,none,low,low]).
management_type(even_aged,stand([none,none,none,low,high]).
management_type(even_aged,stand([none,none,none,high,none]).
management_type(even_aged,stand([none,none,none,high,low]).
management_type(even_aged,stand([none,none,none,high,high]).
management_type(even_aged,stand([none,none,low,none,none]).
management_type(even_aged,stand([none,none,low,none,low]).
management_type(even_aged,stand([none,none,low,none,high]).
management_type(even_aged,stand([none,none,low,low,none]).
management_type(even_aged,stand([none,none,low,low,low]).
management_type(even_aged,stand([none,none,low,low,high]).
management_type(even_aged,stand([none,none,low,high,none]).
management_type(even_aged,stand([none,none,low,high,low]).
management_type(even_aged,stand([none,none,low,high,high]).
management_type(even_aged,stand([none,none,high,none,none]).
management_type(even_aged,stand([none,none,high,none,low]).
management_type(even_aged,stand([none,none,high,none,high]).
management_type(even_aged,stand([none,none,high,low,none]).
management_type(uneven_aged,stand([none,none,high,low,low]).
management_type(uneven_aged,stand([none,none,high,low,high]).
management_type(even_aged,stand([none,none,high,high,none]).
management_type(uneven_aged,stand([none,none,high,high,low]).
management_type(uneven_aged,stand([none,none,high,high,high]).
management_type(even_aged,stand([none,low,none,none,none]).
management_type(even_aged,stand([none,low,none,none,low]).
management_type(even_aged,stand([none,low,none,none,high]).
management_type(even_aged,stand([none,low,none,low,none]).
management_type(even_aged,stand([none,low,none,low,low]).
management_type(even_aged,stand([none,low,none,low,high]).
management_type(even_aged,stand([none,low,none,high,none]).
```



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```
management_type(even_aged,stand([none,low,none,high,low])).
management_type(even_aged,stand([none,low,none,high,high])).
management_type(even_aged,stand([none,low,low,none,none])).
management_type(even_aged,stand([none,low,low,none,low])).
management_type(even_aged,stand([none,low,low,none,high])).
management_type(even_aged,stand([none,low,low,low,none])).
management_type(uneven_aged,stand([none,low,low,low,low])).
management_type(uneven_aged,stand([none,low,low,low,high])).
management_type(even_aged,stand([none,low,low,high,none])).
management_type(even_aged,stand([none,low,low,high,low])).
management_type(uneven_aged,stand([none,low,low,high,high])).
management_type(even_aged,stand([none,low,high,none,none])).
management_type(even_aged,stand([none,low,high,none,low])).
management_type(even_aged,stand([none,low,high,none,high])).
management_type(even_aged,stand([none,low,high,low,none])).
management_type(even_aged,stand([none,low,high,low,low])).
management_type(uneven_aged,stand([none,low,high,low,high])).
management_type(uneven_aged,stand([none,low,high,high,none])).
management_type(uneven_aged,stand([none,low,high,high,low])).
management_type(uneven_aged,stand([none,low,high,high,high])).
management_type(even_aged,stand([none,high,none,none,none])).
management_type(uneven_aged,stand([none,high,none,none,low])).
management_type(uneven_aged,stand([none,high,none,none,high])).
management_type(uneven_aged,stand([none,high,none,low,none])).
management_type(uneven_aged,stand([none,high,none,low,low])).
management_type(uneven_aged,stand([none,high,none,low,high])).
management_type(uneven_aged,stand([none,high,none,high,none])).
management_type(uneven_aged,stand([none,high,none,high,low])).
management_type(uneven_aged,stand([none,high,none,high,high])).
management_type(uneven_aged,stand([none,high,low,none,none])).
management_type(uneven_aged,stand([none,high,low,none,low])).
management_type(uneven_aged,stand([none,high,low,none,high])).
management_type(uneven_aged,stand([none,high,low,low,none])).
management_type(uneven_aged,stand([none,high,low,low,low])).
management_type(uneven_aged,stand([none,high,low,low,high])).
management_type(uneven_aged,stand([none,high,low,high,none])).
management_type(uneven_aged,stand([none,high,low,high,low])).
management_type(uneven_aged,stand([none,high,low,high,high])).
management_type(uneven_aged,stand([none,high,high,none,none])).
management_type(uneven_aged,stand([none,high,high,none,low])).
management_type(uneven_aged,stand([none,high,high,none,high])).
management_type(uneven_aged,stand([none,high,high,low,none])).
management_type(uneven_aged,stand([none,high,high,low,low])).
management_type(uneven_aged,stand([none,high,high,low,high])).
management_type(uneven_aged,stand([none,high,high,high,none])).
management_type(uneven_aged,stand([none,high,high,high,low])).
management_type(uneven_aged,stand([none,high,high,high,high])).
management_type(even_aged,stand([low,none,none,none,none])).
management_type(even_aged,stand([low,none,none,none,low])).
management_type(even_aged,stand([low,none,none,none,high])).
```

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```
management_type(even_aged,stand([low,none,none,low,none]).
management_type(even_aged,stand([low,none,none,low,low]).
management_type(even_aged,stand([low,none,none,low,high]).
management_type(even_aged,stand([low,none,none,high,none]).
management_type(even_aged,stand([low,none,none,high,low]).
management_type(even_aged,stand([low,none,none,high,high]).
management_type(even_aged,stand([low,none,low,none,none]).
management_type(even_aged,stand([low,none,low,none,low]).
management_type(even_aged,stand([low,none,low,none,high]).
management_type(even_aged,stand([low,none,low,low,none]).
management_type(even_aged,stand([low,none,low,low,low]).
management_type(even_aged,stand([low,none,low,low,high]).
management_type(even_aged,stand([low,none,low,high,none]).
management_type(even_aged,stand([low,none,low,high,low]).
management_type(even_aged,stand([low,none,low,high,high]).
management_type(even_aged,stand([low,none,high,none,none]).
management_type(even_aged,stand([low,none,high,none,low]).
management_type(even_aged,stand([low,none,high,none,high]).
management_type(even_aged,stand([low,none,high,low,none]).
management_type(even_aged,stand([low,none,high,low,low]).
management_type(uneven_aged,stand([low,none,high,low,high]).
management_type(uneven_aged,stand([low,none,high,high,none]).
management_type(uneven_aged,stand([low,none,high,high,low]).
management_type(uneven_aged,stand([low,none,high,high,high]).
management_type(even_aged,stand([low,low,none,none,none]).
management_type(even_aged,stand([low,low,none,none,low]).
management_type(even_aged,stand([low,low,none,none,high]).
management_type(even_aged,stand([low,low,none,low,none]).
management_type(even_aged,stand([low,low,none,low,low]).
management_type(uneven_aged,stand([low,low,none,low,high]).
management_type(even_aged,stand([low,low,none,high,none]).
management_type(uneven_aged,stand([low,low,none,high,low]).
management_type(uneven_aged,stand([low,low,none,high,high]).
management_type(uneven_aged,stand([low,low,low,none,none]).
management_type(uneven_aged,stand([low,low,low,none,low]).
management_type(uneven_aged,stand([low,low,low,none,high]).
management_type(uneven_aged,stand([low,low,low,low,none]).
management_type(uneven_aged,stand([low,low,low,low,low]).
management_type(uneven_aged,stand([low,low,low,low,high]).
management_type(uneven_aged,stand([low,low,low,high,none]).
management_type(uneven_aged,stand([low,low,low,high,low]).
management_type(uneven_aged,stand([low,low,low,high,high]).
management_type(uneven_aged,stand([low,low,high,none,none]).
management_type(uneven_aged,stand([low,low,high,none,low]).
management_type(uneven_aged,stand([low,low,high,none,high]).
management_type(uneven_aged,stand([low,low,high,low,none]).
management_type(uneven_aged,stand([low,low,high,low,low]).
management_type(uneven_aged,stand([low,low,high,low,high]).
management_type(uneven_aged,stand([low,low,high,high,none]).
management_type(uneven_aged,stand([low,low,high,high,low]).
```

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```
management_type(uneven_aged,stand([low,low,high,high,high]).
management_type(even_aged,stand([low,high,none,none,none]).
management_type(uneven_aged,stand([low,high,none,none,low]).
management_type(uneven_aged,stand([low,high,none,none,high]).
management_type(uneven_aged,stand([low,high,none,low,none]).
management_type(uneven_aged,stand([low,high,none,low,low]).
management_type(uneven_aged,stand([low,high,none,low,high]).
management_type(uneven_aged,stand([low,high,none,high,none]).
management_type(uneven_aged,stand([low,high,none,high,low]).
management_type(uneven_aged,stand([low,high,none,high,high]).
management_type(uneven_aged,stand([low,high,low,none,none]).
management_type(uneven_aged,stand([low,high,low,none,low]).
management_type(uneven_aged,stand([low,high,low,none,high]).
management_type(uneven_aged,stand([low,high,low,low,none]).
management_type(uneven_aged,stand([low,high,low,low,low]).
management_type(uneven_aged,stand([low,high,low,low,high]).
management_type(uneven_aged,stand([low,high,low,high,none]).
management_type(uneven_aged,stand([low,high,low,high,low]).
management_type(uneven_aged,stand([low,high,low,high,high]).
management_type(uneven_aged,stand([low,high,high,none,none]).
management_type(uneven_aged,stand([low,high,high,none,low]).
management_type(uneven_aged,stand([low,high,high,none,high]).
management_type(uneven_aged,stand([low,high,high,low,none]).
management_type(uneven_aged,stand([low,high,high,low,low]).
management_type(uneven_aged,stand([low,high,high,low,high]).
management_type(uneven_aged,stand([low,high,high,high,none]).
management_type(uneven_aged,stand([low,high,high,high,low]).
management_type(uneven_aged,stand([low,high,high,high,high]).
management_type(even_aged,stand([high,none,none,none,none]).
management_type(even_aged,stand([high,none,none,none,low]).
management_type(uneven_aged,stand([high,none,none,none,high]).
management_type(uneven_aged,stand([high,none,none,low,none]).
management_type(uneven_aged,stand([high,none,none,low,low]).
management_type(uneven_aged,stand([high,none,none,low,high]).
management_type(uneven_aged,stand([high,none,none,high,none]).
management_type(uneven_aged,stand([high,none,none,high,low]).
management_type(uneven_aged,stand([high,none,none,high,high]).
management_type(uneven_aged,stand([high,none,low,none,none]).
management_type(uneven_aged,stand([high,none,low,none,low]).
management_type(uneven_aged,stand([high,none,low,none,high]).
management_type(uneven_aged,stand([high,none,low,low,none]).
management_type(uneven_aged,stand([high,none,low,low,low]).
management_type(uneven_aged,stand([high,none,low,low,high]).
management_type(uneven_aged,stand([high,none,low,high,none]).
management_type(uneven_aged,stand([high,none,low,high,low]).
management_type(uneven_aged,stand([high,none,low,high,high]).
management_type(uneven_aged,stand([high,none,high,none,none]).
management_type(uneven_aged,stand([high,none,high,none,low]).
management_type(uneven_aged,stand([high,none,high,none,high]).
management_type(uneven_aged,stand([high,none,high,low,none]).
```

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management_type(uneven_aged,stand([high,none,high,low,low]).
management_type(uneven_aged,stand([high,none,high,low,high]).
management_type(uneven_aged,stand([high,none,high,high,none]).
management_type(uneven_aged,stand([high,none,high,high,low]).
management_type(uneven_aged,stand([high,none,high,high,high]).
management_type(uneven_aged,stand([high,low,none,none,none]).
management_type(uneven_aged,stand([high,low,none,none,low]).
management_type(uneven_aged,stand([high,low,none,none,high]).
management_type(uneven_aged,stand([high,low,none,low,none]).
management_type(uneven_aged,stand([high,low,none,low,low]).
management_type(uneven_aged,stand([high,low,none,low,high]).
management_type(uneven_aged,stand([high,low,none,high,none]).
management_type(uneven_aged,stand([high,low,none,high,low]).
management_type(uneven_aged,stand([high,low,none,high,high]).
management_type(uneven_aged,stand([high,low,low,none,none]).
management_type(uneven_aged,stand([high,low,low,none,low]).
management_type(uneven_aged,stand([high,low,low,none,high]).
management_type(uneven_aged,stand([high,low,low,low,none]).
management_type(uneven_aged,stand([high,low,low,low,low]).
management_type(uneven_aged,stand([high,low,low,low,high]).
management_type(uneven_aged,stand([high,low,low,high,none]).
management_type(uneven_aged,stand([high,low,low,high,low]).
management_type(uneven_aged,stand([high,low,low,high,high]).
management_type(uneven_aged,stand([high,low,high,none,none]).
management_type(uneven_aged,stand([high,low,high,none,low]).
management_type(uneven_aged,stand([high,low,high,none,high]).
management_type(uneven_aged,stand([high,low,high,low,none]).
management_type(uneven_aged,stand([high,low,high,low,low]).
management_type(uneven_aged,stand([high,low,high,low,high]).
management_type(uneven_aged,stand([high,low,high,high,none]).
management_type(uneven_aged,stand([high,low,high,high,low]).
management_type(uneven_aged,stand([high,low,high,high,high]).
management_type(uneven_aged,stand([high,high,none,none,none]).
management_type(uneven_aged,stand([high,high,none,none,low]).
management_type(uneven_aged,stand([high,high,none,none,high]).
management_type(uneven_aged,stand([high,high,none,low,none]).
management_type(uneven_aged,stand([high,high,none,low,low]).
management_type(uneven_aged,stand([high,high,none,low,high]).
management_type(uneven_aged,stand([high,high,none,high,none]).
management_type(uneven_aged,stand([high,high,none,high,low]).
management_type(uneven_aged,stand([high,high,none,high,high]).
management_type(uneven_aged,stand([high,high,low,none,none]).
management_type(uneven_aged,stand([high,high,low,none,low]).
management_type(uneven_aged,stand([high,high,low,none,high]).
management_type(uneven_aged,stand([high,high,low,low,none]).
management_type(uneven_aged,stand([high,high,low,low,low]).
management_type(uneven_aged,stand([high,high,low,low,high]).
management_type(uneven_aged,stand([high,high,low,high,none]).
management_type(uneven_aged,stand([high,high,low,high,low]).
management_type(uneven_aged,stand([high,high,low,high,high]).

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## APPENDIX C

## TREATMENT RULES

Even-aged:

Format: treatment(T,[stand(A1,A2,A3)])

treatment(clearcut,[stand(even_aged,no_available_seed,operable_cut)]).
treatment(plant_&_direct_seed,[stand(even_aged,no_available_seed, non_operable_cut)]).
treatment(seed_tree,[stand(even_aged,merchantable basal area ≥ 25, available_seed)]).
treatment(shelterwood,[stand(even_aged,merchantable basal area < 25, available_seed)]).

Uneven-aged:

Format: treatment(T,[stand(%_stock(A1),Bm(A2),Bs(A3),Ba_ratio(A4))]).

Each of the following rule indicates that
*T can be applied if stand has A1 of percent stocking, A2 of merchantable basal area, A3 of sawtimber basal area, and A4 of sawtimber/merchantable basal area ratio.*

treatment(leave,[stand(understocked,inadequate,light,low)]).
treatment(leave,[stand(understocked,inadequate,light,medium)]).
treatment(leave,[stand(understocked,inadequate,light,high)]).
treatment(leave,[stand(understocked,inadequate,moderate,low)]).
treatment(leave,[stand(understocked,inadequate,moderate,medium)]).
treatment(leave,[stand(understocked,inadequate,moderate,high)]).
treatment(leave,[stand(understocked,inadequate,heavy,low)]).
treatment(leave,[stand(understocked,inadequate,heavy,medium)]).
treatment(leave,[stand(understocked,inadequate,heavy,high)]).
treatment(leave,[stand(understocked,understocked,light,low)]).
treatment(leave,[stand(understocked,understocked,light,medium)]).
treatment(leave,[stand(understocked,understocked,light,high)]).
treatment(leave,[stand(understocked,understocked,moderate,low)]).
treatment(leave,[stand(understocked,understocked,moderate,medium)]).
treatment(leave,[stand(understocked,understocked,moderate,high)]).
treatment(leave,[stand(understocked,understocked,heavy,low)]).
treatment(leave,[stand(understocked,understocked,heavy,medium)]).
treatment(leave,[stand(understocked,understocked,heavy,high)]).
treatment(leave,[stand(understocked,full_stocked,light,low)]).
treatment(leave,[stand(understocked,full_stocked,light,medium)]).
treatment(leave,[stand(understocked,full_stocked,light,high)]).
treatment(leave,[stand(understocked,full_stocked,moderate,low)]).
treatment(harvest,[stand(understocked,full_stocked,moderate,medium)]).
treatment(harvest,[stand(understocked,full_stocked,moderate,high)]).



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```
treatment(harvest,[stand(understocked,full_stocked,heavy,low)]).
treatment(harvest,[stand(understocked,full_stocked,heavy,medium)]).
treatment(harvest,[stand(understocked,full_stocked,heavy,high)]).
treatment(harvest,[stand(understocked,overstocked,light,low)]).
treatment(harvest,[stand(understocked,overstocked,light,medium)]).
treatment(harvest,[stand(understocked,overstocked,light,high)]).
treatment(harvest,[stand(understocked,overstocked,moderate,low)]).
treatment(harvest,[stand(understocked,overstocked,moderate,medium)]).
treatment(harvest,[stand(understocked,overstocked,moderate,high)]).
treatment(harvest,[stand(understocked,overstocked,heavy,low)]).
treatment(harvest,[stand(understocked,overstocked,heavy,medium)]).
treatment(harvest,[stand(understocked,overstocked,heavy,high)]).
treatment(leave,[stand(adequate,inadequate,light,low)]).
treatment(leave,[stand(adequate,inadequate,light,medium)]).
treatment(leave,[stand(adequate,inadequate,light,high)]).
treatment(leave,[stand(adequate,inadequate,moderate,low)]).
treatment(leave,[stand(adequate,inadequate,moderate,medium)]).
treatment(leave,[stand(adequate,inadequate,moderate,high)]).
treatment(leave,[stand(adequate,inadequate,heavy,low)]).
treatment(leave,[stand(adequate,inadequate,heavy,medium)]).
treatment(leave,[stand(adequate,inadequate,heavy,high)]).
treatment(leave,[stand(adequate,understocked,light,low)]).
treatment(leave,[stand(adequate,understocked,light,medium)]).
treatment(leave,[stand(adequate,understocked,light,high)]).
treatment(leave,[stand(adequate,understocked,moderate,low)]).
treatment(leave,[stand(adequate,understocked,moderate,medium)]).
treatment(leave,[stand(adequate,understocked,moderate,high)]).
treatment(leave,[stand(adequate,understocked,heavy,low)]).
treatment(leave,[stand(adequate,understocked,heavy,medium)]).
treatment(harvest,[stand(adequate,understocked,heavy,high)]).
treatment(harvest,[stand(adequate,full_stocked,light,low)]).
treatment(harvest,[stand(adequate,full_stocked,light,medium)]).
treatment(modify,[stand(adequate,full_stocked,light,high)]).
treatment(harvest,[stand(adequate,full_stocked,moderate,low)]).
treatment(harvest,[stand(adequate,full_stocked,moderate,medium)]).
treatment(harvest,[stand(adequate,full_stocked,moderate,high)]).
treatment(harvest,[stand(adequate,full_stocked,heavy,low)]).
treatment(harvest,[stand(adequate,full_stocked,heavy,medium)]).
treatment(harvest,[stand(adequate,full_stocked,heavy,high)]).
treatment(harvest,[stand(adequate,overstocked,light,low)]).
treatment(harvest,[stand(adequate,overstocked,light,medium)]).
treatment(harvest,[stand(adequate,overstocked,light,high)]).
treatment(harvest,[stand(adequate,overstocked,moderate,low)]).
treatment(harvest,[stand(adequate,overstocked,moderate,medium)]).
treatment(harvest,[stand(adequate,overstocked,moderate,high)]).
treatment(harvest,[stand(adequate,overstocked,heavy,low)]).
```

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## APPENDIX D

## BACKGROUND OF TESTERS

**Tester 1:**

Training: B.S. and M.S. Forestry
Experience: 15 years as Research Forester

**Tester 2:**

Training: B.S. and M.S. Forestry
Experience: 15 years as Industrial Forester

**Tester 3:**

Training: B.S., M.S., Ph.D. Quantitative Silviculture
Experience: 32 years as Research Forester

**Tester 4:**

Training: B.S. Forestry
Experience: 10 years Consulting Forester, 20 years as Industrial Forester



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## APPENDIX E

## BACKGROUND OF EVALUATORS

**Evaluator 1:**

Training: B.S. and M.S. Forestry
Experience: 4 years as inventory forester; 3 years as Silviculturist

**Evaluator 2:**

Training: B.S. Timber Management & Wildlife Biology, M.S. Wildlife Science
Experience: 5 years in the timber industry; currently USFS Forester prior to this, worked as Wildlife Biologist

**Evaluator 3:**

Training: B.S. and M.S. Wildland Resource Science
Experience: 6 years as Operations Research Analyst, Reforestation Forester, Timber Management Assistant, and Forest Planner

**Evaluator 4:**

Training: B.A., Master of Forestry
Experience: 40 years as Consulting Forester

**Evaluator 5:**

Training: B.S. Bus. Adm., M.S. Forestry, Ph.D. Forest Economics
Experience: 14 years Forestry Professor; currently Principal Economist USDA Forest Service

**Evaluator 6:**

Training: B.S. Forestry, M.S. Genetics
Experience: 32 years as Forester with USDA Forest Service



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**Evaluator 7:**

Training: B.S. Forest Management
Experience: 2 years as Industrial Forester, 18 as Silviculturist

**Evaluator 8:**

Training: B.S., M.S. Forestry, Ph.D. Forestry
Experience: 2 years Silviculture Post-doc, currently Assistant Professor of Silviculture

**Evaluator 9:**

Training: B.S. Forestry
Experience: 32 years as Silviculturist with USDA Forest Service

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## APPENDIX F

## INFORMATION ABOUT 25 TEST CASES AS GIVEN TO THE TESTERS



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Table F-1. Information about test case 1 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.00 | 0.00 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 | 0.26 |
| 6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 0.39 |
| 8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 0.70 |
| 10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.55 |
| 12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 14 | 0.00 | 2.00 | 2.14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 16 | 2.00 | 2.79 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 18 | 2.00 | 3.53 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 4.00 | 6.33 | 4.00 | 5.67 | 0.00 | 0.00 | 8.00 | 1.90 |

| | | Pine | Hardwood |
|---|---|---|---|
| Distribution of basal area: | Pulpwood.................. | 0.00 | 1.35 |
| | Sawtimber .............. | 12.00 | 0.55 |
| Stocking: | Percent .................................................. | 11.47 | 4.73 |
| | Milacres ................................................. | 114.67 | 47.34 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 25

Site quality ........................................................... Good ( > 80 ft. @ 50 years)

Product class objective ......................................... Medium sawlog

Yield/Economic objective .................................. Maximize Board-feet harvest

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Table F-2. Information about test case 2 as given to the testers.

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 20.00 | 0.00 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.00 | 0.87 |
| 6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.00 | 1.57 |
| 8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.00 | 1.75 |
| 10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 | 1.64 |
| 12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 1.57 |
| 14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.07 |
| 16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 4.00 | 8.73 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 22 | 2.00 | 5.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 24 | 2.00 | 6.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 8.00 | 20.29 | 0.00 | 0.00 | 0.00 | 0.00 | 29.00 | 8.46 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood | 0.00 | 4.19 |
| Sawtimber | 20.29 | 4.28 |
| Stocking: Percent | 18.24 | 15.78 |
| Milacres | 182.37 | 157.80 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 20

Site quality .................... Medium ( 70-80 ft. @ 50 years)

Product class objective .................... Medium sawlog

Yield/Economic objective .................... Maximize Cubic-feet harvest

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Table F-3. Information about test case 3 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 50.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 100.0 | 0.00 |
| 4 | 0.00 | 0.00 | 12.00 | 1.05 | 0.00 | 0.00 | 10.00 | 1.87 |
| 6 | 0.00 | 0.00 | 5.00 | 0.98 | 0.00 | 0.00 | 10.00 | 1.96 |
| 8 | 0.00 | 0.00 | 12.00 | 4.19 | 0.00 | 0.00 | 10.00 | 3.49 |
| 10 | 0.00 | 0.00 | 12.00 | 6.54 | 0.00 | 0.00 | 12.00 | 6.54 |
| 12 | 1.00 | 0.79 | 2.00 | 1.57 | 0.00 | 0.00 | 7.00 | 5.50 |
| 14 | 0.00 | 0.00 | 1.00 | 1.07 | 0.00 | 0.00 | 5.00 | 5.35 |
| 16 | 1.00 | 1.40 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 2.79 |
| 18 | 2.00 | 3.53 | 2.00 | 3.53 | 0.00 | 0.00 | 2.00 | 3.53 |
| Total | 4.00 | 5.72 | 46.00 | 18.94 | 0.00 | 0.00 | 58.00 | 30.04 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood .............................. | 6.22 | 6.33 |
| Sawtimber ............................ | 18.44 | 23.71 |
| Stocking: Percent ............................................................ | 38.21 | 52.57 |
| Milacres ............................................................ | 382.12 | 525.68 |

Percent of ground covered with understory vegetation (non-pine/hardwood) : 15

Site quality ........................................................... Good ( > 80 ft. @ 50 years)

Product class objective ......................................... Medium sawlog

Yield/Economic objective .................................... Maximize Net present value

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Table F-4. Information about test case 4 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 100.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 150.0 | 0.00 |
| 5 | 10.00 | 1.36 | 0.00 | 0.00 | 2.00 | 0.27 | 7.00 | 0.95 |
| 6 | 12.00 | 2.36 | 0.00 | 0.00 | 1.80 | 0.35 | 9.00 | 1.77 |
| 7 | 15.00 | 4.01 | 0.00 | 0.00 | 1.60 | 0.43 | 7.00 | 1.87 |
| 8 | 10.00 | 3.49 | 0.00 | 0.00 | 5.70 | 1.99 | 6.00 | 2.09 |
| 9 | 10.00 | 4.42 | 0.00 | 0.00 | 2.20 | 0.97 | 4.00 | 1.77 |
| 10 | 5.00 | 2.73 | 0.00 | 0.00 | 5.00 | 2.73 | 6.00 | 3.27 |
| 11 | 3.00 | 1.98 | 0.00 | 0.00 | 3.00 | 1.98 | 3.00 | 1.98 |
| 12 | 4.00 | 3.14 | 0.00 | 0.00 | 4.20 | 3.30 | 2.00 | 1.57 |
| 13 | 2.70 | 2.49 | 0.00 | 0.00 | 2.00 | 1.84 | 0.00 | 0.00 |
| 14 | 2.70 | 2.89 | 0.00 | 0.00 | 2.00 | 2.14 | 0.00 | 0.00 |
| 15 | 2.70 | 3.31 | 0.00 | 0.00 | 2.00 | 2.45 | 0.00 | 0.00 |
| 16 | 2.50 | 3.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 17 | 1.20 | 1.89 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 18 | 1.80 | 3.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 19 | 2.00 | 3.94 | 0.50 | 0.98 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 0.00 | 0.00 | 1.30 | 2.84 | 0.00 | 0.00 | 0.00 | 0.00 |
| 21 | 1.00 | 2.41 | 1.30 | 3.13 | 0.00 | 0.00 | 0.00 | 0.00 |
| 22 | 1.00 | 2.64 | 0.80 | 2.11 | 0.00 | 0.00 | 0.00 | 0.00 |
| 23 | 0.80 | 2.31 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 24 | 1.00 | 3.14 | 0.20 | 0.63 | 0.00 | 0.00 | 0.00 | 0.00 |
| 25 | 0.70 | 2.39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 89.10 | 57.56 | 4.10 | 9.69 | 31.50 | 18.46 | 44.00 | 15.28 |

| | | Pine | Hardwood |
|---|---|---|---|
| Distribution of basal area: | Pulpwood ............................... | 19.68 | 8.45 |
| | Sawtimber ............................. | 66.05 | 6.82 |

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| | | |
|---|---|---|
| Stocking: Percent | 111.37 | 46.01 |
| Milacres | 1113.67 | 460.07 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 15

Site quality ........................................................ Medium ( 70-80 ft. @ 50 years)

Product class objective ........................................ Medium sawlog

Yield/Economic objective .................................. Maximize Board-feet harvest

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Table F-5. Information about test case 5 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 100.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 75.00 | 0.00 |
| 2 | 0.00 | 0.00 | 0.10 | 0.00 | 0.10 | 0.00 | 15.00 | 0.33 |
| 4 | 0.00 | 0.00 | 1.00 | 0.09 | 0.50 | 0.04 | 10.00 | 0.87 |
| 6 | 0.00 | 0.00 | 3.20 | 0.63 | 3.20 | 0.63 | 5.00 | 0.98 |
| 8 | 0.00 | 0.00 | 4.50 | 1.57 | 4.70 | 1.64 | 12.00 | 4.19 |
| 10 | 0.00 | 0.00 | 5.20 | 2.84 | 5.20 | 2.84 | 8.00 | 4.36 |
| 12 | 0.00 | 0.00 | 5.10 | 4.01 | 6.10 | 4.79 | 0.00 | 0.00 |
| 14 | 0.00 | 0.00 | 10.00 | 10.69 | 3.20 | 3.42 | 1.00 | 1.07 |
| 16 | 0.00 | 0.00 | 10.00 | 13.96 | 0.80 | 1.12 | 1.00 | 1.40 |
| 18 | 9.00 | 15.90 | 0.20 | 0.35 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 6.00 | 13.09 | 0.40 | 0.87 | 0.00 | 0.00 | 1.00 | 2.18 |
| 22 | 3.00 | 7.92 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 24 | 2.00 | 6.28 | 0.80 | 2.51 | 0.00 | 0.00 | 0.00 | 0.00 |
| 26 | 0.50 | 1.84 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 20.50 | 45.04 | 40.50 | 37.52 | 23.80 | 14.48 | 53.00 | 15.38 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood .............................. | 4.60 | 6.04 |
| Sawtimber ............................ | 92.44 | 9.01 |
| Stocking: Percent ............................................................ | 113.15 | 35.03 |
| Milacres ............................................................ | 1131.47 | 350.30 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 15

Site quality ........................................................ Good ( > 80 ft. @ 50 years)

Product class objective ...................................... Large sawlog

Yield/Economic objective .................................. Maximize Board-feet harvest

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Table F-6. Information about test case 6 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 500.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1000 | 0.00 |
| 2 | 10.00 | 0.22 | 2.00 | 0.04 | 0.00 | 0.00 | 30.00 | 0.65 |
| 4 | 3.00 | 0.26 | 2.00 | 0.17 | 1.00 | 0.09 | 20.00 | 1.75 |
| 6 | 2.00 | 0.39 | 2.00 | 0.39 | 0.00 | 0.00 | 15.00 | 2.95 |
| 8 | 2.00 | 0.70 | 1.00 | 0.35 | 1.00 | 0.35 | 10.00 | 3.49 |
| 10 | 2.00 | 1.09 | 0.00 | 0.00 | 0.00 | 0.00 | 5.00 | 2.73 |
| Total | 19.00 | 2.66 | 7.00 | 0.96 | 2.00 | 0.44 | 80.00 | 11.56 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood ............................... | 2.71 | 8.18 |
| Sawtimber ............................. | 1.09 | 2.73 |
| Stocking: Percent ............................................................... | 91.79 | 190.82 |
| Milacres ............................................................... | 917.87 | 1908.19 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 20

Site quality ........................................................... Good ( > 80 ft. @ 50 years)

Product class objective ......................................... Medium sawlog

Yield/Economic objective .................................... Maximize Cubic-feet harvest

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Table F-7. Information about test case 7 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 500.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 200.0 | 0.00 |
| 2 | 0.00 | 0.00 | 10.00 | 0.22 | 0.00 | 0.00 | 50.00 | 1.09 |
| 4 | 0.00 | 0.00 | 5.00 | 0.44 | 0.00 | 0.00 | 35.00 | 3.05 |
| 6 | 0.00 | 0.00 | 3.00 | 0.59 | 3.00 | 0.59 | 20.00 | 3.93 |
| 8 | 0.00 | 0.00 | 2.00 | 0.70 | 0.00 | 0.00 | 25.00 | 8.73 |
| 10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.00 | 4.36 |
| 12 | 4.00 | 3.14 | 0.00 | 0.00 | 0.00 | 0.00 | 10.00 | 7.85 |
| 14 | 4.00 | 4.28 | 0.00 | 0.00 | 0.00 | 0.00 | 12.00 | 12.83 |
| 16 | 3.00 | 4.19 | 0.00 | 0.00 | 0.00 | 0.00 | 5.00 | 6.98 |
| Total | 11.00 | 11.61 | 20.00 | 1.94 | 3.00 | 0.59 | 165.0 | 48.83 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood | 1.72 | 15.71 |
| Sawtimber | 11.61 | 32.03 |
| Stocking: Percent | 100.29 | 104.19 |
| Milacres | 1002.91 | 1041.93 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 25

Site quality .......... Medium ( 70-80 ft. @ 50 years)

Product class objective .......... Small sawlog

Yield/Economic objective .......... Maximize Cubic-feet harvest

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Table F-8. Information about test case 8 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 1000 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1500 | 0.00 |
| 2 | 15.00 | 0.33 | 2.00 | 0.04 | 0.00 | 0.00 | 40.00 | 0.87 |
| 4 | 12.00 | 1.05 | 2.00 | 0.17 | 0.00 | 0.00 | 30.00 | 2.62 |
| 6 | 4.00 | 0.79 | 4.00 | 0.79 | 0.00 | 0.00 | 20.00 | 3.93 |
| 8 | 10.00 | 3.49 | 0.00 | 0.00 | 6.00 | 2.09 | 25.00 | 8.73 |
| 10 | 10.00 | 5.45 | 0.00 | 0.00 | 2.00 | 1.09 | 10.00 | 5.45 |
| Total | 51.00 | 11.10 | 8.00 | 1.00 | 8.00 | 3.19 | 125.0 | 21.60 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood | 8.38 | 15.27 |
| Sawtimber | 6.54 | 5.45 |
| Stocking: Percent | 191.73 | 290.80 |
| Milacres | 1917.35 | 2908.04 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 20

Site quality ........................................................ Medium ( 70-80 ft. @ 50 years)

Product class objective ........................................ Small sawlog

Yield/Economic objective .................................. Maximize Board-feet harvest

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Table F-9. Information about test case 9 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 300.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 500.0 | 0.00 |
| 4 | 10.00 | 0.87 | 20.00 | 1.75 | 0.00 | 0.00 | 18.00 | 1.57 |
| 6 | 5.00 | 0.98 | 10.00 | 1.96 | 5.00 | 0.98 | 22.00 | 4.32 |
| 8 | 5.00 | 1.75 | 0.00 | 0.00 | 6.00 | 2.09 | 15.00 | 5.24 |
| 10 | 4.00 | 2.18 | 4.00 | 2.18 | 0.00 | 0.00 | 10.00 | 5.45 |
| 12 | 3.00 | 2.36 | 2.00 | 1.57 | 1.00 | 0.79 | 8.00 | 6.28 |
| 14 | 5.00 | 5.35 | 1.00 | 1.07 | 0.00 | 0.00 | 0.00 | 0.00 |
| 16 | 4.00 | 5.59 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 18 | 2.00 | 3.53 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 1.00 | 2.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 39.00 | 24.78 | 37.00 | 8.53 | 12.00 | 3.86 | 73.00 | 22.86 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood | 10.38 | 11.13 |
| Sawtimber | 26.79 | 11.74 |

| | Pine | Hardwood |
|---|---|---|
| Stocking: Percent | 97.30 | 116.02 |
| Milacres | 973.04 | 1160.22 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 10

Site quality ........................................................ Good ( > 80 ft. @ 50 years)

Product class objective ........................................ Medium sawlog

Yield/Economic objective .................................. Maximize Internal rate of return

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Table F-10. Information about test case 10 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 75.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 150.0 | 0.00 |
| 4 | 11.00 | 0.96 | 0.00 | 0.00 | 10.00 | 0.87 | 17.00 | 1.48 |
| 5 | 10.00 | 1.36 | 0.00 | 0.00 | 9.00 | 1.23 | 21.00 | 2.86 |
| 6 | 8.00 | 1.57 | 0.00 | 0.00 | 8.00 | 1.57 | 19.00 | 3.73 |
| 7 | 7.00 | 1.87 | 0.00 | 0.00 | 7.00 | 1.87 | 14.00 | 3.74 |
| 8 | 6.00 | 2.09 | 0.00 | 0.00 | 6.00 | 2.09 | 7.00 | 2.44 |
| 9 | 4.00 | 1.77 | 0.00 | 0.00 | 2.00 | 0.88 | 9.00 | 3.98 |
| 10 | 5.00 | 2.73 | 0.00 | 0.00 | 2.00 | 1.09 | 7.00 | 3.82 |
| 11 | 4.00 | 2.64 | 0.00 | 0.00 | 2.00 | 1.32 | 0.00 | 0.00 |
| 12 | 2.00 | 1.57 | 0.00 | 0.00 | 4.00 | 3.14 | 0.00 | 0.00 |
| 13 | 5.00 | 4.61 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 14 | 4.00 | 4.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 15 | 4.00 | 4.91 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 16 | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 | 4.19 | 0.00 | 0.00 |
| 17 | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 | 4.73 | 0.00 | 0.00 |
| 18 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 3.53 | 0.00 | 0.00 |
| 19 | 1.00 | 1.97 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 1.00 | 2.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 21 | 1.00 | 2.41 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 22 | 1.00 | 2.64 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 74.00 | 39.55 | 0.00 | 0.00 | 58.00 | 26.52 | 94.00 | 22.06 |

| | | Pine | Hardwood |
|---|---|---|---|
| Distribution of basal area: | Pulpwood .............................. | 18.15 | 18.24 |
| | Sawtimber ............................ | 47.93 | 3.82 |
| Stocking: | Percent .................................................. | 92.12 | 60.87 |
| | Milacres ............................................................ | 921.18 | 608.70 |

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Percent of ground covered with understory vegetation (non-pine/hardwood): 5

Site quality ............................................................. Good ( > 80 ft. @ 50 years)

Product class objective ......................................... Large sawlog

Yield/Economic objective .................................... Maximize Board-feet harvest

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Table F-11. Information about test case 11 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 150.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 300.0 | 0.00 |
| 4 | 8.00 | 0.70 | 4.00 | 0.35 | 0.00 | 0.00 | 15.00 | 1.31 |
| 6 | 10.00 | 1.96 | 5.00 | 0.98 | 0.00 | 0.00 | 12.00 | 2.36 |
| 8 | 12.00 | 4.19 | 6.00 | 2.09 | 0.00 | 0.00 | 10.00 | 3.49 |
| 10 | 15.00 | 8.18 | 5.00 | 2.73 | 0.00 | 0.00 | 8.00 | 4.36 |
| 12 | 17.00 | 13.35 | 2.00 | 1.57 | 0.00 | 0.00 | 6.00 | 4.71 |
| 14 | 17.00 | 18.17 | 0.00 | 0.00 | 0.00 | 0.00 | 6.00 | 6.41 |
| 16 | 16.00 | 22.34 | 0.00 | 0.00 | 0.00 | 0.00 | 4.00 | 5.59 |
| Total | 95.00 | 68.90 | 22.00 | 7.72 | 0.00 | 0.00 | 61.00 | 28.23 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood | 10.28 | 7.16 |
| Sawtimber | 66.34 | 21.07 |
| Stocking: Percent | 110.84 | 84.92 |
| Milacres | 1108.37 | 849.18 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 10

Site quality ........................................ Good ( > 80 ft. @ 50 years)

Product class objective .......................... Medium sawlog

Yield/Economic objective ........................ Maximize Cubic-feet harvest

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Table F-12. Information about test case 12 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 50.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 100.0 | 0.00 |
| 1 | 30.00 | 0.16 | 0.00 | 0.00 | 30.00 | 0.16 | 10.00 | 0.05 |
| 2 | 25.00 | 0.55 | 0.00 | 0.00 | 25.00 | 0.55 | 15.00 | 0.33 |
| 3 | 20.00 | 0.98 | 0.00 | 0.00 | 20.00 | 0.98 | 5.00 | 0.25 |
| 4 | 15.00 | 1.31 | 0.00 | 0.00 | 15.00 | 1.31 | 8.00 | 0.70 |
| 5 | 10.00 | 1.36 | 0.00 | 0.00 | 15.00 | 2.05 | 7.00 | 0.95 |
| 6 | 10.00 | 1.96 | 0.00 | 0.00 | 10.00 | 1.96 | 6.00 | 1.18 |
| 7 | 7.00 | 1.87 | 0.00 | 0.00 | 7.00 | 1.87 | 4.00 | 1.07 |
| 8 | 6.00 | 2.09 | 0.00 | 0.00 | 6.00 | 2.09 | 3.00 | 1.05 |
| 9 | 6.00 | 2.65 | 0.00 | 0.00 | 6.00 | 2.65 | 2.00 | 0.88 |
| 10 | 5.00 | 2.73 | 0.00 | 0.00 | 4.00 | 2.18 | 5.00 | 2.73 |
| 11 | 4.00 | 2.64 | 0.00 | 0.00 | 5.00 | 3.30 | 0.00 | 0.00 |
| 12 | 3.00 | 2.36 | 0.00 | 0.00 | 3.00 | 2.36 | 0.00 | 0.00 |
| 13 | 4.00 | 3.69 | 0.00 | 0.00 | 2.00 | 1.84 | 0.00 | 0.00 |
| 14 | 4.00 | 4.28 | 0.00 | 0.00 | 1.00 | 1.07 | 0.00 | 0.00 |
| 15 | 1.00 | 1.23 | 2.00 | 2.45 | 0.00 | 0.00 | 1.00 | 1.23 |
| 16 | 2.00 | 2.79 | 1.00 | 1.40 | 0.00 | 0.00 | 0.00 | 0.00 |
| 17 | 2.00 | 3.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 18 | 0.00 | 0.00 | 2.00 | 3.53 | 0.00 | 0.00 | 0.00 | 0.00 |
| 19 | 0.00 | 0.00 | 1.00 | 1.97 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 0.00 | 0.00 | 2.00 | 4.36 | 0.00 | 0.00 | 0.00 | 0.00 |
| 21 | 0.00 | 0.00 | 1.00 | 2.41 | 0.00 | 0.00 | 0.00 | 0.00 |
| 22 | 0.00 | 0.00 | 1.00 | 2.64 | 0.00 | 0.00 | 0.00 | 0.00 |
| 23 | 0.00 | 0.00 | 1.00 | 2.89 | 0.00 | 0.00 | 0.00 | 0.00 |
| 24 | 0.00 | 0.00 | 1.00 | 3.14 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 154.0 | 35.80 | 12.00 | 24.79 | 149.0 | 24.37 | 66.00 | 10.41 |

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| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood | 23.19 | 5.83 |
| Sawtimber | 58.40 | 3.95 |
| Stocking: Percent | 135.90 | 37.27 |
| Milacres | 1358.97 | 372.65 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 5

Site quality .......... Good ( > 80 ft. @ 50 years)

Product class objective .......... Large sawlog

Yield/Economic objective .......... Maximize Board-feet harvest

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Table F-13. Information about test case 13 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 100.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 100.0 | 0.00 |
| 5 | 21.00 | 2.86 | 0.00 | 0.00 | 0.00 | 0.00 | 8.00 | 1.09 |
| 6 | 22.00 | 4.32 | 0.00 | 0.00 | 0.00 | 0.00 | 15.00 | 2.95 |
| 7 | 19.00 | 5.08 | 0.00 | 0.00 | 0.00 | 0.00 | 17.00 | 4.54 |
| 8 | 14.00 | 4.89 | 0.00 | 0.00 | 0.00 | 0.00 | 9.00 | 3.14 |
| 9 | 7.00 | 3.09 | 0.00 | 0.00 | 0.00 | 0.00 | 7.00 | 3.09 |
| 10 | 9.00 | 4.91 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 11 | 4.00 | 2.64 | 2.00 | 1.32 | 1.00 | 0.66 | 1.00 | 0.66 |
| 12 | 2.00 | 1.57 | 2.00 | 1.57 | 2.00 | 1.57 | 1.00 | 0.79 |
| 13 | 0.00 | 0.00 | 2.00 | 1.84 | 2.00 | 1.84 | 0.00 | 0.00 |
| 14 | 0.00 | 0.00 | 3.00 | 3.21 | 3.00 | 3.21 | 6.00 | 6.41 |
| 15 | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 | 3.68 | 0.00 | 0.00 |
| 16 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 2.79 | 0.00 | 0.00 |
| Total | 98.00 | 29.36 | 9.00 | 7.94 | 13.00 | 13.76 | 64.00 | 22.67 |

| | | Pine | Hardwood |
|---|---|---|---|
| Distribution of basal area: | Pulpwood | 20.24 | 14.81 |
| | Sawtimber | 30.82 | 7.86 |
| Stocking: | Percent | 81.75 | 47.57 |
| | Milacres | 817.49 | 475.71 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 10

Site quality ........................................................ Good ( > 80 ft. @ 50 years)

Product class objective ........................................ Medium sawlog

Yield/Economic objective ................................... Maximize Net present value

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Table F-14. Information about test case 14 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 1200 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1500 | 0.00 |
| 2 | 10.00 | 0.22 | 2.00 | 0.04 | 0.00 | 0.00 | 10.00 | 0.22 |
| 4 | 8.00 | 0.70 | 2.00 | 0.17 | 0.00 | 0.00 | 7.00 | 0.61 |
| 6 | 6.00 | 1.18 | 2.00 | 0.39 | 0.00 | 0.00 | 6.00 | 1.18 |
| 8 | 6.00 | 2.09 | 0.00 | 0.00 | 0.00 | 0.00 | 4.00 | 1.40 |
| 10 | 4.00 | 2.18 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 1.09 |
| Total | 34.00 | 6.37 | 6.00 | 0.61 | 0.00 | 0.00 | 29.00 | 4.49 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood | 4.54 | 3.19 |
| Sawtimber | 2.18 | 1.09 |
| Stocking: Percent | 213.12 | 259.02 |
| Milacres | 2131.22 | 2590.24 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 15

Site quality .......... Medium ( 70-80 ft. @ 50 years)

Product class objective .......... Small sawlog

Yield/Economic objective .......... Maximize Board-feet harvest

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Table F-15. Information about test case 15 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 200.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 300.0 | 0.00 |
| 4 | 15.00 | 1.31 | 6.00 | 0.52 | 0.00 | 0.00 | 12.00 | 1.05 |
| 6 | 10.00 | 1.96 | 6.00 | 1.18 | 0.00 | 0.00 | 10.00 | 1.96 |
| 8 | 5.00 | 1.75 | 7.00 | 2.44 | 0.00 | 0.00 | 8.00 | 2.79 |
| 10 | 7.00 | 3.82 | 0.00 | 0.00 | 0.00 | 0.00 | 4.00 | 2.18 |
| 12 | 3.00 | 2.36 | 0.00 | 0.00 | 3.00 | 2.36 | 4.00 | 3.14 |
| 14 | 2.00 | 2.14 | 0.00 | 0.00 | 2.00 | 2.14 | 6.00 | 6.41 |
| 16 | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 | 4.19 | 2.00 | 2.79 |
| 18 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 3.53 | 0.00 | 0.00 |
| 20 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 2.18 | 0.00 | 0.00 |
| 22 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 2.64 | 0.00 | 0.00 |
| Total | 42.00 | 13.33 | 19.00 | 4.15 | 12.00 | 17.04 | 46.00 | 20.33 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood | 9.16 | 5.80 |
| Sawtimber | 25.35 | 14.53 |
| Stocking: Percent | 75.64 | 75.53 |
| Milacres | 756.42 | 755.27 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 15

Site quality ........................................ Good ( > 80 ft. @ 50 years)

Product class objective ........................................ Medium sawlog

Yield/Economic objective ........................................ Maximize Internal rate of return

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Table F-16. Information about test case 16 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 250.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 300.0 | 0.00 |
| 4 | 10.00 | 0.87 | 2.00 | 0.17 | 0.00 | 0.00 | 17.00 | 1.48 |
| 6 | 10.00 | 1.96 | 5.00 | 0.98 | 0.00 | 0.00 | 21.00 | 4.12 |
| 8 | 10.00 | 3.49 | 8.00 | 2.79 | 0.00 | 0.00 | 19.00 | 6.63 |
| 10 | 10.00 | 5.45 | 10.00 | 5.45 | 0.00 | 0.00 | 14.00 | 7.64 |
| 12 | 10.00 | 7.85 | 0.00 | 0.00 | 9.00 | 7.07 | 7.00 | 5.50 |
| 14 | 10.00 | 10.69 | 0.00 | 0.00 | 7.00 | 7.48 | 9.00 | 9.62 |
| 16 | 10.00 | 13.96 | 0.00 | 0.00 | 6.00 | 8.38 | 7.00 | 9.77 |
| Total | 70.00 | 44.29 | 25.00 | 9.40 | 22.00 | 22.93 | 94.00 | 44.77 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood ............................... | 10.28 | 12.24 |
| Sawtimber.............................. | 66.34 | 32.53 |
| Stocking: Percent ............................................................... | 127.50 | 104.90 |
| Milacres ............................................................ | 1275.04 | 1048.99 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 10

Site quality ............................................................. Good ( > 80 ft. @ 50 years)

Product class objective ......................................... Medium sawlog

Yield/Economic objective ................................... Maximize Cubic-feet harvest

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Table F-17. Information about test case 17 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 150.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1000 | 0.00 |
| 1 | 30.00 | 0.16 | 0.00 | 0.00 | 30.00 | 0.16 | 50.00 | 0.27 |
| 2 | 25.00 | 0.55 | 0.00 | 0.00 | 25.00 | 0.55 | 60.00 | 1.31 |
| 3 | 20.00 | 0.98 | 0.00 | 0.00 | 20.00 | 0.98 | 35.00 | 1.72 |
| 4 | 15.00 | 1.31 | 0.00 | 0.00 | 15.00 | 1.31 | 25.00 | 2.18 |
| 5 | 15.00 | 2.05 | 0.00 | 0.00 | 10.00 | 1.36 | 20.00 | 2.73 |
| 6 | 10.00 | 1.96 | 0.00 | 0.00 | 10.00 | 1.96 | 25.00 | 4.91 |
| 7 | 9.00 | 2.41 | 0.00 | 0.00 | 5.00 | 1.34 | 8.00 | 2.14 |
| 8 | 6.00 | 2.09 | 0.00 | 0.00 | 6.00 | 2.09 | 25.00 | 8.73 |
| 9 | 8.00 | 3.53 | 0.00 | 0.00 | 4.00 | 1.77 | 8.00 | 3.53 |
| 10 | 7.00 | 3.82 | 0.00 | 0.00 | 2.00 | 1.09 | 8.00 | 4.36 |
| 11 | 7.00 | 4.62 | 0.00 | 0.00 | 2.00 | 1.32 | 0.00 | 0.00 |
| 12 | 5.00 | 3.93 | 0.00 | 0.00 | 1.00 | 0.79 | 10.00 | 7.85 |
| 13 | 6.00 | 5.53 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 14 | 5.00 | 5.35 | 0.00 | 0.00 | 0.00 | 0.00 | 12.00 | 12.83 |
| 15 | 3.00 | 3.68 | 0.00 | 0.00 | 0.00 | 0.00 | 4.00 | 4.91 |
| 16 | 3.00 | 4.19 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.40 |
| Total | 174.00 | 46.15 | 0.00 | 0.00 | 130.00 | 14.72 | 291.0 | 58.87 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood .............................. | 23.19 | 24.22 |
| Sawtimber ............................ | 34.31 | 31.35 |
| Stocking: Percent .............................................................. | 130.59 | 268.27 |
| Milacres .............................................................. | 1305.93 | 2682.65 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 2

Site quality ............................................................ Good ( > 80 ft. @ 50 years)

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Product class objective .......................................... Large sawlog

Yield/Economic objective ..................................... Maximize Cubic-feet harvest

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Table F-18. Information about test case 18 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 500.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 200.0 | 0.00 |
| 3 | 15.00 | 0.74 | 3.00 | 0.15 | 15.00 | 0.74 | 7.00 | 0.34 |
| 4 | 20.00 | 1.75 | 4.00 | 0.35 | 4.00 | 0.35 | 5.00 | 0.44 |
| 5 | 20.00 | 2.73 | 0.00 | 0.00 | 3.00 | 0.41 | 6.00 | 0.82 |
| 6 | 15.00 | 2.95 | 0.00 | 0.00 | 4.00 | 0.79 | 0.00 | 0.00 |
| 7 | 10.00 | 2.67 | 0.00 | 0.00 | 6.00 | 1.60 | 5.00 | 1.34 |
| 8 | 10.00 | 3.49 | 0.00 | 0.00 | 3.00 | 1.05 | 0.00 | 0.00 |
| 9 | 9.00 | 3.98 | 0.00 | 0.00 | 2.00 | 0.88 | 1.00 | 0.44 |
| 10 | 8.00 | 4.36 | 0.00 | 0.00 | 1.00 | 0.55 | 1.00 | 0.55 |
| 11 | 8.00 | 5.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 12 | 6.00 | 4.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 121.0 | 32.65 | 7.00 | 0.50 | 38.00 | 6.36 | 25.00 | 3.92 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood .............................. | 22.98 | 3.03 |
| Sawtimber ............................ | 14.90 | 0.55 |
| Stocking: Percent ................................................................ | 146.94 | 41.18 |
| Milacres ................................................................ | 1469.37 | 411.82 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 5

Site quality .................................................... Good ( > 80 ft. @ 50 years)

Product class objective ......................................... Medium sawlog

Yield/Economic objective .................................... Maximize Cubic-feet harvest

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Table F-19. Information about test case 19 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 75.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 100.0 | 0.00 |
| 3 | 0.00 | 0.00 | 10.00 | 0.49 | 17.00 | 0.83 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 | 11.00 | 0.96 | 11.00 | 0.96 | 7.00 | 0.61 |
| 5 | 0.00 | 0.00 | 10.00 | 1.36 | 9.00 | 1.23 | 14.00 | 1.91 |
| 6 | 0.00 | 0.00 | 10.00 | 1.96 | 6.00 | 1.18 | 19.00 | 3.73 |
| 7 | 0.00 | 0.00 | 10.00 | 2.67 | 3.00 | 0.80 | 9.00 | 2.41 |
| 8 | 0.00 | 0.00 | 7.00 | 2.44 | 2.00 | 0.70 | 3.00 | 1.05 |
| 9 | 0.00 | 0.00 | 5.00 | 2.21 | 2.00 | 0.88 | 3.00 | 1.33 |
| 10 | 0.00 | 0.00 | 10.00 | 5.45 | 0.00 | 0.00 | 2.00 | 1.09 |
| 11 | 5.00 | 3.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 12 | 6.00 | 4.71 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.79 |
| 13 | 3.00 | 2.77 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 14 | 3.00 | 3.21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 15 | 4.00 | 4.91 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 16 | 1.00 | 1.40 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.40 |
| 17 | 0.00 | 0.00 | 1.00 | 1.58 | 0.00 | 0.00 | 0.00 | 0.00 |
| 18 | 0.00 | 0.00 | 2.00 | 3.53 | 0.00 | 0.00 | 0.00 | 0.00 |
| 19 | 1.00 | 1.97 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 1.00 | 2.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 24.00 | 24.44 | 76.00 | 22.67 | 50.00 | 6.58 | 59.00 | 14.30 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood ................................ | 17.36 | 11.03 |
| Sawtimber .............................. | 35.00 | 3.27 |
| Stocking: Percent ...................................................................... | 84.97 | 39.56 |
| Milacres ...................................................................... | 849.70 | 395.55 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 3

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Site quality ............................................................ Good ( > 80 ft. @ 50 years)

Product class objective .......................................... Large sawlog

Yield/Economic objective .................................... Maximize Board-feet harvest

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Table F-20. Information about test case 20 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 500.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1200 | 0.00 |
| 3 | 27.00 | 1.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 | 22.00 | 1.92 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 | 10.00 | 1.36 | 0.00 | 0.00 | 9.00 | 1.23 | 8.00 | 1.09 |
| 6 | 10.00 | 1.96 | 0.00 | 0.00 | 6.00 | 1.18 | 15.00 | 2.95 |
| 7 | 10.00 | 2.67 | 0.00 | 0.00 | 3.00 | 0.80 | 17.00 | 4.54 |
| 8 | 9.00 | 3.14 | 0.00 | 0.00 | 0.00 | 0.00 | 9.00 | 3.14 |
| 9 | 0.00 | 0.00 | 4.00 | 1.77 | 3.00 | 1.33 | 0.00 | 0.00 |
| 10 | 0.00 | 0.00 | 5.00 | 2.73 | 5.00 | 2.73 | 7.00 | 3.82 |
| 11 | 0.00 | 0.00 | 0.00 | 0.00 | 5.00 | 3.30 | 1.00 | 0.66 |
| 12 | 0.00 | 0.00 | 6.00 | 4.71 | 0.00 | 0.00 | 1.00 | 0.79 |
| 13 | 0.00 | 0.00 | 3.00 | 2.77 | 0.00 | 0.00 | 0.00 | 0.00 |
| 14 | 3.00 | 3.21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 15 | 4.00 | 4.91 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 16 | 1.00 | 1.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 96.00 | 21.90 | 18.00 | 11.97 | 31.00 | 10.56 | 58.00 | 16.98 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood | 17.36 | 11.72 |
| Sawtimber | 25.74 | 5.26 |
| Stocking: Percent | 147.19 | 225.04 |
| Milacres | 1471.94 | 2250.39 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 15

Site quality ........................................................ Medium ( 70-80 ft @ 50 years)

Product class objective .......................................... Medium sawlog

Yield/Economic objective ....................................... Maximize Cubic-feet harvest

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Table F-21. Information about test case 21 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 30.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 75.00 | 0.00 |
| 2 | 2.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 0.04 |
| 4 | 2.00 | 0.17 | 2.00 | 0.17 | 0.00 | 0.00 | 2.00 | 0.17 |
| 6 | 5.00 | 0.98 | 2.00 | 0.39 | 0.00 | 0.00 | 4.00 | 0.79 |
| 8 | 9.00 | 3.14 | 2.00 | 0.70 | 0.00 | 0.00 | 6.00 | 2.09 |
| 10 | 10.00 | 5.45 | 3.00 | 1.64 | 0.00 | 0.00 | 8.00 | 4.36 |
| 12 | 10.00 | 7.85 | 5.00 | 3.93 | 0.00 | 0.00 | 10.00 | 7.85 |
| 14 | 10.00 | 10.69 | 7.00 | 7.48 | 0.00 | 0.00 | 4.00 | 4.28 |
| 16 | 4.00 | 5.59 | 5.00 | 6.98 | 0.00 | 0.00 | 2.00 | 2.79 |
| 18 | 2.00 | 3.53 | 2.00 | 3.53 | 0.00 | 0.00 | 1.00 | 1.77 |
| 20 | 1.00 | 2.18 | 1.00 | 2.18 | 0.00 | 0.00 | 1.00 | 2.18 |
| Total | 55.00 | 39.64 | 29.00 | 27.01 | 0.00 | 0.00 | 40.00 | 26.33 |

| | | Pine | Hardwood |
|---|---|---|---|
| Distribution of basal area: | Pulpwood ............................... | 5.56 | 3.05 |
| | Sawtimber .............................. | 61.04 | 23.23 |
| Stocking: | Percent ................................................................ | 76.67 | 41.95 |
| | Milacres ................................................................ | 766.70 | 419.48 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 10

Site quality ........................................................ Good ( > 80 ft. @ 50 years)

Product class objective ......................................... Large sawlog

Yield/Economic objective .................................... Maximize Board-feet harvest

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Table F-22. Information about test case 22 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 40.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 150.0 | 0.00 |
| 4 | 2.00 | 0.17 | 0.00 | 0.00 | 2.00 | 0.17 | 20.00 | 1.75 |
| 6 | 2.00 | 0.39 | 3.00 | 0.59 | 2.00 | 0.39 | 20.00 | 3.93 |
| 8 | 4.00 | 1.40 | 2.00 | 0.70 | 4.00 | 1.40 | 20.00 | 6.98 |
| 10 | 5.00 | 2.73 | 3.00 | 1.64 | 3.00 | 1.64 | 10.00 | 5.45 |
| 12 | 7.00 | 5.50 | 4.00 | 3.14 | 2.00 | 1.57 | 5.00 | 3.93 |
| 14 | 10.00 | 10.69 | 5.00 | 5.35 | 0.00 | 0.00 | 3.00 | 3.21 |
| 16 | 10.00 | 13.96 | 5.00 | 6.98 | 0.00 | 0.00 | 2.00 | 2.79 |
| 18 | 4.00 | 7.07 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.77 |
| 20 | 2.00 | 4.36 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 2.18 |
| Total | 46.00 | 46.27 | 22.00 | 18.39 | 13.00 | 5.17 | 82.00 | 31.98 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood | 5.21 | 12.65 |
| Sawtimber | 64.62 | 19.33 |
| Stocking: Percent | 80.04 | 66.94 |
| Milacres | 800.37 | 669.42 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 15

Site quality .......... Good ( > 80 ft. @ 50 years)

Product class objective .......... Medium sawlog

Yield/Economic objective .......... Maximize Net present value

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Table F-23. Information about test case 23 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 40.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 50.00 | 0.00 |
| 4 | 7.00 | 0.61 | 0.00 | 0.00 | 0.00 | 0.00 | 10.00 | 0.87 |
| 6 | 5.00 | 0.98 | 10.00 | 1.96 | 0.00 | 0.00 | 12.00 | 2.36 |
| 8 | 15.00 | 5.24 | 10.00 | 3.49 | 0.00 | 0.00 | 15.00 | 5.24 |
| 10 | 20.00 | 10.91 | 10.00 | 5.45 | 0.00 | 0.00 | 11.00 | 6.00 |
| 12 | 25.00 | 19.63 | 10.00 | 7.85 | 0.00 | 0.00 | 7.00 | 5.50 |
| 14 | 5.00 | 5.35 | 5.00 | 5.35 | 0.00 | 0.00 | 3.00 | 3.21 |
| 16 | 5.00 | 6.98 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 2.79 |
| 18 | 3.00 | 5.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 2.00 | 4.36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 87.00 | 59.36 | 45.00 | 24.11 | 0.00 | 0.00 | 60.00 | 25.96 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood | 12.28 | 8.46 |
| Sawtimber | 71.19 | 17.50 |
| Stocking: Percent | 101.12 | 41.23 |
| Milacres | 1011.17 | 412.26 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 10

Site quality .............................................................. Good ( > 80 ft. @ 50 years)

Product class objective .......................................... Medium sawlog

Yield/Economic objective .................................... Maximize Cubic-feet harvest

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Table F-24. Information about test case 24 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 40.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 20.00 | 0.00 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 | 10.00 | 0.87 | 12.00 | 1.05 |
| 6 | 5.00 | 0.98 | 0.00 | 0.00 | 10.00 | 1.96 | 7.00 | 1.37 |
| 8 | 5.00 | 1.75 | 0.00 | 0.00 | 15.00 | 5.24 | 5.00 | 1.75 |
| 10 | 10.00 | 5.45 | 0.00 | 0.00 | 20.00 | 10.91 | 3.00 | 1.64 |
| 12 | 20.00 | 15.71 | 0.00 | 0.00 | 10.00 | 7.85 | 2.00 | 1.57 |
| 14 | 10.00 | 10.69 | 0.00 | 0.00 | 5.00 | 5.35 | 1.00 | 1.07 |
| 16 | 5.00 | 6.98 | 0.00 | 0.00 | 2.00 | 2.79 | 0.00 | 0.00 |
| 18 | 4.00 | 7.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 59.00 | 48.63 | 0.00 | 0.00 | 72.00 | 34.97 | 30.00 | 8.44 |

| | Pine | Hardwood |
|---|---|---|
| Distribution of basal area: Pulpwood ............................... | 10.80 | 4.17 |
| Sawtimber ............................. | 68.66 | 4.28 |
| Stocking: Percent ................................................................. | 97.01 | 15.94 |
| Milacres ................................................................. | 970.06 | 159.38 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 10

Site quality ............................................................ Good ( > 80 ft. @ 50 years)

Product class objective .......................................... Large sawlog

Yield/Economic objective .................................... Maximize Board-feet harvest

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Table F-25. Information about test case 25 as given to the testers

| DBH | Pine Growers | | Pine Thinners | | Pine Cutters | | Hardwood | |
|---|---|---|---|---|---|---|---|---|
| | #TPA | BA | #TPA | BA | #TPA | BA | #TPA | BA |
| 0 | 10.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 20.00 | 0.00 |
| 2 | 0.00 | 0.00 | 9.00 | 0.20 | 0.00 | 0.00 | 20.00 | 0.44 |
| 4 | 10.00 | 0.87 | 1.00 | 0.09 | 0.00 | 0.00 | 10.00 | 0.87 |
| 6 | 15.00 | 2.95 | 2.00 | 0.39 | 0.00 | 0.00 | 15.00 | 2.95 |
| 8 | 20.00 | 6.98 | 5.00 | 1.75 | 0.00 | 0.00 | 15.00 | 5.24 |
| 10 | 30.00 | 16.36 | 5.00 | 2.73 | 0.00 | 0.00 | 12.00 | 6.54 |
| 12 | 10.00 | 7.85 | 10.00 | 7.85 | 0.00 | 0.00 | 3.00 | 2.36 |
| 14 | 10.00 | 10.69 | 5.00 | 5.35 | 0.00 | 0.00 | 1.00 | 1.07 |
| 16 | 10.00 | 13.96 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 18 | 7.00 | 12.37 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 0.00 | 0.00 | 4.00 | 8.73 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 112.0 | 72.04 | 41.00 | 27.07 | 0.00 | 0.00 | 76.00 | 19.46 |

| | | Pine | Hardwood |
|---|---|---|---|
| Distribution of basal area: | Pulpwood | 13.02 | 9.05 |
| | Sawtimber | 85.89 | 9.97 |
| Stocking: | Percent | 114.52 | 33.54 |
| | Milacres | 1145.20 | 335.44 |

Percent of ground covered with understory vegetation (non-pine/hardwood): 5

Site quality ............................................................ Good ( > 80 ft. @ 50 years)

Product class objective .......................................... Medium sawlog

Yield/Economic objective .................................... Maximize Net present value

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# APPENDIX G

## PRESCRIPTIONS FOR 25 CASES, AS GIVEN TO THE EVALUATORS



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Table G-1. Prescriptions for Case 1, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| The stand is inadequately stocked to initiate uneven-aged management. But since there is no good seed source, clearcut, site prep, and plant back in pine and manage as even-aged. | The stand is inadequately stocked to initiate or continue uneven-aged management. But since there are sufficient pines of large dbh for seed trees, prescribe burn and leave the stand until it reaches at least 40% milacre stocking and 1000 pines per acre at which time cut the seed trees and manage as an even-aged stand. | — | The stand is inadequately stocked to initiate or continue uneven-aged management. Manage the stand using seed tree method by leaving 5-15 (or 5-10 sq. ft. per acre of basal area) well-spaced high-quality seed-bearing trees per acre. No mid/overstory hardwood control is recommended at this time, but evaluate the need at the end of each cutting cycle. | - | The stand is inadequately stocked to initiate or continue uneven-aged management. But since there is seed source for natural regeneration, spray and burn late summer or early fall. Leave the stand for 2 years at which time remove the seed trees and pre-commercial thin if greater than 1500 stems per acre of pines become established. Leave the stand for 20 years then manage as an even-aged. | The stand is inadequately stocked to initiate or continue uneven-aged management. Remove all hardwoods and regenerate using seed tree or shelterwood system. | The stand is inadequately stocked to initiate or continue uneven-aged management. Manage the stand using seed tree method by leaving 5-15 (or 5-10 sq. ft. per acre of basal area) well-spaced high-quality seed-bearing trees per acre. No mid/overstory hardwood control is recommended at this time, but evaluate the need at the end of each cutting cycle. |

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Table G-2. Prescriptions for Case 2, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| The stand is inadequately stocked to initiate or continue uneven-aged management. But since there are sufficient pines of large DBH for seed trees, prescribe burn and leave the stand until it reaches 40% milacre stocking with 1000 pines per acre at which time cut the seed trees and manage as an even-aged stand. Remove hardwoods by injecting with herbicides. | Continue to manage the stand using seed tree method by leaving 5-15 (or 5-10 sq.ft. per acre of basal area) well-space high-quality seed-bearing trees per acre. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. | The stand is inadequately stocked to initiate or continue uneven-aged management. But since there is adequate regeneration, remove immediately all pine and merchantable hardwood. Leave stand for about 15 years at which time begin managing the stand as an even-aged stand. | Continue to manage the stand using seed tree method by leaving 5-15 (or 5-10 sq.ft. per acre of basal area) well-space high-quality seed-bearing trees per acre. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. | - | The stand is inadequately stocked to initiate uneven-aged management. But since there is good seed source, leave stand for about 5 years or whenever pine reproduction is established cut seed trees then manage stand as even-aged. Salvage merchantable hardwood in year 1 and herbicide spray in year 2. | The stand is inadequately stocked to initiate uneven-aged management. Regenerate using seed tree or shelterwood. Harvest and kill non-merchantable hardwoods. | — |

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Table G-3. Prescriptions for Case 3, as given to the evaluators ( Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| The stand is adequately stocked to initiate uneven-aged management. Delay harvest for about 5 years then leave 55-60 sq. ft. per acre by cutting trees 15-inch DBH and larger. Apply a broadcast herbicide or stem inject the hardwoods to release the pines. | The stand is adequately stocked to initiate uneven-aged management. Leave stand for 15-20 years then leave 60 sq. ft. per acre by cutting trees 16-inch DBH and larger on a 5-year cutting cycle. Harvest and kill non-merchantable hardwoods. | - | The stand is adequately stocked to initiate uneven-aged management. Delay harvest for 5 years and then leave 35 sq. ft. per acre by cutting trees 16-inch DBH and larger. Cut all hardwood 6 inches and larger and spray to release regeneration. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 11 years at which time a residual growing stock of 54 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH plus trees from smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or treat with herbicides. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 7-11 years at which time a residual growing stock of 42-54 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH plus trees from smaller classes. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide applications. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 11 years at which time a residual growing stock of 45 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH plus trees from smaller classes. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or treat with herbicides. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is inadequately stocked to initiate uneven-aged management. There is not enough good seed source, thus clearcut, site prep and plant back in pine and manage stand as even-aged plantation. If pine is well distributed salvage hardwoods in year 1 and herbicide spray in year 2. |

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Table G-4. Prescriptions for Case 4, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| The stand is adequately stocked to initiate or continue uneven-aged management. Harvest and leave 65-70 sq. ft. per acre by cutting all cutters and thinners 18 inches DBH and larger. Leave stand for 3 years at which time retain residual growing stock of 55-60 sq. ft. per acre by cutting every 5 years trees above 18-inch DBH and thinning pines in smaller classes. Postpone hardwood control until the next cycle cut. | The stand has adequate stocking to initiate or continue uneven-aged management. Reduce cutters and leave stand for 1 year at which time an operable cut is possible and a residual growing stock of 64 sq. ft. per acre can be sustained by cutting every 5 years trees above 17-inch DBH plus trees from smaller classes. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand has adequate stocking to initiate or continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 45 sq. ft. per acre which can be sustained by cutting every 7 years trees above 14-inch DBH plus trees from smaller classes. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 7 years. | The stand has adequate stocking to initiate or continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 50-65 sq. ft. per acre which can be sustained by cutting every 5 years trees above 17-inch DBH plus trees from smaller classes. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is adequately stocked to initiate or continue uneven-aged management. Harvest and leave 50 sq. ft. per acre by cutting all cutters 19-inch DBH and larger. Leave stand for 5 years at which time retain residual growing stock of 50 sq. ft. per acre by cutting every 5 years trees above 16-inch DBH and thinning pine pulpwood. Remove all hardwood pulpwood and selectively spray for release of reproduction and saplings from hardwood. | — | The stand is adequately stocked to initiate or continue uneven-aged management. Leave stand for 3 years at which time a residual growing stock of 15 sq. ft. per acre can be sustained by cutting trees over 22-inch DBH on a 7-year cutting cycle. Salvage hardwood in year 1. Herbicide spray in year 2. | The stand is adequately stocked to initiate or continue uneven-aged management. Harvest and leave 60 sq. ft. per acre in 2 cuts about 3 years apart by cutting all cutters and thinners 16-inch DBH and larger. Harvest and kill non-merchantable hardwoods. |

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Table G-5. Prescriptions for Case 5, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| The stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 60 sq. ft. per acre of residual basal area, a 5-year cutting cycle, and a maximum DBH of 20 inches. Postpone harvest of mid/overstory hardwood until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately to 75 sq. ft. per acre and to 65 sq. ft. per acre in 2-3 years, after which a 7-year cutting cycle is used and a maximum DBH of 16 inches. Postpone harvest of mid/overstory hardwood until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 7 years. | The stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced to 60 sq. ft. per acre in 2 cuts about 3 years apart by cutting trees 18-inch DBH and larger on a 5-year cutting cycle. Harvest merchantable hardwood and kill non-merchantable hardwoods. | The stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 45-60 sq. ft. per acre of residual basal area, a 5-year cutting cycle, and a maximum DBH of 20 inches. Postpone harvest of mid/ overstory hardwood until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 75 sq. ft. per acre of residual basal area, a 5-year cutting cycle, and a maximum DBH of 20 inches. Postpone harvest of mid/overstory hardwood until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is well-stocked to initiate uneven-aged management. Basal area stocking should be immediately reduced to 15-20 sq. ft. per acre by cutting all cutters and thinning some thinners and growers. A residual growing stock of 80 sq. ft. per acre can be sustained on a 7-year cutting cycle by cutting trees above 22-inch DBH and thinning in smaller classes. Salvage hardwood in year 2. Herbicide spray in year 3. | The stand has excessive stocking for uneven-aged management. Basal area stocking should be immediately reduced to about 70-75 sq. ft. per acre by cutting all cutters and some thinners. Leave stand for 3 years at which time retain a residual growing stock of 55-60 sq. ft. per acre by cutting every 5 years trees above 19-inch DBH and thinning cutters and thinners. Cut and sell merchantable hardwoods during the first harvest and inject residual hardwoods. | The stand is heavily stocked for uneven-aged management. Basal area stocking should be immediately reduced to 50 sq. ft. per acre by removing thinners and cutters. Leave stand for 5 years at which time retain a residual growing stock of 50 sq. ft. per acre by cutting every 5 years trees above 20-inch DBH and larger. Remove all hardwood 6-inch DBH and larger. Inject remaining hardwood 2 inches at ground line. Spray or inject every 10 years. |

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Table G-6. Prescriptions for Case 6, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| The stand is inadequately stocked. There is no potential seed source,hence, site prepare, and either plant or direct seed. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. | - | The stand is inadequately stocked to immediately initiate or continue uneven-aged management. Leave stand for 15 years at which time an operable cut may be possible and a residual growing stock of 50 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH. Cut hardwood pulpwood and spray for release of pine. | The stand is fully stocked to initiate uneven-aged management. Leave stand for 15-20 years and manage as even-aged stand. Salvage larger hardwood in year 1 of possible. Herbicide spray to kill hardwood brush in year 2. | The stand is inadequately stocked. There is no potential seed source, hence, site prepare, and either plant or direct seed. Postpone harvest of mid/ overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. | The stand is understocked to immediately initiate uneven-aged management. Leave stand for 10 years at which time an operable cut is possible and a residual growing stock of 60 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH and thinning in the smaller classes. Harvest merchantable hardwood and kill non-merchantable hardwoods. | - | The stand is understocked to immediately initiate or continue uneven-aged management. Leave stand for 5 years at which time an operable cut may be possible. After the cut, manage as an even-aged stand. Hardwood density is excessive, so treat the stand with broadcast herbicides. |

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Table G-7. Prescriptions for Case 7, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 12-16 years at which time a residual growing stock of 43-51 sq. ft. per acre can be sustained by cutting every 5 years trees above 11-inch DBH plus trees in the smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or treat with herbicide. No understory woody vegetation control is recommended but evaluate in 5 years. Under-story woody and non-woody vegetation control is recommended during pine cyclic cut. | The stand is adequately stocked to initiate or continue uneven-aged management. Leave the stand for __ years at which time a residual growing stock of 60 sq. ft. per acre can be sustained by cutting trees 14-inch DBH and larger and thinning in smaller classes. Harvest merchantable hardwoods and kill the non-merchantable ones. | The stand is adequately stocked to initiate or continue uneven-aged management. Leave stand for 10 years at which time a residual growing stock of 80 sq. ft. per acre can be sustained by cutting trees above 22-inch DBH plus smaller classes on a 7-year cutting cycle. Salvage merchantable hardwood in year 1. Herbicide spray in year 2. | — | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 16 years at which time a residual growing stock of 55 sq. ft. per acre can sustained by cutting every 7 years trees above 12-inch DBH plus trees in the smaller classes. You might also consider a seed tree cut. Harvest and sell or remove mid/overstory hardwood immediately. Hardwood removal could include chainsaw fell or treat with herbicide. No understory woody vegetation control is recommended but evaluate | The stand is inadequately stocked to initiate or continue uneven-aged management. Leave stand for 5 years and remove trees 10-inch DBH and larger. Manage the residual pines as even-aged stand. Remove all merchantable hardwood by herbicide spray. | The stand is not adequately stocked to initiate or continue uneven-aged management. Harvest all merchantable hardwoods by injection with herbicides. Manage the residual pines as an even-aged stand. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 16 years at which time a residual growing stock of 51 sq. ft. per acre can be sustained by cutting every 5 years trees above 11-inch DBH plus trees in the smaller classes. You might also consider a seed tree cut. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide treatment. No understory woody vegetation control is recommended but evaluate in 5 years. |

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Table G-8. Prescriptions for Case 8, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 10 years at which time an operable cut may be possible. Cut less than growth until a growing stock of 50 sq. ft. per acre can be retained by cutting trees 10-inch DBH and larger. Cut all merchantable hardwood, spray for release. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 14 years at which time a residual growing stock of 55 sq. ft. per acre can be sustained by cutting every 7 years trees above 10-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately by either chainsaw fell or herbicide treatment. No understory woody vegetation control is recommended prior to next cyclic cut. Evaluate the need for competing vegetation control periodically. Understory non-woody vegetation control is recommended during pine cyclic cut. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 10 years at which time a residual growing stock of 80 sq. ft. per acre can be sustained by cutting every 7 years trees above 22-inch DBH and thinning in the smaller classes. Salvage merchantable hardwood. Herbicide spray to eliminate hardwood competition. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 12-16 years at which time a residual growing stock of 43-51 sq. ft. per acre can be sustained by cutting every 5 years trees above 11-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/ overstory hardwood immediately by either chainsaw fell or herbicide treatment. No understory woody vegetation control is recommended prior to next cyclic cut. Evaluate the need for competing vegetation control periodically. Understory non-woody vegetation control recommended during pine cyclic cut. | The stand is inadequately stocked to initiate uneven-aged management. Leave stand for ___ years at which time a residual growing stock of 60 sq. ft. per acre can be sustained by cutting trees 14-inch DBH and larger and thinning in smaller classes. Harvest merchantable hardwoods and kill the non-merchantable ones. | - | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 16 years at which time a residual growing stock of 51 sq. ft. per acre can be sustained by cutting every 5 years trees above 11-inch DBH plus trees in smaller classes. You might also consider a seed tree cut by leaving 5-15 well-spaced high quality seed-bearing trees per acre. Harvest and sell or remove mid/ overstory hardwood immediately by either chainsaw fell or herbicide treatment. No understory woody vegetation control is recommended prior to next cyclic cut. Evaluate the need for competing vegetation control periodically. Understory non-woody vegetation control is recommended during pine cyclic cut. | Stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 10 years at which time an operable cut may be possible leaving a residual growing stock of 55-60 sq. ft. per acre. Control hardwoods with broadcast herbicides. |

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Table G-9. Prescriptions for Case 9, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 9 years at which time a residual growing stock of 45 sq. ft. per acre can be sustained by cutting every 5 years trees above 18-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide application. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | Stand is adequately stocked to continue uneven-aged management. Leave stand for at least 5 years at which time an operable cut may be possible and leaving a residual growing stock of 55 sq. ft. per acre, cut every 5 years trees larger than 18-inch DBH and all cutters. Cut merchantable hardwoods and inject residual hardwoods with herbicides. | - | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 5-9 years at which time a residual growing stock of 42-54 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide application. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 9 years at which time a residual growing stock of 54 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide application. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | Stand is adequately stocked to continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 50 sq. ft. per acre by cutting thinners and cutters above 16-inch DBH. Cut every 5 years trees larger than 16-inch DBH. Cut all merchantable hardwood and spray fore release of good regeneration. | The stand is well-stocked to initiate uneven-aged management. Leave stand for 10 years at which time a residual growing stock of 80 sq. ft. per acre can be sustained by cutting every 7 years trees above 22-inch DBH and thinning smaller classes. Salvage all merchantable hardwoods in year 1 and herbicide spray in year 2. | The stand is adequately stocked to initiate uneven-aged management. Leave stand until a residual growing stock of 60 sq. ft. per acre can be retained by cutting trees 16 inches and larger and thinning in smaller classes. |

Table G-10. Prescriptions for Case 10, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| The stand has adequate stocking to initiate or continue uneven-aged management. Reduce cutters and leave stand for 4 years at which time an operable cut is possible and a residual growing stock of 58 sq. ft. per acre can be sustained by cutting every 5 years trees above 20-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide treatment. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | Tne stand is well-stocked to initiate or continue uneven-aged management. Leave stand for about 5 years at which time an operable cut is possible by light thinning pine pulpwood and sawtimber. A residual growing stock of 80 sq. ft. per acre can be sustained on a 7-year cutting cycle by cutting 22-inch DBH class and thinning from smaller classes. Harvest or salvage all merchantable hardwood. At year 6 herbicide spray to kill remaining hardwood. | The stand has adequate stocking to initiate or continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 45-46 sq. ft. per acre which can be sustained by cutting every 5 years trees above 20-inch DBH class plus trees in smaller classes. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide treatment. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is adequately stocked to initiate or continue uneven-aged management. Leave stand for 3 years at which time a residual growing stock of 55 sq. ft. per acre may be sustained by cutting every 5 years all trees larger than 20-inch DBH and thinning in smaller classes. Harvest merchantable hardwoods and inject residuals with herbicides. | The stand has adequate stocking to initiate or continue uneven-aged management. Reduce cutters and leave stand for 3 years at which time an operable cut is possible and a residual growing stock of 55 sq. ft. per acre can be sustained by cutting every 7 years trees above 14-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately by either chainsaw fell or herbicide treatment. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 7 years. | The stand is adequately stocked to initiate or continue uneven-aged management. Leave stand for about 5 years at which time a residual growing stock of 60 sq. ft. per acre can be sustained by cutting trees 18-inch DBH and larger. Harvest merchantable hardwoods and kill the non-merchantable ones. | The stand has adequate stocking to initiate or continue uneven-aged management. Reduce cutters and leave stand for 4 years at which time an operable cut is possible and a residual growing stock of 58 sq. ft. per acre can be sustained by cutting every 5 years trees above 20-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide treatment. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is adequately stocked to initiate or continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 50 sq. ft. per acre by cutting trees 20-inch DBH and larger and thinning cutters and growers 12-inch DBH and up. Continue on 5-year cutting cycle. Remove all merchantable hardwood, spray for release of good regeneration. |



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Table G-11. Prescriptions for Case 11, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
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| The stand has adequate stocking to initiate or continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of about 50 sq. ft. per acre by cutting trees 16-inch DBH and up and thinning in smaller classes. Remove all merchantable hardwood. You might also consider managing the stand as even-aged. | Stand has adequate stocking to initiate or continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 55 sq. ft. per acre may be sustained by cutting every 5 years trees above 15-inch DBH class and thinners and growers in smaller DBH classes. Harvest merchantable hardwoods and inject residual hardwoods with herbicides. | The current stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 45-60 sq. ft. per acre of residual basal area, a 5-year cutting cycle, and a maximum DBH of 16 inches. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide treatment. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | Stand has adequate stocking to initiate or continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 60 sq. ft. per acre which can be sustained by cutting every 5 years trees above 16-inch DBH and trees in smaller classes. Harvest merchantable hardwoods and kill non-merchantable hardwoods. | – | The current stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 45 sq. ft. per acre of residual basal area, a 5-year cutting cycle, and a maximum DBH of 16 inches. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide application. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The current stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 60 sq. ft. per acre of residual basal area, a 5-year cutting cycle, and a maximum DBH of 16 inches. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide treatment. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | Stand is well-stocked to initiate uneven-aged management. Leave stand for 5 years at which time a residual growing stock of 80 sq. ft. per acre can be sustained by cutting every 7 years trees above 22-inch DBH plus smaller classes. Salvage all merchantable hardwood in 3 years. Herbicide spray in year 4. |

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Table G-12. Prescriptions for Case 12, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
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| The stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced to 65-70 sq. ft. per acre by cutting trees 18-inch DBH and larger. Continue on a 5-year cutting cycle or manage as even-aged stand. Remove all merchantable hardwood. | The stand has adequate stocking to initiate or continue uneven-aged management. Reduce cutters and leave stand for 4 years at which time an operable cut is possible and a residual growing stock of 58 sq. ft. per acre which can be sustained by cutting every 5 years trees above 16-inch DBH plus trees in smaller classes. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand has adequate stocking to initiate uneven-aged management. A harvest cut can be made leaving a residual growing stock of 60 sq. ft. per acre which can be sustained by cutting every 5 years trees above 18-inch DBH plus trees in smaller classes. Harvest merchantable hardwoods and kill the non-merchantable ones. | The stand has adequate stocking to initiate or continue uneven-aged management. Reduce cutters and leave stand for 4 years at which time an operable cut is possible and residual growing stock of 58 sq. ft. per acre which can be sustained by cutting every 5 years trees above 16-inch DBH plus trees in smaller classes. Postpone harvest of mid/over-story hardwood until either an operable cut is possible or until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand has adequate stocking to initiate or continue uneven-aged management. Reduce cutters and leave stand for 3 years at which time an operable cut is possible and residual growing stock of 55 sq. ft. per acre which can be sustained by cutting every 7 years trees above 14-inch DBH plus trees in smaller classes. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 7 years. | The stand has adequate stocking to initiate or continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 45-46 sq. ft. per acre which can be sustained by cutting every 5 years trees above 16-inch DBH plus trees in smaller classes. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is well-stocked to initiate uneven-aged management. Reduce basal area stocking by thinning pine cutters and thinners. Leave stand for 3 years at which time an operable cut is possible and a residual growing stock of 80 sq. ft. per acre can be sustained on a 7-year cutting cycle. Cut all the merchantable hardwood in year 1 and herbicide spray if necessary. | The stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately to 65-70 sq. ft. per acre by cutting thinners larger than 18-inch DBH and cutters in smaller size classes. Leave stand for 3 years at which time a residual growing stock of 55-60 sq. ft. per acre may be sustained on a 5-year cutting cycle. No need for hardwood control but reassess at time of second harvest. |

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Table G-13. Prescriptions for Case 13, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
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| The stand is well-stocked to initiate uneven-aged management. Leave stand for 5 years at which time retain 80 sq. ft. per acre by cutting cutters and thinners which can be sustained on a 7-year cutting cycle. Harvest and remove all merchantable hardwood in year 1. Herbicide spray in year 2 if necessary. | Stand is adequately stocked to initiate or continue uneven-aged management. Cut 10 sq. ft. per acre and leave stand for 5 years at which time retain 40 sq. ft. per acre which can be sustained on a 5-year cutting cycle. Remove all merchantable hardwood, spray to release regeneration. | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for about 5 years at which time an operable cut is possible and a residual growing stock of 60 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH plus trees in smaller classes. Harvest merchantable hardwoods and kill non-merchantable hardwoods. | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 2-6 years at which time an operable cut is possible and a residual growing stock of 42-54 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide application. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | Stand is adequately stocked to initiate or continue uneven-aged management. Leave stand for 5 years at which time a residual growing stock of 55 sq. ft. per acre may be sustained on a 5-year cutting cycle. Remove cutters to achieve desired basal area. Inject the hardwoods immediately to release established pine seedlings and saplings. | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 6 years at which time an operable cut is possible and a residual growing stock of 54 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide application. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | - | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 4 years at which time an operable cut is possible and a residual growing stock of 55 sq. ft. per acre can be sustained by cutting every 5 years trees above 13-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide application. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. |

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Table G-14. Prescriptions for Case 14, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
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| The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 10-15 years at which time an operable cut may be possible leaving a residual growing stock of 55-60 sq. ft. per acre by cutting every 5 years trees larger than 14-inch DBH and thinning in smaller classes. Apply a broadcast herbicide to release established pines. | The stand is inadequately stocked to initiate uneven-aged management. Leave stand until an operable cut can be made by cutting trees 14-inch DBH and up and a residual growing stock of 60 sq. ft. per acre can be left and sustained. Harvest merchantable and kill non-merchantable hardwoods. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand 21 years at which time an operable cut is possible and a residual growing stock of 51 sq. ft. per acre can be sustained by cutting every 5 years trees above 11-inch DBH plus trees in smaller classes. You might also consider a seed tree cut by leaving 5-15 well-spaced high-quality seed-bearing trees per acre. No mid/overstory hardwood control is recommended at this time, but evaluate the need at the end of each cutting cycle. No understory woody vegetation control is recommended prior to next cyclic cut. Evaluate the need for competing vegetation control periodically. No understory non-woody vegetation control is recommended but evaluate every 5 years. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand 17-21 years at which time an operable cut is possible and a residual growing stock of 43-51 sq. ft. per acre can be sustained by cutting every 5 years trees above 11-inch DBH plus trees in smaller classes. You might also consider a seed tree cut by leaving 5-15 well-spaced high-quality seed-bearing trees per acre. No mid/overstory hardwood control is recommended at this time, but evaluate the need at the end of each cutting cycle. No understory woody vegetation control is recommended prior to next cyclic cut. Evaluate the need for competing vegetation control periodically. No understory non-woody vegetation control is recommended but evaluate every 5 years. | - | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand 19 years at which time an operable cut is possible and a residual growing stock of 45 sq. ft. per acre can be sustained by cutting every 7 years trees above 10-inch DBH plus trees in smaller classes. You might also consider a seed tree cut by leaving 5-15 well-spaced high-quality seed-bearing trees per acre. No mid/overstory hardwood control is recommended at this time, but evaluate the need at the end of each cutting cycle. No understory woody vegetation control is recommended prior to next cyclic cut. Evaluate the need for competing vegetation control periodically. No understory non-woody vegetation control is recommended but evaluate every 7 years. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 10 years at which time an operable cut may be possible leaving residual growing stock of 15 sq. ft. per acre by cutting every 5 years trees larger than 12-inch DBH and thinning in smaller classes. Cut all merchantable hardwoods, spray to release pine. | The stand is fully stocked to initiate uneven-aged management. Leave stand for about 15 years at which time an operable cut is possible and a residual growing stock of 80 sq. ft. per acre can be sustained by cutting 22-inch DBH plus smaller classes on a 7-year cutting cycle. Salvage merchantable hardwood and herbicide spray residuals. |

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Table G-15. Prescriptions for Case 15, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
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| The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 9 years at which time a residual growing stock of 45 sq. ft. per acre can be sustained by cutting every 5 years trees above 18-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide application. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | Stand has adequate stocking to continue uneven-aged management. A harvest cut can be made leaving 24 sq. ft. per acre by cutting 16-inch DBH. Continue on a 5-year cutting cycle cutting 1/2 of growth until 40-50 sq. ft. per acre can be retained. Cut merchantable hardwood, spray to release reproduction. | - | The stand has adequate stocking to continue uneven-aged management. Leave stand for 10-15 years at which time a residual growing stock of 60 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH and trees in smaller classes. Cut merchantable hardwood and kill non-merchantable. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 5-9 years at which time a residual growing stock of 42-54 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide application. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 9 years at which time a residual growing stock of 54 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide application. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | Stand has adequate stocking to continue uneven-aged management. If operable, harvest pine cutters larger than 16-inch DBH. Postpone second harvest 10 years. During first harvest, cut and sell merchantable hardwoods and inject residual hardwoods with herbicides. | The stand is adequately stocked to initiate uneven-aged management. Leave stand for 10 years at which time a residual growing stock of 80 sq. ft. per acre can be sustained by cutting every 7 years trees above 22-inch DBH and thinning from smaller classes. Salvage all merchantable hardwood immediately. Herbicide spray in year 2 if needed. |

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Table G-16. Prescriptions for Case 16, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
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| The stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 45 sq. ft. per acre, a 5-year cutting cycle and a maximum DBH of 16 inches. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide application. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand has adequate stocking to initiate or continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 55 sq. ft. per acre of basal area which may be sustained by cutting every 5 years trees above 18-inch DBH class and thinning in smaller classes. Cut and sell merchantable hardwoods and inject residuals with herbicides. | - | The stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 60 sq. ft. per acre, a 5-year cutting cycle and a maximum DBH of 16 inches. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide application. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is adequately stocked to initiate uneven-aged management. Reduce basal area stocking immediately to 60 sq. ft. per acre by cutting all cutters and thinners. Leave stand for 5 years at which time a residual growing stock of 80 sq. ft. per acre can be sustained on a 7-year cutting cycle. Cut all merchantable hardwood immediately. Herbicide spray in year 2. | The stand has adequate stocking to initiate uneven-aged management. A harvest cut can be made leaving a residual growing stock of 50 sq. ft. per acre by cutting trees 16-inch DBH and larger and which can be sustained on a 5-year cutting cycle. Cut merchantable and kill non-merchantable hardwoods. | Stand has adequate stocking to initiate or continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 50 sq. ft. per acre by removing cutters 12 to 16 inches DBH. A residual growing stock of 45-50 sq. ft. per acre can be sustained on a 5-year cycle. Remove all merchantable hardwood, spray to release pine reproduction. | The stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 45-60 sq. ft. per acre, a 5-year cutting cycle and a maximum DBH of 16 inches. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide application.Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. |

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Table G-17. Prescriptions for Case 17, as given to the evaluators (prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| The stand has adequate stocking to initiate or continue uneven-aged management. A harvest cut can be made leaving about 40 sq. ft. per acre by cutting cutters 12-inch DBH and larger. A residual growing stock can be sustained on a 5-year cycle cutting trees 22-inch DBH and larger. Cut all merchantable hardwood, spray to release pine. | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for about 5 years at which time an operable cut is possible and a residual growing stock of 60 sq. ft. per acre can be sustained by cutting every 5 years trees larger than 18-inch DBH and thinning cutters and thinners in smaller classes. Cut merchantable hardwood and kill non-merchantable ones. | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for about 6 years at which time an operable cut is possible and a residual growing stock of 55-60 sq. ft. per acre may be sustained by cutting every 5 years trees larger than 19-inch DBH and thinning cutters and thinners in smaller classes. Need to harvest merchantable hardwoods immediately and inject the residuals with herbicides. | - | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 5 years at which time an operable cut is possible and a residual growing stock of 57 sq. ft. per acre can be sustained by cutting every 5 years trees above 19-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide treatment. No understory woody vegetation control is recommended prior to next cyclic cut. Evaluate the need for competing vegetation control periodically. No understory non-woody vegetation control is recommended but evaluate every 5 years. | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 3 years at which time an operable cut is possible and a residual growing stock of 55 sq. ft. per acre can be sustained by cutting every 7 years trees above 13-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide treatment. No understory woody vegetation control is recommended prior to next cyclic cut. Evaluate the need for competing vegetation control periodically. No understory non-woody vegetation control is recommended but evaluate every 5 years. | The stand is well-stocked to initiate uneven-aged management. Reduce basal area stocking to 50 sq. ft. per acre by cutting all cutters. Leave stand for 7-10 years at which time a residual growing stock of 80 sq. ft. per acre can be sustained on a 7-year cutting cycle. Salvage all merchantable hardwood. Herbicide spray to kill remaining hardwood. | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 1-5 years at which time an operable cut is possible and a residual growing stock of 45-57 sq. ft. per acre can be sustained by cutting every 5 years trees above 19-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide treatment. No understory woody vegetation control is recommended prior to next cyclic cut. Evaluate the need for competing vegetation control periodically. No understory non-woody vegetation control is recommended but evaluate every 5 years. |

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Table G-18. Prescriptions for Case 18, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
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| The stand is in-adequately stocked to immediately initiate uneven-aged management. Leave stand for 10 years at which time a residual growing stock of 60 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH plus trees in smaller classes. Cut merchantable hardwoods and kill non-merchantable. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 9 years at which time a residual growing stock of 54 sq. ft. per acre can be sustained by cutting every 5 years trees above 14-inch DBH plus trees in smaller classes. No mid/overstory hardwood control is recommended at this time but evaluate the need at the end of each cutting cycle. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 5-9 years at which time a residual growing stock of 42-54 sq. ft. per acre can be sustained by cutting every 5 years trees above 14-inch DBH plus trees in smaller classes. No mid/overstory hardwood control is recommended at this time but evaluate the need at the end of each cutting cycle. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is adequately stocked to initiate uneven-aged management. Leave stand for 5 years then thin pulpwood class. Leave stand for another 5 years at which time a residual growing stock of 80 sq. ft. per acre can be sustained by cutting pine sawtimber on 7-year cutting cycle. Salvage all merchantable hardwood. Herbicide spray to kill hardwood brush. | The stand is adequately stocked to initiate or continue uneven-aged management. Leave stand for 5 years at which time an operable cut is possible and residual growing stock,of 50 sq. ft. per acre can be sustained by cutting every 5 years. Postpone hardwood cut until pine harvest. | - | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 9 years at which time a residual growing stock of 45 sq. ft. per acre can be sustained by cutting every 7 years trees above 13-inch DBH plus trees in smaller classes. No mid/overstory hardwood control is recommended at this time but evaluate the need at the end of each cutting cycle. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is adequately stocked to initiate or continue uneven-aged management. Leave stand for 5-10 years at which time an operable cut may be possible and a residual growing stock of 55 sq. ft. per acre may be sustained by cutting every 5 years. Delay hardwood control until the pine harvest. |

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Table G-19. Prescriptions for Case 19, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
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| The stand is well-stocked to initiate uneven-aged management. Leave stand for 5-10 years at which time a residual growing stock of 80 sq. ft. per acre can be sustained by cutting every 7 years trees above 22-inch DBH and thinning in smaller classes. Salvage all merchantable hardwood. | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 6 years at which time an operable cut is possible and a residual growing stock of 53 sq. ft. per acre can be sustained by cutting every 5 years trees above 20-inch DBH plus trees in smaller classes. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 4 years at which time an operable cut is possible and a residual growing stock of 45 sq. ft. per acre can be sustained by cutting every 7 years trees above 13-inch DBH plus trees in smaller classes. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 7 years. | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 3-6 years at which time an operable cut is possible and a residual growing stock of 44-53 sq. ft. per acre can be sustained by cutting every 5 years trees above 20-inch DBH plus trees in smaller classes. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is adequately stocked to initiate or continue uneven-aged management. Leave stand for 5-10 years at which time an operable cut is possible and a residual growing stock of 60 sq. ft. per acre may be sustained by cutting every 5 years trees above 18-inch DBH and thinning in smaller classes. Cut merchantable and kill non-merchantable hardwoods. | — | The stand is adequately stocked to continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 40 sq. ft. per acre by cutting trees 12-inch DBH and larger. Continue on a 5-year cutting cycle. Cut all hardwood, spray for pine release. | The stand is adequately stocked to initiate or continue uneven-aged management. Leave stand for 5 years at which time an operable cut is possible and a residual growing stock of 55 sq. ft. per acre may be sustained by cutting every 5 years trees above 19-inch DBH and thinning cutters and thinners in smaller classes. Postpone hardwood control until the first pine harvest. |

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Table G-20. Prescriptions for Case 20, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| - | The stand is fairly well-stocked to initiate uneven-aged management. Leave stand for about 5 years at which time a residual growing stock of 80 sq. ft. per acre can be sustained on a 7-year cutting cycle. Salvage all merchantable hardwood in year 4. Thin pine sawtimber in year 5. Herbicide spray in year 6. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 4-8 years at which time a residual growing stock of 43-51 sq. ft. per acre can be sustained by cutting every 5 years trees above 17-inch DBH plus trees in smaller classes. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. No understory woody vegetation control is recommended prior to next cyclic cut. Evaluate the need for competing vegetation control periodically. No understory non-woody vegetation control is recommended but evaluate every 5 years. | Stand is adequately stocked to initiate or continue uneven-aged management. Leave stand for about 10 years at which time a residual growing stock of 55 sq. ft. per acre may be sustained by cutting every 5 years trees above 18-inch DBH and thinning cutters and thinners in smaller DBH classes. Inject or broadcast spray hardwoods with herbicides if the hardwoods overtop the pine seedlings. | The stand is adequately stocked to initiate or continue uneven-aged management. Leave stand for 5 years at which time a residual growing stock of 45-50 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH. Cut all hardwood, spray to release reproduction. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 8 years at which time a residual growing stock of 51 sq. ft. per acre can be sustained by cutting every 5 years trees above 17-inch DBH plus trees in smaller classes. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. No understory woody vegetation control is recommended prior to next cyclic cut. Evaluate the need for competing vegetation control periodically. No understory non-woody vegetation control is recommended but evaluate every 5 years. | The stand is inadequately stocked to immediately initiate uneven-aged management. Leave stand for 8 years at which time a residual growing stock of 55 sq. ft. per acre can be sustained by cutting every 7 years trees above 14-inch DBH plus trees in smaller classes. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. No understory woody vegetation control is recommended prior to next cyclic cut. Evaluate the need for competing vegetation periodically. No understory non-woody vegetation control is recommended but evaluate every 7 years. | Stand is adequately stocked to initiate or continue uneven-aged management. Leave stand for about 10-15 years at which time a commercial cut can be made and a residual growing stock of 60 sq. ft. per acre may be sustained by cutting every 5 years trees above 16-inch DBH and thinning in smaller DBH classes. Cut merchantable and kill non-merchantable hardwoods. |

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Table G-21. Prescriptions for Case 21, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| The stand is adequately stocked to initiate or continue uneven-aged management. If there is an operable cut of 1500 fbm per acre, leave a residual growing stock of 55 sq. ft. per acre may be sustained by cutting every 5 years trees above 18-inch DBH and thinning in smaller classes. Harvest merchantable hardwoods,and inject residuals with herbicides. | The stand is adequately stocked to initiate or continue uneven-aged management. Leave stand for about 3 years at which time an operable cut is possible leaving a residual growing stock of 60 sq. ft. per acre which can be sustained by cutting every 5 years trees above 18-inch DBH and thinning in smaller classes. Cut merchantable hardwoods and kill non-merchantable ones. | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 2 years at which time an operable cut is possible and a residual growing stock of 58 sq. ft. per acre can be sustained by cutting every 5 years trees above 20-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide treatment. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 2 years at which time an operable cut is possible and a residual growing stock of 58 sq. ft. per acre can be sustained by cutting every 5 years trees above 20-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide treatment. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is adequately stocked to initiate or continue uneven-aged management. A harvest cut can be made leaving 40 sq. ft. per acre by cutting all trees 12-inch DBH and larger which can be sustained on a 5-year cutting cycle cutting trees 20-inch DBH and larger. Cut all hardwood now, spray to release reproduction. | The stand adequate stocking to initiate or continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 45 sq. ft. per acre which can be sustained by cutting every 5 years trees above 18-inch DBH class plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide treatment. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand adequate stocking to initiate or continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 45-52 sq. ft. per acre which can be sustained by cutting every 5 years trees above 20-inch DBH class plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide treatment. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is fairly heavily stocked. Leave stand for 5 years at which time harvest cut can be made leaving a residual growing stock of 80 sq. ft. per acre which can be sustained by cutting every 7 years trees above 22-inch DBH and thinning in smaller classes. Salvage all merchantable hardwood. |

Table G-22. Prescriptions for Case 22, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| The stand is adequately stocked to initiate or continue uneven-aged management. If there is an operable cut of 1500 fbm per acre, leave a residual growing stock of 55 sq. ft. per acre which may be sustained by cutting every 5 years trees above 18-inch DBH and thinning cutters and thinners in smaller classes.Harvest merchantable hardwoods and inject residuals with herbicides. | The stand is adequately stocked to initiate or continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 60 sq. ft.per acre which can be sustained by cutting every 5 years trees above 16-inch DBH and thinning in smaller classes. Cut merchantable and kill non-merchantable hardwoods. | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 1 year at which time an operable cut is possible and a residual growing stock of 55 sq. ft. per acre can be sustained by cutting every 7 years trees above 16-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide application. Neither understory woody nor non-woody vegetation is recommended but evaluate in 7 years. | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 1 year at which time an operable cut is possible and a residual growing stock of 58 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide spray. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand has adequate stocking to initiate or continue uneven-aged management. Leave stand for 1 year at which time an operable cut is possible and a residual growing stock of 58 sq. ft. per acre can be sustained by cutting every 5 years trees above 16-inch DBH plus trees in smaller classes. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide spray. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand has adequate stocking to initiate or continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 45-55 sq. ft. per acre which can be sustained by cutting every 5 years trees above 16-inch DBH class plus trees in smaller classes. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide application. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is well-stocked to initiate uneven-aged management. Leave stand for 5 years at which time a residual growing stock of 80 sq. ft. per acre can be sustained by cutting every 7 years trees above 22-inch DBH and thinning in smaller classes. Salvage all merchantable hardwood and herbicide spray after pine thinning if necessary. | The stand is adequately stocked to initiate or continue uneven-aged management. A harvest cut can be made leaving a residual growing stock of 45 sq. ft.per acre which can be sustained by cutting every 5 years trees above 16-inch DBH and thinning in smaller classes. Cut all hardwood, spray to release reproduction. |



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Table G-23. Prescriptions for Case 23, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| The stand has adequate stocking to initiate or continue uneven-aged management. Reduce basal area to 70 sq. ft. per acre by thinning in the sawtimber classes. A residual growing stock of 80 sq. ft. per acre can be sustained by cutting on a 7-year cycle trees above 22-inch DBH and thinning in smaller classes. Salvage all merchantable hardwood in year 1. Herbicide spray in year 2. | The stand has excessive stocking for uneven-aged management. A harvest cut can be made leaving a residual growing stock of 50 sq. ft. per acre which can be sustained on a 5-year cutting cycle by cutting trees 16-inch DBH and larger and thinning in smaller classes. Cut all hardwood and spray to release pine reproduction. | The stand has excessive stocking for uneven-aged management. Cut trees larger than 16 inches and thin thinners to achieve desired diameter distribution leaving a residual basal area of about 70 sq. ft. per acre. Repeat in 3 years, cutting to a residual of 60 sq. ft. per acre. Cut merchantable and kill non-merchantable hardwoods. | The current stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 45 sq. ft. per acre of residual basal area, a 5-year cutting cycle, and a maximum DBH of 18 inches. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide application. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand has excessive stocking for uneven-aged management and needs thinning immediately. Cut growers larger than 18 inches and selectively thin thinners to achieve desired diameter distribution leaving a residual basal area of 70 sq. ft. per acre. Repeat in 3 years, cutting to a residual of 55 sq. ft. per acre. Cut and sell merchantable hardwoods and inject the residuals at time of first harvest. After second harvest, go to a 5-year cutting cycle. | The current stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 45-60 sq. ft. per acre of residual basal area, a 5-year cutting cycle, and a maximum DBH of 16 inches. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide spray. Neither understory woody or non-woody vegetation control is recommended but evaluate in 5 years. | - | The current stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 60 sq. ft. per acre of residual basal area, a 5-year cutting cycle, and a maximum DBH of 16 inches. Harvest and sell or remove mid/overstory hardwood immediately either by chainsaw fell or herbicide spray. Neither understory woody or non-woody vegetation control is recommended but evaluate in 5 years. |

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Table G-24. Prescriptions for Case 24, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| Stand is adequately stocked to continue uneven-aged management. Selectively thin all cutters and some growers to achieve desired diameter distribution. leaving 55 sq. ft. per acre. Repeat on a 5-year cutting cycle and consider hardwood injection at time of second cut. | The current stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 45-60 sq. ft. per acre of residual basal area, a 5-year cutting cycle, and a maximum DBH of 20 inches. Postpone harvest of mid/overstory hardwood until either an operable cut is possible or until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand has adequate stocking to initiate or continue uneven-aged management. Reduce basal area to 70 sq. ft. per acre by thinning pulpwood and sawtimber cutters. A residual growing stock of 80 sq. ft. per acre can be sustained by cutting on a 7-year cutting cycle trees above 22-inch DBH and thinning in smaller classes. Salvage all merchantable hardwood pulpwood. | The current stand is adequately stocked for uneven-aged management. A harvest cut can be made leaving a residual growing stock of 60 sq. ft. per acre which can be sustained on a 5-year cutting cycle by cutting trees 18-inch DBH and larger and thinning in smaller classes. Cut merchantable hardwood and kill non-merchantable ones. | - | The current stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 60 sq. ft. per acre of residual basal area, a 5-year cutting cycle, and a maximum DBH of 20 inches. Harvest and sell or remove mid/ overstory hardwood immediately either by chainsaw fell or herbicide spray. Neither understory woody or non-woody vegetation control is recommended but evaluate in 5 years. | The current stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 45 sq. ft. per acre of residual basal area, a 5-year cutting cycle, and a maximum DBH of 18 inches. Postpone harvest of mid/overstory hardwood until either an operable cut or until the first pine cyclic cut. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The current stand has excessive stocking for uneven-aged management. A harvest cut can be made leaving a residual growing stock of 50 sq. ft. per acre which can be sustained on a 5-year cutting cycle by cutting trees 16-inch DBH and larger and thinning in smaller classes. Cut all hardwood and spray to release pine reproduction. |

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Table G-25. Prescriptions for Case 25, as given to the evaluators (Prescriptions were randomly numbered 1 to 8).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| The current stand has excessive stocking for uneven-aged management. Basal area stocking should be immediately reduced to about 75 sq. ft. per acre by cutting thinners. Leave stand for 3 years at which time a residual growing stock of 60 sq. ft. per acre may be sustained by cutting every 5 years trees 15-inch DBH and larger and thinning in smaller DBH classes to improve diameter distribu-tion.Harvest all merchantable hardwoods and inject residuals with herbicides. | The current stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 45-60 sq. ft. per acre of residual basal area, a 5-year cutting cycle, and a maximum DBH of 16 inches. Harvest and sell mid/overstory hardwood. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is heavily stocked to initiate uneven-aged management. Reduce basal area to 80 sq. ft. per acre by thinning pine sawtimber classes. A residual growing stock of 80 sq. ft per acre can be sustained by cutting on a 7-year cycle trees above 22-inch DBH and thinning in smaller classes. Salvage all merchantable hardwood during pine cyclic cut. | The current stand has excessive stocking for uneven-aged management. Basal area stocking should be immediately reduced to 75 sq. ft. per acre and to 45 sq. ft. per acre in 2-3 years, after which a 5-year cutting cycle is used and a maximum DBH of 18 inches. Harvest and sell mid/overstory hardwood. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The stand is heavily stocked for uneven-aged management. Basal area stocking should be immediately reduced to 45 sq. ft. per acre by cutting trees 12-inch DBH and up. A residual growing stock of 50 sq. ft. per acre can be sustained on a 5-year cutting cycle by cutting trees 15-inch DBH and larger. Cut all hardwood, spray to release pine reproduction. | The current stand has excessive stocking for uneven-aged management. Basal area stocking should be immediately reduced to about 75 sq. ft. per acre by cutting thinners. Leave stand for 3 years at which time a residual growing stock of 60 sq. ft. per acre may be sustained by cutting every 5 years trees 16-inch DBH and larger and thinning in smaller DBH classes. Cut merchantable hardwoods and kill the non-merchantable ones. | The current stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 60 sq. ft. per acre of residual basal area, a 5-year cutting cycle, and a maximum DBH of 16 inches. Harvest and sell mid/overstory hardwood. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. | The current stand has excessive stocking for uneven-aged management. Basal area stocking should be reduced immediately by applying the following prescription: 75 sq. ft. per acre, a 5-year cutting cycle, and a maximum DBH of 16 inches. Harvest and sell mid/ overstory hardwood. Neither understory woody nor non-woody vegetation control is recommended but evaluate in 5 years. |

## APPENDIX H

## SCORES OF THE PRESCRIPTIONS GIVEN BY 9 EVALUATORS



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Table H-1. Scores of the prescriptions given by evaluator #1 ( 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

| CASE # | H1 | H2 | H3 | H4 | E1a | E1b | E1c | E2 |
|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 2 | 5 | 4 | 3 | 3 | . | 3 |
| 2 | 4 | 3 | 4 | 1 | 2 | 2 | . | 2 |
| 3 | 4 | 4 | 4 | 3 | 3 | 3 | . | 3 |
| 4 | 3 | 1 | 5 | 5 | 2 | 2 | . | 2 |
| 5 | 5 | 1 | 5 | 4 | 2 | 2 | 4 | 2 |
| 6 | 2 | 5 | 1 | 4 | 3 | 3 | . | 3 |
| 7 | 3 | 1 | 3 | 2 | 4 | 2 | . | 4 |
| 8 | 3 | 1 | 4 | 3 | 4 | 4 | . | 1 |
| 9 | 4 | 1 | 3 | 2 | 4 | 4 | . | 2 |
| 10 | 5 | 3 | 4 | 4 | 3 | 4 | 4 | 3 |
| 11 | 5 | 3 | 5 | 5 | 4 | 3 | . | 4 |
| 12 | 4 | 2 | 5 | 4 | 2 | 2 | 3 | 1 |
| 13 | 3 | 1 | 3 | 4 | 2 | 2 | . | 4 |
| 14 | 3 | 2 | 3 | 4 | 3 | 3 | . | 3 |
| 15 | 4 | 1 | 3 | 5 | 3 | 3 | . | 3 |
| 16 | 3 | 3 | 4 | 5 | 4 | 5 | . | 4 |
| 17 | 5 | 3 | 5 | 1 | 5 | 5 | . | 3 |
| 18 | 5 | 3 | 5 | 3 | 2 | 5 | . | 3 |
| 19 | 4 | 3 | 5 | 1 | 3 | 4 | . | 2 |
| 20 | 3 | 2 | 5 | 4 | 2 | 2 | . | 4 |
| 21 | 5 | 3 | 5 | 2 | 4 | 4 | 4 | 3 |
| 22 | 4 | 2 | 5 | 3 | 4 | 5 | 4 | 4 |
| 23 | 5 | 3 | 4 | 4 | 4 | 5 | . | 4 |
| 24 | 3 | 4 | 3 | 1 | 3 | 5 | . | 1 |
| 25 | 4 | 1 | 5 | 4 | 1 | 5 | 4 | 3 |

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Table H-2. Scores of the prescriptions given by evaluator #2 (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

| CASE # | H1 | H2 | H3 | H4 | E1a | E1b | E1c | E2 |
|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 5 | 4 | 4 | 3 | 3 | . | 3 |
| 2 | 2 | 2 | 3 | 1 | 4 | 4 | . | 4 |
| 3 | 1 | 2 | 2 | 3 | 4 | 4 | . | 4 |
| 4 | 4 | 1 | 2 | 1 | 3 | 3 | . | 3 |
| 5 | 5 | 1 | 3 | 4 | 2 | 4 | 5 | 2 |
| 6 | 3 | 2 | 2 | 4 | 1 | 1 | . | 1 |
| 7 | 2 | 1 | 2 | 3 | 5 | 4 | . | 4 |
| 8 | 2 | 1 | 1 | 5 | 3 | 4 | . | 5 |
| 9 | 1 | 1 | 4 | 1 | 3 | 4 | . | 2 |
| 10 | 4 | 2 | 3 | 4 | 5 | 4 | 4 | 2 |
| 11 | 5 | 1 | 4 | 3 | 2 | 2 | . | 1 |
| 12 | 5 | 1 | 4 | 2 | 2 | 2 | 2 | 2 |
| 13 | 4 | 1 | 3 | 3 | 5 | 5 | . | 4 |
| 14 | 2 | 1 | 3 | 1 | 4 | 4 | . | 4 |
| 15 | 5 | 1 | 3 | 4 | 4 | 3 | . | 3 |
| 16 | 3 | 1 | 4 | 5 | 5 | 4 | . | 4 |
| 17 | 4 | 1 | 3 | 2 | 4 | 3 | . | 2 |
| 18 | 5 | 1 | 4 | 3 | 4 | 4 | . | 3 |
| 19 | 4 | 1 | 5 | 1 | 4 | 4 | . | 1 |
| 20 | 3 | 1 | 4 | 4 | 3 | 3 | . | 4 |
| 21 | 5 | 1 | 5 | 1 | 4 | 4 | 4 | 3 |
| 22 | 3 | 1 | 3 | 4 | 4 | 3 | 3 | 3 |
| 23 | 4 | 1 | 2 | 3 | 4 | 4 | . | 3 |
| 24 | 5 | 1 | 5 | 3 | 4 | 4 | . | 4 |
| 25 | 4 | 1 | 4 | 1 | 4 | 5 | 4 | 2 |

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Table H-3. Scores of the prescriptions given by evaluator #3 (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

| CASE # | H1 | H2 | H3 | H4 | E1a | E1b | E1c | E2 |
|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 5 | 4 | 5 | 4 | 4 | . | 4 |
| 2 | 2 | 3 | 3 | 1 | 4 | 4 | . | 4 |
| 3 | 1 | 2 | 1 | 1 | 2 | 2 | . | 2 |
| 4 | 3 | 2 | 3 | 3 | 4 | 4 | . | 4 |
| 5 | 5 | 2 | 4 | 4 | 4 | 4 | 4 | 3 |
| 6 | 3 | 4 | 1 | 1 | 1 | 1 | . | 1 |
| 7 | 3 | 1 | 1 | 3 | 1 | 2 | . | 2 |
| 8 | 1 | 1 | 1 | 4 | 2 | 2 | . | 1 |
| 9 | 2 | 1 | 4 | 1 | 3 | 2 | . | 3 |
| 10 | 4 | 3 | 4 | 5 | 4 | 5 | 5 | 4 |
| 11 | 5 | 2 | 5 | 5 | 4 | 3 | . | 2 |
| 12 | 4 | 3 | 5 | 5 | 3 | 4 | 5 | 3 |
| 13 | 4 | 2 | 3 | 3 | 5 | 4 | . | 3 |
| 14 | 1 | 1 | 3 | 1 | 2 | 2 | . | 2 |
| 15 | 4 | 1 | 4 | 5 | 4 | 3 | . | 5 |
| 16 | 4 | 2 | 3 | 5 | 4 | 4 | . | 3 |
| 17 | 4 | 3 | 4 | 2 | 3 | 3 | . | 4 |
| 18 | 3 | 3 | 3 | 3 | 4 | 3 | . | 5 |
| 19 | 5 | 2 | 4 | 3 | 4 | 4 | . | 3 |
| 20 | 4 | 2 | 3 | 5 | 3 | 3 | . | 3 |
| 21 | 4 | 2 | 5 | 2 | 4 | 5 | 5 | 4 |
| 22 | 5 | 3 | 5 | 5 | 5 | 5 | 5 | 5 |
| 23 | 3 | 3 | 4 | 5 | 5 | 5 | . | 4 |
| 24 | 5 | 3 | 5 | 5 | 5 | 5 | . | 4 |
| 25 | 4 | 3 | 4 | 4 | 5 | 5 | 3 | 4 |

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Table H-4. Scores for the prescriptions given by evaluator #4 (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

| CASE # | H1 | H2 | H3 | H4 | E1a | E1b | E1c | E2 |
|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 4 | 4 | 3 | 5 | 5 | . | 5 |
| 2 | 3 | 5 | 4 | 1 | 3 | 3 | . | 3 |
| 3 | 2 | 3 | 2 | 3 | 1 | 1 | . | 5 |
| 4 | 4 | 1 | 2 | 3 | 5 | 2 | . | 2 |
| 5 | 5 | 1 | 4 | 2 | 3 | 4 | 4 | 3 |
| 6 | 2 | 4 | 5 | 3 | 1 | 1 | . | 1 |
| 7 | 4 | 3 | 2 | 4 | 4 | 2 | . | 2 |
| 8 | 4 | 3 | 4 | 2 | 2 | 2 | . | 2 |
| 9 | 4 | 2 | 2 | 2 | 5 | 5 | . | 3 |
| 10 | 3 | 2 | 5 | 3 | 3 | 3 | 3 | 4 |
| 11 | 4 | 2 | 4 | 2 | 5 | 4 | . | 5 |
| 12 | 4 | 3 | 4 | 3 | 3 | 5 | 5 | 4 |
| 13 | 4 | 2 | 5 | 3 | 5 | 5 | . | 4 |
| 14 | 1 | 1 | 1 | 1 | 3 | 3 | . | 3 |
| 15 | 2 | 2 | 4 | 3 | 4 | 5 | . | 4 |
| 16 | 3 | 2 | 4 | 5 | 4 | 3 | . | 2 |
| 17 | 3 | 4 | 4 | 2 | 5 | 4 | . | 1 |
| 18 | 4 | 3 | 3 | 4 | 4 | 3 | . | 3 |
| 19 | 4 | 2 | 5 | 1 | 3 | 3 | . | 1 |
| 20 | 3 | 2 | 4 | 3 | 3 | 3 | . | 5 |
| 21 | 4 | 2 | 4 | 2 | 3 | 5 | 5 | 4 |
| 22 | 2 | 1 | 5 | 4 | 4 | 3 | 3 | 3 |
| 23 | 5 | 2 | 4 | 4 | 3 | 4 | . | 3 |
| 24 | 4 | 2 | 4 | 2 | 4 | 5 | . | 3 |
| 25 | 5 | 1 | 4 | 3 | 4 | 4 | 3 | 3 |

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Table H-5. Scores of the prescriptions given by evaluator #5 (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

| CASE # | H1 | H2 | H3 | H4 | E1a | E1b | E1c | E2 |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 4 | 2 | 4 | 2 | 2 | . | 2 |
| 2 | 4 | 3 | 4 | 2 | 4 | 4 | . | 2 |
| 3 | 2 | 4 | 2 | 2 | 4 | 1 | . | 3 |
| 4 | 4 | 1 | 5 | 4 | 3 | 3 | . | 3 |
| 5 | 5 | 1 | 5 | 2 | 2 | 2 | 3 | 3 |
| 6 | 1 | 1 | 1 | 1 | 4 | 4 | . | 4 |
| 7 | 1 | 1 | 1 | 1 | 3 | 4 | . | 4 |
| 8 | 3 | 1 | 1 | 1 | 1 | 1 | . | 1 |
| 9 | 5 | 1 | 4 | 1 | 2 | 2 | . | 2 |
| 10 | 4 | 2 | 4 | 4 | 2 | 4 | 4 | 4 |
| 11 | 4 | 1 | 5 | 5 | 2 | 4 | . | 1 |
| 12 | 4 | 2 | 5 | 4 | 3 | 4 | 4 | 4 |
| 13 | 4 | 2 | 4 | 1 | 2 | 4 | . | 4 |
| 14 | 1 | 1 | 1 | 1 | 1 | 1 | . | 1 |
| 15 | 4 | 1 | 5 | 1 | 4 | 1 | . | 1 |
| 16 | 4 | 4 | 3 | 4 | 4 | 4 | . | 1 |
| 17 | 4 | 1 | 4 | 1 | 4 | 4 | . | 4 |
| 18 | 4 | 1 | 4 | 2 | 1 | 3 | . | 1 |
| 19 | 3 | 3 | 4 | 1 | 2 | 2 | . | 1 |
| 20 | 4 | 2 | 4 | 2 | 4 | 2 | . | 4 |
| 21 | 4 | 2 | 5 | 1 | 3 | 4 | 4 | 4 |
| 22 | 4 | 2 | 4 | 2 | 3 | 4 | 2 | 2 |
| 23 | 5 | 2 | 4 | 2 | 3 | 4 | . | 2 |
| 24 | 4 | 2 | 4 | 2 | 3 | 4 | . | 2 |
| 25 | 4 | 2 | 4 | 2 | 3 | 4 | 3 | 3 |

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Table H-6. Scores of the prescriptions given by evaluator #6 (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

| CASE # | H1 | H2 | H3 | H4 | E1a | E1b | E1c | E2 |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 5 | 3 | 1 | 2 | 2 | . | 1 |
| 2 | 3 | 2 | 5 | 1 | 1 | 1 | . | 1 |
| 3 | 1 | 4 | 1 | 1 | 1 | 1 | . | 1 |
| 4 | 2 | 1 | 3 | 4 | 1 | 1 | . | 1 |
| 5 | 4 | 1 | 2 | 2 | 1 | 1 | 1 | 1 |
| 6 | 4 | 1 | 1 | 3 | 1 | 1 | . | 1 |
| 7 | 2 | 1 | 1 | 3 | 1 | 1 | . | 1 |
| 8 | 1 | 1 | 1 | 1 | 1 | 1 | . | 1 |
| 9 | 4 | 1 | 1 | 1 | 1 | 2 | . | 2 |
| 10 | 2 | 1 | 1 | 4 | 1 | 1 | 1 | 2 |
| 11 | 2 | 1 | 4 | 2 | 1 | 1 | . | 1 |
| 12 | 1 | 2 | 4 | 2 | 1 | 1 | 1 | 1 |
| 13 | 3 | 2 | 5 | 2 | 1 | 1 | . | 1 |
| 14 | 1 | 1 | 5 | 1 | 1 | 1 | . | 1 |
| 15 | 2 | 1 | 5 | 1 | 1 | 1 | . | 1 |
| 16 | 3 | 2 | 2 | 4 | 1 | 1 | . | 1 |
| 17 | 2 | 4 | 5 | 1 | 1 | 1 | . | 1 |
| 18 | 1 | 2 | 3 | 4 | 1 | 1 | . | 1 |
| 19 | 1 | 1 | 4 | 2 | 1 | 1 | . | 1 |
| 20 | 3 | 1 | 5 | 4 | 1 | 1 | . | 1 |
| 21 | 4 | 1 | 5 | 1 | 1 | 1 | 3 | 1 |
| 22 | 5 | 1 | 4 | 2 | 2 | 1 | 1 | 3 |
| 23 | 4 | 1 | 4 | 1 | 1 | 1 | . | 1 |
| 24 | 2 | 1 | 4 | 1 | 1 | 5 | . | 1 |
| 25 | 4 | 1 | 5 | 1 | 1 | 1 | 1 | 1 |

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Table H-7. Scores of the prescriptions given by evaluator #7 (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

| CASE # | H1 | H2 | H3 | H4 | E1a | E1b | E1c | E2 |
|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 4 | 4 | 4 | 4 | 4 | . | 2 |
| 2 | 5 | 4 | 4 | 1 | 3 | 3 | . | 2 |
| 3 | 1 | 3 | 4 | 2 | 4 | 2 | . | 4 |
| 4 | 4 | 1 | 2 | 2 | 4 | 4 | . | 4 |
| 5 | 4 | 1 | 4 | 3 | 3 | 4 | 3 | 4 |
| 6 | 2 | 4 | 2 | 4 | 2 | 2 | . | 2 |
| 7 | 4 | 2 | 2 | 2 | 5 | 2 | . | 2 |
| 8 | 4 | 1 | 2 | 5 | 4 | 2 | . | 2 |
| 9 | 2 | 2 | 2 | 5 | 4 | 2 | . | 4 |
| 10 | 4 | 2 | 4 | 5 | 4 | 3 | 2 | 4 |
| 11 | 4 | 2 | 2 | 4 | 4 | 4 | . | 4 |
| 12 | 4 | 2 | 4 | 5 | 4 | 3 | 3 | 2 |
| 13 | 4 | 2 | 4 | 3 | 2 | 4 | . | 4 |
| 14 | 2 | 1 | 4 | 3 | 4 | 4 | . | 4 |
| 15 | 4 | 1 | 5 | 4 | 4 | 4 | . | 4 |
| 16 | 3 | 4 | 4 | 5 | 1 | 4 | . | 2 |
| 17 | 4 | 2 | 5 | 2 | 2 | 2 | . | 2 |
| 18 | 4 | 1 | 2 | 2 | 4 | 4 | . | 4 |
| 19 | 3 | 2 | 5 | 4 | 4 | 2 | . | 4 |
| 20 | 4 | 1 | 4 | 4 | 2 | 4 | . | 4 |
| 21 | 4 | 4 | 5 | 2 | 3 | 5 | 5 | 4 |
| 22 | 4 | 3 | 4 | 5 | 2 | 2 | 2 | 2 |
| 23 | 5 | 4 | 4 | 5 | 4 | 4 | . | 2 |
| 24 | 4 | 4 | 4 | 4 | 2 | 2 | . | 2 |
| 25 | 4 | 2 | 5 | 4 | 4 | 4 | 4 | 2 |

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Table H-8. Scores of the prescriptions given by evaluator #8 (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

| CASE # | H1 | H2 | H3 | H4 | E1a | E1b | E1c | E2 |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 5 | 1 | 1 | 1 | 1 | . | 1 |
| 2 | 2 | 4 | 5 | 1 | 1 | 1 | . | 2 |
| 3 | 2 | 1 | 1 | 1 | 1 | 2 | . | 1 |
| 4 | 3 | 1 | 2 | 4 | 5 | 1 | . | 2 |
| 5 | 5 | 1 | 3 | 2 | 4 | 3 | 4 | 2 |
| 6 | 4 | 3 | 1 | 1 | 1 | 1 | . | 1 |
| 7 | 2 | 1 | 2 | 2 | 2 | 2 | . | 2 |
| 8 | 1 | 1 | 2 | 2 | 2 | 2 | . | 2 |
| 9 | 4 | 1 | 2 | 2 | 3 | 4 | . | 3 |
| 10 | 4 | 1 | 1 | 2 | 3 | 4 | 4 | 1 |
| 11 | 1 | 1 | 3 | 3 | 3 | 2 | . | 2 |
| 12 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 |
| 13 | 4 | 1 | 4 | 2 | 3 | 4 | . | 2 |
| 14 | 4 | 1 | 1 | 1 | 2 | 2 | . | 2 |
| 15 | 1 | 1 | 4 | 1 | 2 | 3 | . | 4 |
| 16 | 3 | 1 | 1 | 4 | 4 | 4 | . | 4 |
| 17 | 2 | 1 | 1 | 1 | 2 | 1 | . | 1 |
| 18 | 4 | 1 | 5 | 2 | 3 | 2 | . | 4 |
| 19 | 3 | 1 | 4 | 2 | 4 | 4 | . | 1 |
| 20 | 3 | 1 | 4 | 1 | 2 | 2 | . | 2 |
| 21 | 2 | 1 | 4 | 1 | 4 | 5 | 5 | 2 |
| 22 | 4 | 1 | 2 | 4 | 4 | 4 | 4 | 4 |
| 23 | 2 | 1 | 1 | 2 | 4 | 4 | . | 2 |
| 24 | 2 | 1 | 4 | 2 | 2 | 5 | . | 3 |
| 25 | 3 | 1 | 3 | 1 | 3 | 5 | 1 | 1 |

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Table H-9. Scores of the prescriptions given by evaluator #9 (1= strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

| CASE # | H1 | H2 | H3 | H4 | E1a | E1b | E1c | E2 |
|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 3 | 3 | 2 | 4 | 4 | . | 4 |
| 2 | 5 | 4 | 3 | 2 | 4 | 4 | . | 4 |
| 3 | 2 | 2 | 2 | 3 | 5 | 3 | . | 3 |
| 4 | 2 | 2 | 2 | 2 | 4 | 2 | . | 2 |
| 5 | 4 | 2 | 2 | 3 | 2 | 3 | 3 | 2 |
| 6 | 5 | 3 | 4 | 4 | 1 | 1 | . | 1 |
| 7 | 2 | 2 | 2 | 1 | 4 | 2 | . | 2 |
| 8 | 2 | 2 | 2 | 3 | 4 | 2 | . | 2 |
| 9 | 2 | 2 | 3 | 1 | 4 | 3 | . | 3 |
| 10 | 2 | 2 | 2 | 2 | 4 | 2 | 2 | 3 |
| 11 | 4 | 2 | 2 | 2 | 3 | 2 | . | 3 |
| 12 | 2 | 2 | 4 | 2 | 2 | 3 | 3 | 3 |
| 13 | 3 | 2 | 2 | 3 | 4 | 3 | . | 2 |
| 14 | 4 | 1 | 3 | 2 | 2 | 2 | . | 2 |
| 15 | 4 | 2 | 3 | 2 | 4 | 3 | . | 2 |
| 16 | 3 | 2 | 3 | 4 | 2 | 2 | . | 2 |
| 17 | 2 | 4 | 2 | 2 | 2 | 2 | . | 2 |
| 18 | 3 | 2 | 3 | 3 | 5 | 4 | . | 4 |
| 19 | 2 | 2 | 4 | 2 | 2 | 3 | . | 2 |
| 20 | 2 | 2 | 2 | 4 | 4 | 3 | . | 5 |
| 21 | 4 | 2 | 4 | 2 | 2 | 2 | 3 | 3 |
| 22 | 3 | 2 | 2 | 2 | 4 | 2 | 2 | 4 |
| 23 | 2 | 2 | 2 | 4 | 4 | 5 | . | 2 |
| 24 | 3 | 2 | 4 | 2 | 4 | 3 | . | 2 |
| 25 | 4 | 2 | 3 | 2 | 3 | 3 | 5 | 2 |

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# VITA

Alfredo Lorenzo was born in Laoag City, Philippines on October 11, 1952. He received his B.S. in Forestry from the University of the Philippines at Los Banos in 1974. For the ensuing three years, he worked as Nursery Foreman, Company Forester, and Instructor at Marcos State University. In 1977, he started a 3-year contract as Assistant Conservator of Forests with the Nigerian government. He entered Lincoln University in Fall 1981 for graduate study in business administration. After receiving an MBA in 1983, he then started his Forestry graduate program at the University of California, Berkeley. He received his M.S. in Forestry in 1987. He started his Ph.D. program in Forest Management and Economics at Louisiana State University in Fall 1987. He is currently a candidate for Doctor of Philosophy in Forestry.



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DOCTORAL EXAMINATION AND DISSERTATION REPORT

**Candidate:** Alfredo B. Lorenzo

**Major Field:** Forestry

**Title of Dissertation:** Development and Evaluation of an Expert System Approach to Uneven-aged Management of Loblolly-Shortleaf Pine Stands in the West Gulf Region

**Approved:**

Quang V Cao
**Major Professor and Chairman**

**Dean of the Graduate School**

**EXAMINING COMMITTEE:**

Paul A. Murphy

Michael P. Mailander

**Date of Examination:**

October 22, 1993

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