AN ABSTRACT OF THE THESIS OF

Sarah Rebecca Hirte for the degree of Master of Science in Forest Resources presented September 13, 2002. Title: A Comparison Of The Value Of Forest Plans Developed Under Three Levels Of Detail Regarding Management Intentions.

Signature redacted for privacy.

Abstract approved:

Pete Bettinger

In the field of forest planning, assumptions regarding the appropriate modeling of management behavior, translated through management prescriptions, minimum harvest ages, green-up periods, and other variables are needed if a stand-level optimization process is not used to guide the selection of stand management regimes. Forest planners thus generally have a few options regarding the level of detail of management intentions they can model, from detailed, finely-tuned assumptions to coarser, less detailed assumptions. The question of interest to this study is whether similar forest plan results can be obtained over a range of detail assumed in the management intentions. With that in mind, forest plans are developed under three different levels of detail of management intentions. Using a simulated annealing heuristic, forest plans were developed for a 95,063 acre eastern Oregon private industrial forest, covering a fifty-year planning horizon.

Within this landscape 32,782 acres were even-aged forests, 22,106 acres were uneven-aged, and 40,175 acres were indicated as meadow or grassland.

A survey conducted by the Oregon Department of Forestry was used to define the management intentions. The finest level of detail was one where all of the management intention data available were used, allowing prescriptions to be developed by site class and species breakdowns. The intermediate level of detail, called the medium scale, represented management intentions, and hence prescriptions, developed by species information only, since site class information is generally difficult to obtain in a geographic information system (GIS) database across broad landscapes. The most aggregated level of detail was called the coarse scale. Here both site class and species information was ignored, and a generalized idea of what the management intentions, hence prescriptions, would be on uneven-aged and even-aged stands in eastern Oregon was developed.

Measure of economic, or commodity production, results were represented by net present value (NPV), timber volume production, and harvested acres. One measure of ecological value (great gray owl, *Strix nebulosa,* nesting habitat) was also evaluated in the ensuing forest plans. No significant differences in owl habitat were found across the three levels of detail in management intentions. However, a significant difference in the NPVs generated among the three management intention scales was observed. A non-parametric rank sum test showed that the mean of the values of the NPV were significantly different (all combinations having a one-sided p-value < 0.0001). In addition, large differences in the timing of harvest volumes, and hence revenue generated and acres treated, were observed. This analysis indicates that if resources are available (databases, time budget), the finest level of detail should be used when developing forest plans in order to produce the most accurate results in forest planning efforts.

A Comparison Of The Value Of Forest Plans Developed Under Three Levels Of Detail Regarding Management Intentions

by

Sarah Rebecca Hirte

A THESIS

Submitted to

Oregon State University

In partial fulfillment

of the requirements for the

degree of

Master of Science

Presented September 13, 2002

Commencement June 2003

Master of Science Thesis of Sarah Rebecca Hirte presented on September 13, 2002

APPROVED:

Signature redacted for privacy.

Major Professor, representing Forest Resources

Signature redacted for privacy.

Head of Department of Forest Resources

Signature redacted for privacy.

Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Signature redacted for privacy.

Sarah Rebecca Hirte, Author

ACKNOWLEDGEMENTS

With the development of this research I have learned many things. This knowledge would not have been achievable without the help of other people. Dr. Pete Bettinger gave me more insight and understanding as to what goes on with the creation and completion of a research project. My thanks goes first to him not only for his unflagging advice, but also his guidance on every aspect of this research such as geographic information systems, computer programming and writing skills. I am honored to have been one of his students.

This research would not be completed if it were not for my other committee members; to them I would like to extend thanks. Dr. John Sessions was always the one to set my standards higher and push me when I did not think I could go anymore. He also gave me valuable knowledge on heuristics, without which this research could not have been attempted. Dr. Darius Adams constantly gave support and guidance in the achievement of this research. He was always willing to meet and was prompt to respond to questions. This is a valuable trait.

Much appreciation goes to Greg Latta and Duncan Wilson who gave me assistance even when it was inconvenient for them. Greg and his patience taught me how to use FVS and the FIA data. Duncan furthered my education in statistics, and FVS data and double-checked my FVS results. He even went above and beyond by offering to write an ingrowth model specifically curtailed for my research.

I would also like to extend thanks to all the other faculty and graduate students I worked with during my time here. Many of you have given me valuable assistance in all areas of graduate school survival. Not only were the people here at OSU an integral part of my graduate school career but also my parents, who constantly encouraged me, and my husband, Bob Hirte, who supported me through all aspects of graduate school.

TABLE OF CONTENTS

TABLE OF CONTENTS CONTINUED

TABLE OF CONTENTS CONTINUED

LIST OF FIGURES

LIST OF FIGURES CONTINUED

LIST OF FIGURES CONTINUED

LIST OF TABLES

LIST OF TABLES CONTINUED

Table Page

A Comparison Of The Value Of Forest Plans Developed Under Three Levels Of Detail Regarding Management Intentions

1 INTRODUCTION

Within the field of forest planning there are a number of ways to characterize planning processes. One is where three levels of analysis are distinguished: stand-level, forest-level, and landscape-level. Stand-level analysis concerns determining which set of prescriptions are best for individual stands based on some criteria such as economic, physical, organizational, and regulatory. Forest-level analysis examines the effects of individual stand-level decisions across time and space (within a specific landscape or ownership). The "decisions" chosen can be optimal for each stand, or alternatively based on previously defined assumptions about management intentions. Landscape-level analysis concerns stand-level decisions across time (generally long time frames) and space (all ownerships) as well. Little has been published on how forest management intentions have been used as input data into a forest-level or landscape-level model.

The techniques associated with quantitative forest planning allow forest managers to develop a schedule of activities, positioned appropriately on the landscape and in a time frame, that provide for the greatest achievement of an objective, subject to a set of spatial, temporal, or budgetary constraints. These schedules are part of an overall forest plan; hence fall within the scope of forest-level analysis. The scheduling techniques range from the more traditional methods such as linear programming, mixed integer programming, and binary search, to more recently developed heuristics like tabu search, simulated annealing, and simulation models. Each forest management organization selects or develops a technique based on its set of preferences, whether it is cost, familiarity, or other reasons. Some forestry organizations in the Pacific Northwest and southeastern United States continue to use linear programming models such as Woodstock (REMSOFT, 2001) and Spectrum (USDA Forest Service, 1998a) while others have developed heuristic models to develop their forest plans.

Traditional optimization methods can provide global optimum solutions to planning problems, within limitations. Heuristic optimization models do not guarantee a global optimum will be generated, but they produce near optimum solutions or at least feasible solutions to difficult planning problems. Heuristic models such as tabu search, simulated annealing, and threshold accepting provide feasible solutions to assist landowners, forest planners, and policy makers in their efforts to formulate future management plans for the land they manage. The models used in forestry were developed to simulate relevant dynamic features, such as tree growth and harvest location and size, through time. The quality of solutions produced by a model is dependent on the input data and modeling assumptions. If the input data and assumptions closely reflect actual management processes then the model output is likely to be somewhat realistic.

The type of data used in a forest planning effort includes growth and yield information, spatial databases, and assumptions regarding management intentions. Management intentions are important because they provide information regarding how and when to harvest management units. Most management intentions are based on assumptions of what the landowner intends to do with the land. The assumptions vary by landowners, and perhaps by stand and site characteristics. For example, one intention may be to maximize net present value (NPV) from stand-level management, (requiring an optimization technique to determine timing and intensity treatments) while another may provide explicit instructions (thin at age 35, cutting x board feet, clearcut at age 60). The level of detail assumed in the management intentions may increase (or decrease) the difficulty in modeling them on non-uniform landscapes. When landscapes are large, the problem is exacerbated due to the variety of assumptions pertaining to individual stands. Since the initial spatial characterization of the landscape usually does not change during forest planning this portion of the process is generally fixed.

Forest planners generally have a few options regarding the level of detail of management intentions. Their options often range from detailed (or fine scaled) assumptions (based on site class, species, ecoregion, and owner group) to coarser, less detailed assumptions (species, ecoregion, and owner group, or just ecoregion and owner group). Either there is a limiting factor (e.g. lack of site quality information in a spatial database, lack of appropriate growth and yield models, lack of knowledge of management behavior) that determines the level of detail modeled or a conscious decision is made to reduce the level of detail. The question of interest to this study whether aggregation of the management intention assumptions (thus modeling lower levels of detail) produces roughly the same results as when very detailed management intention assumptions are used.

This project examines the above question by modeling industrial forest landowners' coarse, medium and fine scale assumptions about management intentions in the Blue Mountains region of eastern Oregon. It is to determine whether using three different scales of management intentions produces different forest planning results, as measured in terms of harvested acres, harvest levels, net present value (NPV), and wildlife habitat for the (great gray owl, *Strix nebulosa*).

2 JUSTIFICATION

Conclusions drawn from an analysis of forest planning alternatives are only as good as the information on which they are based. The results of this study will enable forest planners to think about the perceived accuracy of their results, in this case a function of the level of detail to which management intentions are recognized. For example, if the plan was developed using aggregated management intentions due to an inability or some other factor barring all the data to be used, the planner is able to perceive the answers to be different compared to the same plan where fine scale management intention data was used. This study is one of the first of its kind to determine whether the results generated by various levels of detail differ when used in forest planning. This is important to planners who are pondering the use of very detailed management intention assumptions, or considering aggregated assumptions in their planning model. The main disadvantages of using detailed assumptions of management intentions are that it is time consuming to gather the data, and more difficult to implement in a model. Aggregated assumptions require compiling the management intentions into fewer categories, thus requiring less data and less time to implement.

The overall objective of this research is to understand the differences in forest plan results when different levels of management intentions are used. Determining the limitations and impacts of using aggregated management intention assumptions, rather than detailed assumptions, is the area in which this research fits. After organizing these assumptions into three levels of detail (fine, medium, and coarse), based on a survey of eastern Oregon private industrial landowners (Lettman, 1998), the different levels of detail are incorporated into a forest-planning model; results are generated, and statistically analyzed. Two questions I hope to answer include: (1) do the different levels of detail result in relatively similar measures of forest plan goal achievement? and (2) what level of management intention assumptions should planners use in order to adequately model the forest management system and make efficient use of their time and budgets? Developing hypotheses around these questions, and analyzing the significant differences in results might answer these questions. The forest planning results compared include economic or commodity-driven (NPV, acres treated, volume harvested) and ecological (owl habitat).

3 LITERATURE REVIEW

3.1 INTRODUCTION

A considerable amount of research has been published in the last ten years to describe how quantitative modeling techniques can be used to facilitate the development of forest plans. Examples include those using linear programming (Kelly et al., 1986), mixed integer programming (Nelson and Brodie 1990; Weintraub et al. 1994), and heuristics (Bettinger et al., 1997; Bettinger et al., 1998a; Bettinger et al., 1998b; Bettinger et al., 1999; Brumelle et al., 1998; Clark et al., 2000; Graetz, 2000; Gustafson et al., 2000; Hof, 1992; Hoganson and Borges, 2000; Johnson et al., 1998; Liu et al., 2000; Lockwood and Moore, 1993; Murray and Church, 1994; Murray and Church, 1995; Murray and Church, 1996a; Murray and Church, 1996b; Murray, 1999; Murray and Snyder, 2000; Richards and Gunn, 2000; Weintraub et al., 1994; Yoshimoto et al., 1994). In forest planning we generally use three levels of analysis in developing forest plans: stand-level, forest-level, and landscape-level. The stand level analysis concerns determining which set of prescriptions is best for individual stands based on economic, physical, organizational, or regulatory criteria. The forest-level problem looks at the effects of individual stand-level decisions across time and within a specific landscape or ownership. Landscape level planning examines large area (all ownerships) and long time frames. The "decisions" in forest and landscape-level planning may, or may not, be optimal for each stand, or may be based on previously defined assumptions about management behavior. A fourth level of planning, operational planning, deals with the location of landings, skyline corridors, and roads. The detailed nature or this level of planning is generally not noted in forest plans themselves, but in individual harvest plans. Very little has been is published on the impact of various levels of detail of forest management intentions on forest plan results. This literature review thus focuses on some of the common types of quantitative methods used in forest-level analysis. The problem formulation (as we will see) contains spatial constraints, thus is combinatorial, and utilizes a large number of decision variables.

3.2 FOREST-LEVEL PLANNING TOOLS

Developing a plan of action for the management of renewable resources is important to land and resource management organizations. The continuous development of tools assists decision makers with their planning efforts, since management problems continually change. Tools evolve for (at least) two reasons: 1) to generate better or more realistic forest plans faster, or 2) because the type and level of analysis expected in a forest plan is becoming more complex. For example, just a decade ago incorporating adjacency constraints in a forest plan was a novel approach in forest planning. Now we are seeing an increase in the acknowledgement of other spatial relationships such as wildlife habitat (Bettinger et al., 2002) and fire (Graetz, 2000). Of course these analyses are performed with computers, and advances in computer technology of late have facilitated the advances in tools and modeling approaches.

There are two main groups of forest-level analysis techniques: traditional mathematical techniques and heuristics. Traditional techniques include linear programming (LP) and mixed-integer programming (MIP). With these techniques one can locate the optimal solution to planning or scheduling

Heuristic techniques can be used to obtain "near" optimal forest plans in a relatively short amount of time, as opposed to the time-consuming exact solution process, to an inexact problem. Heuristics can take the form of a simplified model and use inexact or limited data to estimate model parameters that may inherently contain errors (Zanakis and Evans 1981), or may take the form of more complex models to utilize realistic management assumptions and volumes of data. Heuristics are generally used when linear programming (LP) or mixed-integer programming (MIP) methods seem unable to obtain the type results and/or solve the forest plan desired by a planning team.

Heuristics can incorporate integer variables as well as non-linear constraints thus treating a forest-level problem as a combinatorial optimization problem (Reeves, 1993). Some of the common heuristics used today (tabu search, Monte

Carlo, and simulated annealing) are described below after a discussion of the traditional optimization techniques.

3.2.1 Linear programming

Linear programming (LP) is a commonly used analysis technique in renewable resource management and planning. It can be used in developing forest plans that incorporate clearcut size and adjacency constraints to optimize spatial layouts in single or multiple time periods, within limits. Decision variables are continuous, and model structures are either model I (where each acre is treated throughout the planning horizon), or model II (where acres are aggregated into "bins" of acres when regenerated). Some linear programming formulations that use a geometric model structure (such as data derived from vector geographic information system (GIS) databases: irregular polygons), as opposed to a cellular grid structure, allow inclusion of "fragmentation effects" and may not require an integer solution (Hof and Joyce, 1992).

Linear programming is generally associated with strategic planning; long-term planning including one or more time rotations. These plans can get very complex with many goals and constraints. The more complex the goal or constraint, the larger the model becomes, and the solution time generally increases. Therefore, it may be necessary to aggregate some data to meet the model size limitations. Once aggregated, data may no longer represent individual stands (i.e., the use of stratas is implied) and may produce inaccurate results. Studies comparing linear programming to heuristics show that heuristics may be better than linear programming in developing more complex forest plans (Elwood and Rose, 1990).

3.2.2 LP extensions: integer programming and mixed integer programming

Linear programming assumes that the decision variables are continuous. For example, assigning a clearcut to a portion of a stand is possible (rather than to the entire stand or not at all). The location of this treated area within a stand is unknown. These models thus give operationally unrealistic optimal solutions when the harvest units are assumed as continuous variables. Most spatial plans laid out in the forest are divided into units of harvest and leave areas. This assumes that dichotomous integer variables (0 or 1) are used to represent each harvest unit in each time period. These types of variables simplify the decision criteria in each period into harvest (1) or no harvest (0) for each unit. Integer programming (IP) and mixed integer programming (MIP) (Kirby et al. 1986), extensions of LP, facilitate using binary variables when developing spatial harvest scheduling plans.

Both IP and MIP have a limitation on the size of a problem (number of decision variables). Large combinatorial problems therefore, may be intractable with these techniques. However, some effort aimed at reducing the combinatorial size of the problems for IP techniques has been made (Jones et al., 1991), but these are not likely to resolve problems where forest plans contain a large number of management units, or where forest management plans consider more spatial restrictions than simply adjacency.

3.2.3 Monte Carlo simulation

Monte Carlo simulation techniques are named for the casino game that is based on random chance of rolling dice. In forest planning, for example, random assignment of management regimes to stands are examined in an effort to seek out the solution to a problem. Randomization, however, may lead to inconsistent results. In one run of a Monte Carlo simulation the program may choose a set of stands and harvest schedules to apply them to, and a second run can randomly choose completely different stands and schedules, resulting in a different solution. Clements and Dallain (1990) and O'Hara et al. (1989) used this technique to solve a variety of spatial harvest scheduling problems that included adjacency constraints. Pure random search lacks neighborhood search and has been shown to produce inadequate results (Bettinger et al., 2002), thus modifications to Monte

Carlo techniques are required to develop a forest plan that is reasonable, given the objectives and constraints assumed.

3.2.4 Simulated annealing

Simulated annealing is a stochastic, neighborhood search heuristic technique and as such can be categorized as a form of Monte Carlo simulation. It was named for the process in which metal is slowly cooled in a water bath. At a higher temperature (the beginning of the annealing process) elements of metal move freely. They rearrange themselves into optimum locations as the temperature cools, to a point where they cannot move any more. With the simulated annealing optimization program, the time a process has been operating and iterations used within the program represent the temperature. The algorithm temporarily changes some of the characteristics of the decision variables and evaluates the objective function. If the objective function is higher than previously noted (assuming a maximization problem), this arrangement is accepted, if not, there is some small chance that the changes are also acceptable even though the resulting objective function value may decrease. Each of these decision steps is thought of as an iteration. The “temperature” (a parameter used in the calculation of the chance of a lower value of the objective function) cools (decreases) through each iteration thus, as the temperature cools, changes that decrease the objective function are less likely to be chosen (Appendix A-1). Simulated annealing has been used to solve large combinatorial optimization problems (Kirkpatrick et al., 1983) and also to solve timber harvest scheduling problems when considering exclusion periods and maximum clearcut size restrictions (Lockwood and Moore, 1993). Simulated annealing, when compared head-to-head with other heuristic techniques, has been shown to produce very good solutions in a relatively short amount of time (Bettinger et al., 2002).

3.2.5 Tabu search

Tabu search is generally thought of as a deterministic search process whereby a solution to a forest plan is changed iteratively by changing a characteristic of a decision variable. This is called "neighborhood search", where the search process moves from one solution to another very similar solution. Neighborhood search is used in many programs (linear programming, simulated annealing, genetic algorithms, threshold accepting, and great deluge algorithms). It searches the surrounding solution space for a better, or not much worse, solution. Within tabu search, however, the decision variable and the characteristic that is changed are chosen by first examining all possible changes that are possible in the neighborhood search, then choosing the change that either: 1) results in the best improvement in solution value from the previous solution value, or 2) results in the least depreciation of solution value from the previous solution value. The main idea of tabu search is a tabu list. This is a list of changes that the program has made "recently", and is not allowed to revisit for an established period of time. This is done hoping that visiting inferior regions of the solution space may lead to more superior solutions in the long run. Some variations on tabu search have included randomly choosing the decision variables and characteristics thereof to change (Glover and Laguna, 1993), intensifying the search process by swapping the characteristics of two management units (Bettinger et al. 1999b) and allowing infeasible solutions to be generated via "strategic oscillation" (Sharer, 2000; Richards and Gunn 2000), although each is generally not found in straight-forward tabu search results.

Tabu search has been used as a method to optimize forest level planning problems with timber volume and environmental constraints (Richards and Gunn 2000). The main limitation of tabu search is the need to evaluate all, or some portion of, the possible changes to a solution before choosing one to accept. Further, enhancing the search process by intensifying the search in "good" areas of the solution space produces better results then straightforward tabu search (Bettinger et al., 2002). This enhancement, however, comes with a cost: longer processing time requirements.

3.2.6 Threshold accepting and the great deluge algorithm

Threshold accepting and the great deluge algorithm are optimization algorithms that are very similar to simulated annealing. The process of threshold accepting was introduced by Dueck and Scheuer (1990). In threshold accepting a threshold is chosen, a change to a solution, and the objective function value calculated. If the potential change to the solution is greater than the previous objective function value minus the threshold (assuming a maximization problem) the proposed solution is accepted. After a series of iterations the threshold is decreased. When there is no change in the quality of solutions or after a set period of time the algorithm stops (Dueck, 1993).

The great deluge algorithm (GDA) was introduced by Dueck (1993) and proved to be superior to Monte Carlo based algorithms when solving a Traveling Salesman Problem. The GDA is similar to threshold accepting in that they both use an initial threshold ("water-level" in GDA) that changes as the solution is optimized. In GDAs the solution must be greater than the "water-level" to be accepted. The programmer chooses an initial water level and the solution is then calculated. If this solution is greater than the "water-level" (assuming a maximization problem) it is accepted and the water level increases by a preset incremental value. When there is no change in the quality of solutions or after a set period of time, the algorithm stops (Dueck, 1993). The goal of the GDA is to find the maximum point on a surface. The GDA leads to solutions that are equally good as those found in simulated annealing even when parameter estimation is poor.

3.2.7 Genetic algorithms

Genetic algorithms (GAs) are a complex heuristic technique. They were first developed by Holland (1975) and their creation was inspired by natural evolution, as described by Davis (1991). GAs have been used in forestry in the context of operational planning and harvest scheduling problems (Lu and Eriksson, 1999; Mullen and Butler, 1999).

The idea behind GAs lies within population genetics. These techniques begin with an initial population of feasible solutions, which are labeled chromosomes. From these chromosomes a new population, or offspring, is created. The parents are selected randomly, or with a goal of using the best feasible solutions, and then their characteristics are combined to create the offspring who then might become part of the parent population by replacing the lesser of the two parents. The process consists of an interchange of data, where the parent solutions are split and reformed to create the offspring. Like natural evolution, genetic mutations are possible in genetic algorithms. Which occurs randomly throughout the generations. This evolution process for solving problems transpires in hope of creating a better solution by occasionally introducing better material into chromosomes (Davis, 1987).

3.3 MODEL VERIFICATION AND VALIDATION

LP, IP, and MIP techniques generally provide the optimal solution for forest planning problems as formulated. Their results can include other data, such as shadow prices, to evaluate the sensitivity (or impact) of individual decision variables with regard to the final solution, although shadow prices are not reliable in IP or MIP. Heuristic techniques generally do not guarantee the optimal solution to a problem will be located (Dannenbring, 1977), nor do they generally provide other information, such as shadow prices, to evaluate the sensitivity of decision variables. If one intends to use a heuristic technique, it is thus important to verify that it is finding solutions close to the global optimum solution. One way of accomplishing this is through coding and debugging the model in small steps and checking the output with hand calculations to make sure that the answers are realistic (Bettinger et al., 1998a). This is also true for LP, IP, and MIP. To make sure the model is running at its optimum performance, a sensitivity analysis is preformed to check whether the best possible model parameters are being used.

To validate the results produced by heuristic techniques one needs to compare them to a standard. One method is to compare heuristic solutions to those produced by LP, IP, or MIP. If the traditional techniques can't solve the forest problem, a relaxed version of the problem can be solved and used for comparison. Relaxed problems however, can be viewed as merely upper bounds on the true problem solution, thus not necessarily the current solution. Since the traditional methods may not be able to locate a global optimum solution to complex spatial forest planning problems, another approach may be considered: estimating the global optimum solution to a planning problem through the use of extreme value statistical theory.

Model validation can thus consist of comparing the results estimated by heuristics to known optimal solutions or to a statistically calculated global optimal. One assumption behind the use of extreme value theory is that the data (objective function values) fit a Weibull probability distribution. This distribution is of importance because it describes either the estimated minimum or maximum, or extreme values, from independent samples when drawn from the same parent population. It is important to note that the use of extreme value theory does not guarantee that the estimated global optimum is near the true global optimum. It only presents the extreme value based on a sample. Poor heuristics such as Monte Carlo simulation may thus produce misleading estimates of the global optimum solution to a planning problem. It is assumed that a three-parameter Weibull distribution is approached as the sample size increases toward infinity (Los and Lardinois, 1982).

$$F(x) = Exp\left[-\left(\frac{(a-x)}{b}\right)^{c}\right]$$

Where:

$a =$ Weibull location parameter

$b =$ Weibull scale parameter

$c =$ Weibull shape parameter

Using these three parameters the Weibull distribution is formed and the estimated location parameter, a, becomes the estimate of the global optimum (Bettinger et al., 1997; Boston, 1996; Golden and Alt, 1979; Los and Lardinois, 1982). The use of extreme value theory for large combinatorial optimization problems was first described by McRoberts (1971), later Dannenbring (1977), Golden and Alt (1979) and Los and Lardinois (1982) expanded on the use of it for combinatorial heuristic models, and Bettinger et al. (1998) and Boston and Bettinger (1999) evaluated its use in forest planning.

There is much discussion on the appropriateness of fitting a Weibull distribution to the objective function values generated by heuristics (Bettinger et al., 1999a). There are assumptions implicit in the methodology that should be adhered to; one important assumption is the independence of samples. The Fisher-Tippett theorem requires that independence be given to all samples (Los and Lardinois, 1982). Independence is an issue for heuristic models because where there are N local optima many of those N samples may have identical local optima and are "heuristically" related since they all attempt to achieve the same goal. Randomization of the starting point of each heuristic process can allow one to assume that statistical independence is obtained with the location of each local optima (Los and Lardinois, 1982; Golden and Alt, 1979). The other assumption is the samples come from a continuous distribution of samples. Los and Lardinois (1982) inform us that, "in combinatorial programming problems the number of possible values is finite." However, as a problem grows more complex, there are more decision variables, causing the number of discrete problem solutions to grow exponentially, approximating a continuous distribution of sample solutions. This assumption has been found to be acceptable in practice (Dannenbring 1977; Los and Lardinois, 1982).

It is important, however, that the goodness-of-fit of the samples to a Weibull distribution be tested (Boston and Bettinger, 1999) before utilizing the resulting Weibull distribution parameters to arrive at an estimate of the global optimum solution to a problem. The performance of a least squares/goodness-of-fit analysis tests whether the sample data can be represented by a Weibull distribution (Golden, 1978). Three statistics, the Kolmogorov-Smirnov, Chi squared and the Anderson-Darling statistic, can be used to evaluate goodness-of-fit. If (1) the goodness-of-fit statistics indicate that the heuristic solution values (samples) fit well with a Weibull distribution, (2) the number of samples is large (implying that they were obtained from a continuous distribution), and (3) each heuristic solution started with a randomly assigned initial starting point, we can assume the independence and continuous distribution assumptions were met and use the results from the fitting of the Weibull distribution to estimate the global optimum solution value to a forest planning problem.

3.4 COMPARATIVE CASE STUDIES

No known studies comparing different levels of detail in management intentions in forest planning efforts have been recorded. Some studies have evaluated hierarchical planning processes comparing results of a simultaneous strategic/tactical model to two-phase models (e.g. Boston and Bettinger, 2001). In the simultaneous model a single set of management assumptions were used. In the two-phase model a strategic plan was developed with one set of management assumptions, then a tactical model with a second set.

Differences in scale for soil properties have been examined (Shirazi et al., 2001; McKenzie et al., 2000). These studies used regional soil and elevation maps as the aggregated data and sample soil points as the fine scale data. Shirazi et al. (2001) found that extrapolation of broad scale data to low-elevation map units is less precise than upland elevation maps. McKenzie et al. (2000) found that the fine scale sample points are more accurate in describing soil properties, indicating a "more direct measurement of relevant soil properties is required to overcome the reliance on presumed correlations with conventional soil morphology." Decker et al. (1999) analyzed a soil enzyme at three different scales: regional, topographic, and individual tree, finding that there are significant differences in enzyme activity at all three of these scales. They concluded that "scaling-up of results from individual soil samples or plots to the landscape scale [is] problematic." Although it is a stretch, from these studies we can speculate that the modeling of fine-scale management behavior (assuming the databases necessary to support the modeling are available) may produce more accurate results than the coarser scales.

3.5 CASE STUDIES INVOLVING MANAGEMENT INTENTIONS

Past studies have been fairly informal in their treatment of management intentions, both in terms of numbers of classes and specific practices included. Usually, when management intentions are required for timber harvest planning assumptions are made about the desired level of detail. The level selected is usually based on prior studies or readily available data and tests to determine the best level of detail are not usually performed. Often forest planners use all the detail available when modeling management intentions in a forest planning or harvest-scheduling model. Adams et al. (1992) wanted to "establish a specific set of management regimes or intensities" and in doing so sought specific and detailed management intentions to characterize the landowners' current and future plans. These regimes were determined using more than one survey instrument to provide the most detail possible. Other studies, however, omit, or don't describe, the level of detail used when developing management intentions (Bare et al., 1995). In the case of Adams et al. (1996), when performing an analysis on the impact of public harvest policies on private forest management, the level of detail assumed for the management regimes was not modeled after prior studies. The study did not use management intentions based on survey results and instead developed management regimes that the authors thought were reasonable. Other case studies indicate that all the data available were used to develop the management intentions. For example, in one particular case the management intentions are based on forest owner survey information (Adams et al., 2002). Here they allocated management intentions by ecoregion, site class, forest type, and owner group. Krumland and McKillop (1990) based their management options on a survey of industrial and nonindustrial forest management practices yet failed to mention if they used all the data from the survey or aggregated it.

The past studies do not indicate why particular levels of management intention detail were chosen for the studies nor were they tested to indicate if the level used was appropriate. Having a clear understanding of how the management intentions used in models is obtained and the level of detail used is important for research. If less detail can be used and still obtain the same or similar results, planners can save time and money while maintaining confidence in the results of their modeling efforts.

3.6 SUMMARY OF LITERATURE REVIEW

This literature review indicates that at this point in time heuristic techniques may be a better method of developing forest plans that include large data sets, and multiple spatial constraints and goals (resulting in a combinatorial planning problem). Linear programming and its extensions IP and MIP are limited by model size. Monte Carlo simulation, which is based on randomization, may provide inconsistent results. Tabu search is good at providing near optimum results but is time consuming to utilize because a large neighborhood of solutions must be evaluated at each iteration of the model's operation. Simulated annealing appears to be among the best choices for developing spatial forest plans, since it can provide reliable results and has been shown to operate with a relatively fast processing speed.

One of the gaps in the forest planning literature that this study hopes to address is the appropriate level of detail required to model management behavior in forest planning models. If databases were available to model behavior at a fine scale, and time and cost considerations allowed, would it be worth the effort (as opposed to modeling behavior at coarser scales)? Of course, the databases may not be available to model behavior at a fine scale, or time and cost considerations may preclude doing so. In these cases would we expect to arrive at reasonable solutions by aggregating our assumptions? By examining the economic (NPV, timber volume, area treated) and ecological (great gray owl habitat) results of forest plans, we seek to answer these questions.

4 METHODS

The primary focus of this research is to compare the results from the three different scales (or levels) of detail used to model the landowners' management intentions. The case study area is industrial lands in the Blue Mountains region of eastern Oregon. Individual ownership boundaries are ignored and it is assumed that all industrial land is managed under one objective: to maximize NPV of the harvest over a fifty-year planning horizon. Four measures of forest plan performance are reported, three related to economics or commodity production (NPV, timber harvest volume, area treated) and one related to ecological goals (area of great gray owl habitat).

The format of the methods section is as follows. First a description of the management intention survey data used is presented, then the inventory data assigned to the geographic data, and the management prescriptions modeled. Then a discussion of the heuristic model that was developed to generate forest plans and the algorithms it utilized is described. Finally, a discussion of the quality of the resulting management plans is presented.

4.1 MANAGEMENT INTENTION SURVEY DATA

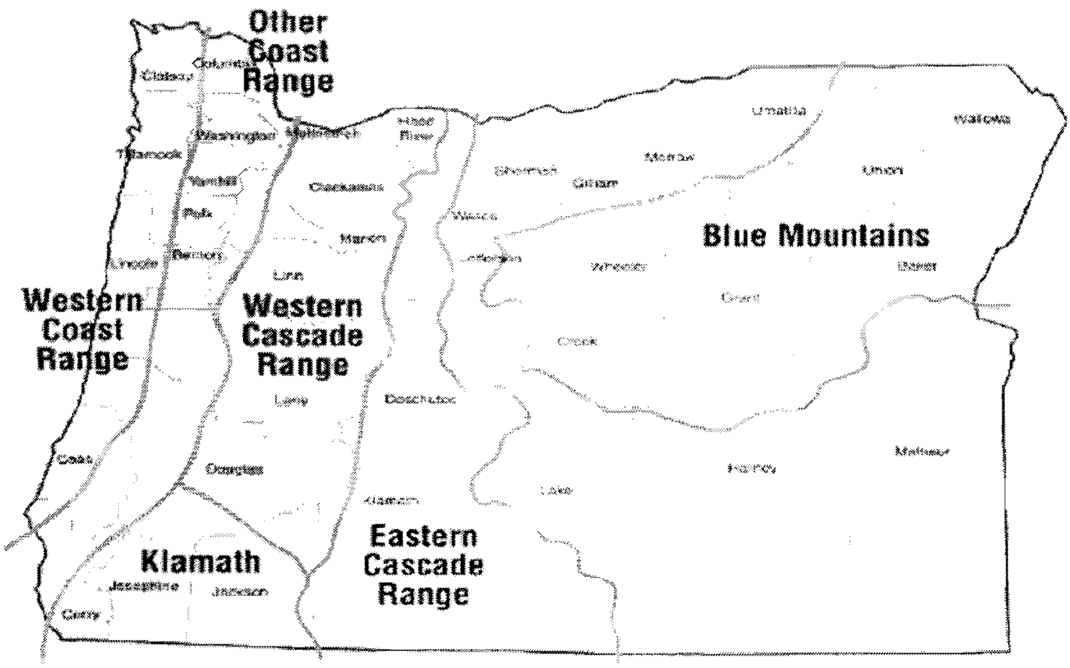
A survey of forest management intentions was administered by the Oregon Department of Forestry in 1998 (Lettman, 1998). The survey provided a glimpse of the private landowner's management regimes for the present and future forests in eastern Oregon. Management intentions reported in the surveys were summarized (Bettinger and Schoonover, 2000) (Appendix A-2) to three different scales. The fine scale (most detail) represented management intentions that were designed for both site class and species breakdowns of the industrial land base in the Blue Mountains ecoregion. In medium scale site class was removed as a characteristic, leaving ecoregion, and species. In coarse scale both species and site class were removed. The management intentions were summarized by these three different scales in order to examine how the results of management plans may change based on the availability of information. Weighting the acreage for each group, then recording the predominant regime for the group, allowed a derivation of the management intentions used in this project. For this research, the scales were designed around three variables: ecoregion, species, and site class (Table 1), only the Blue Mountains ecoregion was used in the analysis (Figure 1).

Table 1. The structure of management intention scales, based on ecoregion, species, and site class data from a management intention survey.

Scale	Ecoregion	Species	Site Class
Fine	X	X	X
Medium	X	X	---
Coarse	X	---	---

x = survey data was used to describe the management intentions of industrial landowners.

Figure 1. Regions used in management intentions survey conducted by the Oregon department of forestry (Lettman (1998) (From Adams et al. 2002)).



4.2 FOREST INVENTORY DATA

Forest inventory data used in this study consisted of the Forest Inventory Analysis (FIA) plots measured in the Blue Mountains area of Oregon. The FIA data collection process (USDA Forest Service, 1998b) divides the plots into 5 subplots, and within these subplots the forest cover may be divided into different cover types, otherwise known as condition classes. These condition classes each had their own tree lists, and the trees per acre were weighted according to the size of the condition class within a subplot (indicating that each subplot might be used as a sample treelist). Thus each subplot was treated as a separate inventory plot.

The FIA data was reformatted before it was used in the growth and yield model chosen for this analysis, the Forest Vegetation Simulator (FVS) (Wykoff et al., 1982). For example, the diameter at breast height (dbh) was converted from metric to English units, and small trees (<0.1 inches) were assumed to be the minimum size acceptable for FVS.

The FIA inventory data was categorized by dominant species and site class. The dominant species was determined weighting the tree species data by the basal area each represented. Site classes of high, medium, or low were derived directly from the each FIA plot's mean annual increment. The landowner surveys indicated that site classes were represented by cubic feet per acre per year growth (Table 2).

Table 2. A site class classification for the Blue Mountains region of Oregon.

Study Site Class	Landowner Survey Site Class	Cubic feet per acre per year growth (cf/ac/yr)	100-yr any species site index (Blue Mountains)
High	4	85 – 119+	110 – 123+
Medium	5	50 - 84	90 - 109
Low	6	20 - 49	<90

(Lettman, 1998)

The FIA data, when processed with the growth and yield model and then assigned to units on the GIS vegetation database (to be discussed in section 4.8), yielded the initial conditions of each stand on the landscape. As can be seen in Table 3, pine and Douglas-fir forests dominate the landscape, most of which are low site classes. Although pine has the most acreage represented, these stands do not contain the most volume on the landscape.

In even-aged stands Douglas-fir initially has the most amount of volume per acre and almost all of it is located in the 71-80 age class (Figure 2). Pine, on the other hand, has much smaller volume per acre in even-aged stands, most of which is in the 11-20 and the 51-60 age class. Mixed conifer stands represent the smallest portion of the landscape. Its volume per acre is predominantly in the lower age classes (0-10; 11-20) in even-aged stands. These values illustrate a problem within the FIA data: stand ages and timber volumes are not necessarily positively correlated. A more detailed examination of how stand age is determined and why young stands have significant timber volume would help explain these curious statistics. For example young stands may have significant residual leave trees (post-regeneration), resulting in high timber volume for certain age classes. If so, it would seem that the residual trees do not contribute to the computation of stand age.

Grand fir, also a small portion of the landscape, has almost all its volume located in the 51-60 age class in even-aged stands. Pine differs greatly between its volume per acre on even and uneven-aged stands (Figure 3). The initial uneven-

Table 3. Distribution of species, site classes, and structure on a landscape in the Blue Mountains region of Oregon after assignment of inventory plot data to a vegetation GIS database.

	Site class	Species: Douglas-fir	Species: Pine	Species: Mixed conifer	Species: Grand fir	None	Total
		Acres					
Uneven-aged stands	High	464	287	2	426	0	1,179
	Medium	838	453	6	154	0	1,451
	Low	13,282	10,762	0	6,108	0	30,152
Even-aged stands	High	26	14	28	29	0	97
	Medium	608	350	83	71	0	1,111
	Low	5,372	11,415	946	3,165	0	20,898
Non-forested						40,175	40,175
Totals		20,589	23,282	1,065	9,953	40,175	95,063

Figure 2. The current average volume levels for even-aged stands by species for the Blue Mountains region of eastern Oregon.

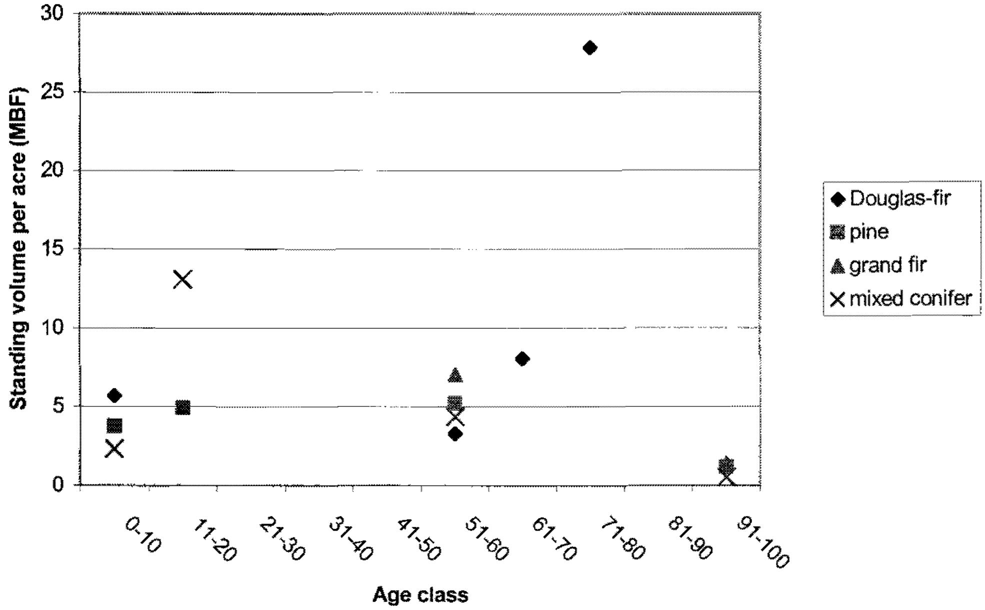
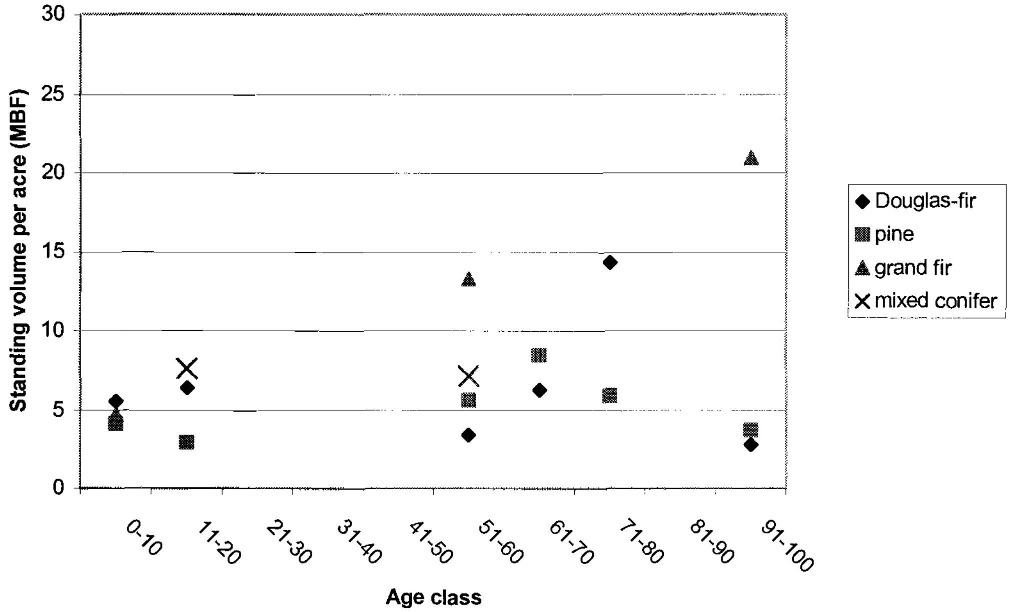


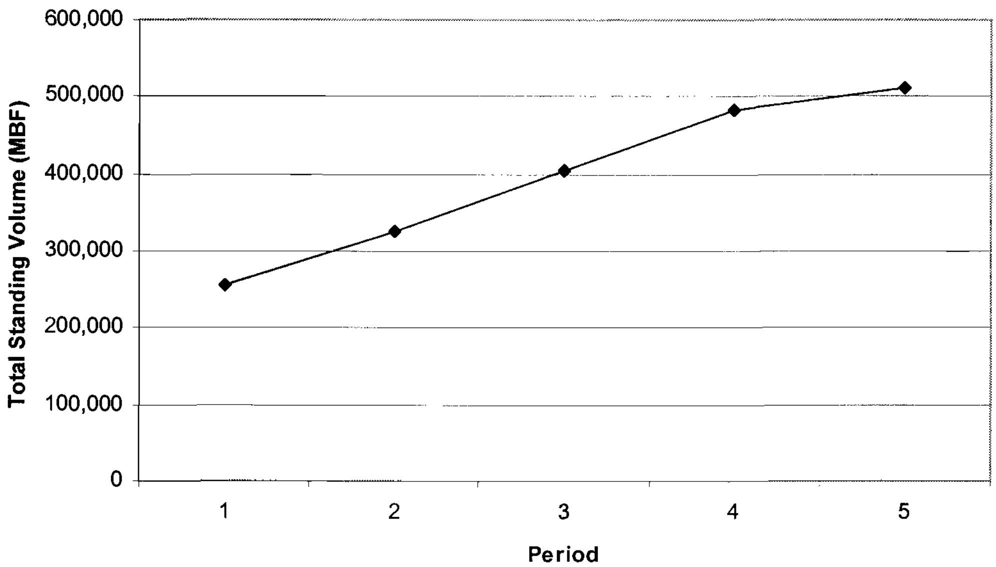
Figure 3. The current average volume levels for uneven-aged stands by species for the Blue Mountains region of eastern Oregon.



aged volume per acre for pine spans ages 51-80, dropping at age class 81-90 and rising again at age class 91-100. Douglas-fir has a large amount of volume per acre in uneven-aged stands as it did in the even-aged stands, only decreasing in the 71-80 age class.

The species and their volume per acre represented on the landscape are mostly located on low site classes providing less annual growth over the planning horizon. There are approximately 55,000 acres of forested lands in the study area. If they were allowed to simply grow for 50 years the average growth of the forest would be approximately 140 board feet per acre per year (Figure 4). These growth rates are consistent with those used in the Wallowa-Whitman National Forest Plan (USDA Forest Service, 1990) and empirical studies by Meyers (1961) and Cochran (1979) for east-side forests. The mean annual increment (MAI) is somewhat confounded by the age/volume issue mentioned earlier. Douglas-fir MAI values (approximately 200 board feet per acre per year) are slightly higher than grand fir (180 board feet per acre per year) and pine (160 board feet per acre per year), while mixed conifer forests lag well behind (50 board feet per acre per year).

Figure 4. Total standing volume using a "grow only" scenario on the forested 54,888 acre landscape in the Blue Mountains region of eastern Oregon.

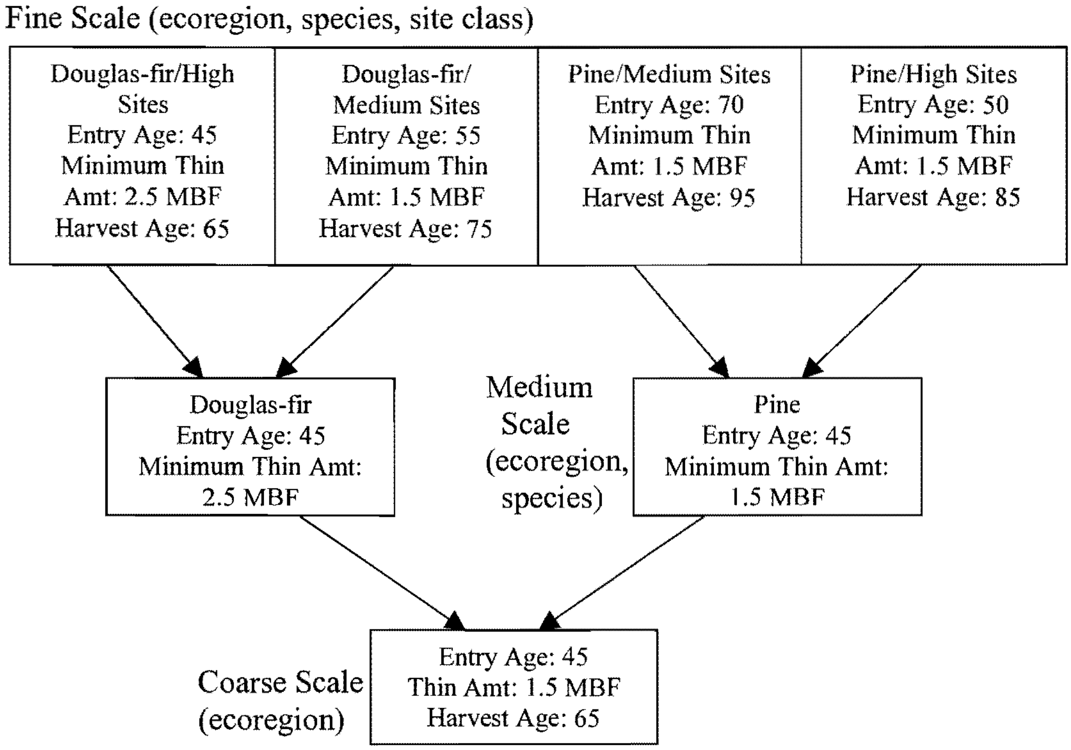


4.3 MANAGEMENT PRESCRIPTIONS

Management prescriptions describe how a stand of trees will be managed as well as the resulting stand structure. They are developed by taking the inventory plot data and manipulating (cutting, growing, adding to, etc.) as suggested by the management intentions. The prescriptions were projected in FVS for 50 years. Thirty-six different prescriptions, along with a no-harvest prescription, were generated for use in the fine-scale management intensity scenario. Sixteen prescriptions were generated for the medium scale management intensity scenario, and seven were generated for the coarse scale management intention scenario (Figure 5).

Management prescriptions vary according to the assumed rotation age, minimum volume thinned, or time between thinning. Each prescription was projected with FVS on every inventory plot, assuming that the heuristic planning technique would pick the most appropriate prescription for each stand. Inventory plots were assigned to each management unit in the vegetation GIS database, a process described shortly, thus a match between the vegetation GIS attributes and the inventory plots was critical. In the fine scale scenario, however, some management intentions were lacking for some of the species and site combinations present on the landscape. This occurred due to data omissions in the survey results. Some assumptions were made to fill in the gaps in the data

Figure 5. Example of varying scales of management intentions.



(Table 4). Another gap included specific species and site classes that were represented in the GIS vegetation database and the FIA inventory yet not reported in the management intention survey as being managed. In order for every stand in the GIS vegetation database to be available for management, a potential prescription needed to be developed for every forest type of every site class. Two options were clear, change the vegetation database or make some assumptions about the prescriptions to fill in the gaps in the data. The latter was chosen, and prescriptions were developed to manage those species/site class combinations in a fashion similar to data that was available (Table 5) with a difference retained in the minimum harvest ages for clearcuts and minimum volume requirements on uneven-aged stands (Table 6). These residual levels were considered the absolute minimum levels required after harvesting. The high minimum residual volumes in Douglas-fir and pine low sites are important: most of the acres of land in the study area fall into these categories and the current volume levels are lower than these minimum residual volume levels.

In addition, the management intention surveys indicated that a minimum of 1,000, 1,500, 2,000, or 2,500 board feet (BF) per acre must be cut at every thinning entry (depending on the prescription) regardless of even-aged or uneven-aged. Management prescriptions were formulated for uneven-aged stands so that on average, harvest was thirty percent of the stand would be harvested during each entry.

Table 4. Minimum harvest ages for clearcuts modeled in a fine-scale management intention scenario on industrial lands in the Blue Mountains region of eastern Oregon.

	Site Class		
Species	High	Med	Low
Douglas-fir	65	75	90*
Grand fir	65	80*	90*
Mixed conifer	60	75	90
Pine	65	95	110*

* Assumed minimum harvest age

Table 5. Non-represented survey data and the prescriptions used to model those lands in the Blue Mountains region of eastern Oregon.

Non-Represented in Survey Data	Prescription Used
Uneven-aged grand fir, medium site	Uneven-aged grand fir, high site
Even-aged grand fir, medium sites	Even-aged grand fir, high sites
Even-aged grand fir, low sites	Even-aged grand fir, high sites
Uneven-aged grand fir, low site	Even-aged grand fir, high sites
Uneven-aged Douglas-fir, low site	Uneven-aged Douglas-fir, medium sites
Even-aged Douglas-fir, low sites	Even-aged Douglas-fir, medium sites
Even-aged pine, low sites	Even-aged pine, medium sites

Table 6. Minimum residual volume for partial cuts considered in uneven-aged stands, on industrial land in the Blue Mountains region of Oregon.

Species	Fine scale Site Class High	Medium	Low	Medium Scale	Coarse Scale
Douglas-fir	[a]	7,981	10,802	10,480	--
Grand fir	10,000[b]	[a]	[a]	9,234[b]	--
Mixed conifer	10,206	9,256	5,774	7,993	--
Pine	14,454	9,368	7,988	9,502	--
All	--	--	--	--	9,234

[b] indicates data not available for the uneven aged category; assumed numbers used.

[a] indicates data not available for uneven-aged stands and management intentions did not assign prescriptions to particular category.

The minimum standing volume required prior to harvest was determined by examining the average FIA stand in each 10-year age class and thus varied by management scale. The stand was then only thinned if the residual volume was greater or equal to 70% of the standing volume in the average stand of each 10-year age class. Thinning in even-aged stands were only allowed if the standing timber volume was 3.5 times the minimum allowable cut volume (1,000, 1,500, 2,000, or 2,500 BF). Therefore, it was assumed that around 30% of the stand would be thinned allowing a more economical commercial thin.

The designation of uneven-aged and even-aged stands was preset at the beginning of the computer simulation based on each stand's "structure code" representing the stand structure reported by FVS. Future management decisions for even-aged stands were determined as part of the computer simulation rather than the growth and yield model (FVS). For example, the harvest scheduling heuristic determined the period of clearcut for a management unit, after which a regenerated stand tree list was assigned. This eliminated the use of FVS for applying regeneration to the clearcut stand. In order to assign a regenerated stand to the clearcut area, the search procedure located a regenerated stand with similar qualities as the one that was cut, such as the dominant tree species within the stand and site class.

Uneven-aged stands require periodic ingrowth, or an addition of small trees into the diameter distribution of the stand. FVS does not currently have the ability to represent this ingrowth in its Blue Mountain Variant. Ingrowth however, is very important to future harvests and to descriptions of the conditions of uneven-aged stands. Without ingrowth, a stand would unrealistically be depleted (due to harvest) before the end of the time horizon. Duncan Wilson (personal communication) developed a process to allow the modeling of the ingrowth process within FVS.

4.4 FOREST PLANNING PROBLEM FORMULATION

A heuristic forest-planning model was developed in Microsoft Visual Basic on a standard desktop computer, and used a standard simulated annealing approach discussed in section 3.2.4 to scheduling management activities. The simulated annealing model was a straight-forward approach (no strategic oscillation or 2-opt moves). All moves were 1-opt moves (choices) where there is a change in the characteristics of management unit, and not a swap of characteristics between two units (2-opt). This heuristic used was designed to help develop forest plans, as described by the objectives and constraints, to evaluate the differences in results of the three management intention scales.

The first process of the forest-planning model matched the GIS stand-level data with the appropriate growth and yield data by pairing each stand with a similar species, site class, and structure. In some cases a perfect match was not available, in which case stands were assigned growth and yield data that differed in structure yet had the same species and site class ore differed in site class yet had the same species and structure. This was dealt with on a stand-by-stand level. After pairing, the heuristic scheduling model was allowed to choose the prescription for each stand that produced the highest NPV while considering the constraints. The next few sections describe the objective function and constraints of the forest-planning problem then the heuristic planning model that was developed.

4.4.1 Objective function

The objective function used for this study is to maximize NPV over a 50 year planning horizon.

$$\sum_{i=2}^{3841}\sum_{t=2}^{5}\sum_{p=1}^{60}\left[\frac{\left(Vol_{ipt}\left(LP_i - LC_{gi}\right)A_i X_{it}\right) - \left(Vol_{ipt} A_i X_{it} HC_i\right)}{\left(1+PR\right)^{(t*10-5)}}\right]$$

Where:

t = a time period.

i = a management unit.

p = a management prescription.

g = type of logging system used.

VOL_{ipt} = the amount of volume (thousand board feet) harvested per acre from unit i during time period t using prescription p.

LP_i = the log price per thousand board feet in unit i.

LC_{gi} = the logging cost per thousand board feet for unit i with logging system g. Units with slope over 35% use skyline logging while less than 35% slopes ground-based logging systems.

A_i = the area of unit i (acres).

HC_i = the haul cost (dollars/MBF) for unit i. This is dependent on the distance each management unit is from the mill, the length of gravel road on this path, and the type of harvest.

PR = the interest rate. The real interest rate here is assumed to be 7%.

X_{it} = a binary variable indicating whether (1) or not (0) management unit i was clearcut in period t.

By optimizing this objective function, the heuristic model was allowed to assign prescriptions that vary by harvest age and entry timing to management units that, in aggregate, yield the best NPV. A schedule of activities results, and from this schedule the harvest volume, revenue, and owl habitat per period can be determined.

4.4.2 Constraints

An adjacency constraint is assumed in developing forest plans with the heuristic planning model. The size of the openings created via clearcutting in each time period is limited to 48.56 ha (120 acres), to resemble a realistic forest green-up policy (e.g. Oregon state legislature, 2002). The adjacency constraint uses an area restriction technique (as described by Murray, 1999) to determine how large the clearcuts are in any one time period.

$$A_i X_{it} + \sum_{z \in Ni \cup Si} A_z X_{zt} \leq \text{maximum clearcut size}_t \qquad \forall i, t$$

Where:

N_i = the set of units adjacent to management unit i.

S_i = the subset of treated adjacent units to the neighbors of management unit i and all units adjacent to neighbors of neighbors, and so on.

z = a single management unit from the set S_i.

Thus clearcuts that are, in aggregate, larger than 48.56 ha result in an infeasible solution. One option to this hard constraint might be to penalize the objective function for all clearcuts greater than the minimum size, hoping the penalties would force the solution into feasible region of solutions. However this option was not explored in this study.

Due to the complexity of stands possibly shifting from uneven-aged management to even-aged management and differences in cutting cycles and timing amongst the types of management practices, only one type of management was assumed per stand, eliminating the potential of an uneven-aged stand becoming even-aged or visa versa within the 50 year planning horizon. In addition, due to the lowest minimum clearcut age given by the management intentions only one clearcut was possible per stand during the 50 year planning horizon therefore:

$$\sum_{t=1}^{5} X_{it} \leq 1 \qquad \forall i$$

In accordance with the direction provided by the forest landowner survey, we assumed that clearcuts could occur only after a minimum stand age had been attained. Minimum harvest ages also vary by the scale of the planning process (fine, medium, coarse), and the logic used was as follows:

$$If\ AGE_{it} < R_{msc},\ X_{it} = 0$$

$$If\ AGE_{it} \geq R_{msc},\ X_{it} \in \{0,1\}$$

Where:

AGE_{it} = the stand age of management unit *i* during time period *t*.

R_{msc} = minimum age requirement of the management scale assumed (m) which is dependent on species *s* and site class *c*.

A minimum merchantable volume level was assumed in all stands proposed for clearcut, based on guidance provided by Adams (2002). All even-aged regeneration harvests needed a minimum of 12 (MBF) per acre available in the stand in an effort to model realistic harvest opportunities. Consequently:

$$If\ Vol_{it} < 12\ ,\ \ X_{it} = 0$$

$$If\ Vol_{it} \geq 12\ ,\ \ X_{it} \in \{0,1\}$$

When a stand has a volume greater or equal to 12 MBF and meets all other regeneration harvest conditions such as the minimum age requirement and adjacency, X_{it} will take on a value of either 0 or 1 (from the set $\{0,1\}$), yet can only have a value of 1 once over the entire 50-year planning horizon.

4.5 COSTS AND PRICES RELATED TO HARVESTING

To evaluate NPV actual, logging costs, haul costs, and log prices for the La Grande area were utilized. This information was obtained from Tom Burry the La Grande Ranger District Engineer Logging Specialist on the Wallowa-Whitman National Forest La Grande, OR, and was based on a recent logging operation in an area near La Grande.

Two logging systems were assumed to be available: mechanical ground-based logging and skyline logging. Ground-based logging was assumed to be performed on stands with less than or equal to 35% slope. The cost of logging with this method was assumed to be \$210/MBF. Skyline logging was assumed to be performed in stands with slopes steeper than 35%. The cost of logging with this method was assumed to be $200/MBF.

Haul cost computations involved both fixed and variable components. Haul costs were a function of the distance from each stand to the mill, the volume hauled, the road surface (gravel, dirt, or paved), and the cost of owning and operating a truck. The log prices assumed are a function of the majority species type harvested, and represent reasonable recent values in the Blue Mountains region (Table 7).

4.6 MEASURES OF FOREST PLAN PERFORMANCE

In addition to reporting the NPV of each forest plan that is developed, three other measures are reported as resulting values of a forest plan timber volume produced, acres treated, and owl habitat.

4.6.1 Timber volume produced

Timber volume is summed in the development of a forest plan using the following approach:

Table 7. Log prices assumed for the Blue Mountains region.

Ponderosa Pine:	\$375/MBF
Grand fir/ White fir:	\$320/MBF
Douglas-fir/ Western larch:	\$350/MBF
Other:	\$320/MBF

Source: Tom Bury, the La Grande Ranger District Engineer
Logging Specialist on the Wallowa-Whitman National Forest
La Grande, OR (Personal Communication, 9/21/01)

$$\sum_{s=1}^{0}\sum_{i=2}^{3841}\sum_{p=1}^{60}\left[Vol_{sipt}\right]A_i \qquad \forall t$$

Timber volume is subsequently reported for each time period, and can also be summed to produce a total harvest volume over the 50 year planning horizon.

4.6.2 Acres treated

Clearcut acres are summed in the following manner:

$$\sum_{i=2}^{3841} X_{it} A_i \qquad \forall t$$

For uneven-aged stands, acres treated are summed by determining whether timber volume was extracted from a management unit:

$$\textit{If } Vol_{sipt} > 0 \textit{ then } UEA\_acres_t = UEA\_acres_t + A_i \qquad \forall_{i,p,t,s}$$

The amount of acres entered under uneven-aged management can then be determined for each time period.

4.6.3 Owl habitat

Great gray owl habitat was calculated in each time period as a measure of the ecological impact of each forest plan. The area indicated as owl habitat was derived by summing the acreage that meets the nesting and foraging requirements within a 500 meter radius of the nesting patch. The habitat levels can be compared between the three different management intention scales to determine if a change in assumptions affects the level of management, hence habitat.

The nesting and foraging requirements of the great gray owl, as suggested by literature on the subject, are shown in Table 8. Since there was no documented guidance on the appropriate sizes of nesting or foraging patches, we assumed: (1) a nesting patch must be greater than or equal to 20 ha (49ac) and (2) owls need 10 hectares (25 acres) or more of forage land within a 500 meters radius of the nesting patch.

To enable owl habitat modeling of the entire study area, knowledge of the vegetative characteristics of the adjacent parcels of land outside of the study area is necessary. Thus the exterior boundary of the study area was buffered 500 meters (the area to be 50% forested for nesting) and the vegetation of these exterior stands were used to evaluate owl suitability within study area plots. These exterior plots were not assigned harvest prescriptions and were evaluated for owl habitat assuming that they were under a "grow only" management.

4.7 HEURISTIC MODEL VERIFICATION AND VALIDATION

A general approach to model validation was presented in section 3.3. This section details the specific actions that were taken to validate the forest-planning model described in previous sections. Since heuristic models do not guarantee that an optimal solution to a planning problem will be located, it is important to ensure the model is operating well through verification and validation processes. To verify that the model operates as intended, the performance is checked and debugged in a variety of ways. A sensitivity analysis was also preformed to ensure that the appropriate starting simulated annealing temperatures, iterations, and reduction factors were used for each management scale. Each portion of the model was debugged, as was the transfer of data between subroutines. The final results (volumes, acres treated, value, habitat) were then evaluated to determine whether they were reasonable.

In model validation the goal is to determine how closely a model corresponds to an actual system (Law and Kelton 1991). Here, we attempt to determine whether the solution values produced (NPV) from the forest plans can give us an indication of the global optimum solution value.

Since heuristic models may only produce near-optimum solutions to planning problems, statistical methods are necessary to estimate the global optimum. In this study we used the characteristics of a Weibull distribution to do

Table 8. Owl nesting and foraging requirements as suggested by related literature.

Nesting Requirements:

- Patch must have greater than 60% canopy closure (Bull and Henjum, 1990)
- Patch must be greater than or equal to 70 years for lodgepole pine (also used for Douglas-fir within the simulation) or 150 years for ponderosa pine (Oregon Department of Fish and Wildlife, 1991)
- 50% of the area within 500 meters (194 acres) of patch must be forested (Bull and Henjum, 1990)

Forage Requirements:

- Meadows forested and patches less than 10 years old are considered foraging habitat
- Stands that have 11-59% crown closure are preferred for forage and meadows are disliked (Bull and Henjum, 1990)

so. To induce a statistically independent sample, each run of the heuristic model used a random generation of initial starting points. This was repeated 20 times for the all three scales (coarse, medium, and fine). The optimum solution values from each of these sets of 20 runs for each model were then tested to see whether they fit well within a Weibull distribution. If the hypothesis that a Weibull distribution could be represented well with the data and not be rejected, it was assumed that the data were acceptable for further use for the analysis. Bestfit statistical software (Palisade Corp., 2002) was used to determine whether the data could validly represent a Weibull distribution.

If a valid fit is suggested by Bestfit, The location parameter (a) from the three-parameter Weibull distribution can then be used as an estimate of the global optimum solution to a planning problem. In the event the solution values from the forest plans cannot be represented by a Weibull distribution, a non-statistical examination of these values will be made, and inferences about their quality developed.

4.8 GIS DATABASES

A number of GIS databases were required to facilitate the modeling process, including: vegetation, ownership, roads and streams. A vegetation GIS database of the vegetation of the Blue Mountains region was provided by the Interior Northwest Landscape Analysis System (INLAS) project (La Grande Forestry Sciences Laboratory, 2002). This database consisted of vector polygons representing management units. Each polygon contained attributes such as species, structure, site class, acreage, and slope. An ownership GIS database was also obtained from the INLAS project and used to extract only those vegetation polygons on industrial forestland. A portion of the industrial ownership in the Blue Mountains region, approximately 95,063 acres, was selected as the study area for this research (Figure 6).

A roads GIS database was obtained from Oregon Department of Forestry (Oregon Department of Forestry, 2002). With this database, main roads within the area of interest were selected for hauling timber products. Since locating the optimal path from each management unit to a mill location was not an objective of this research, few evenly spaced points were located along each road (Figure 7) to represent timber entry points to the road system. Each entry point has an associated distance to La Grande, Oregon, where a mill is assumed. An algorithm was developed to find the closest entry point to each polygon centroid. Thus a distance from each stand to a mill was estimated. These distances were further described by the type of road that they represented (paved, rock). The Oregon Gazetteer (DeLorme Mapping Company, 1991) was used to identify the paved roads, all other roads were assumed to be rock roads.

Figure 6. A portion of the industrial forestland ownership in the Blue Mountains region of Oregon.

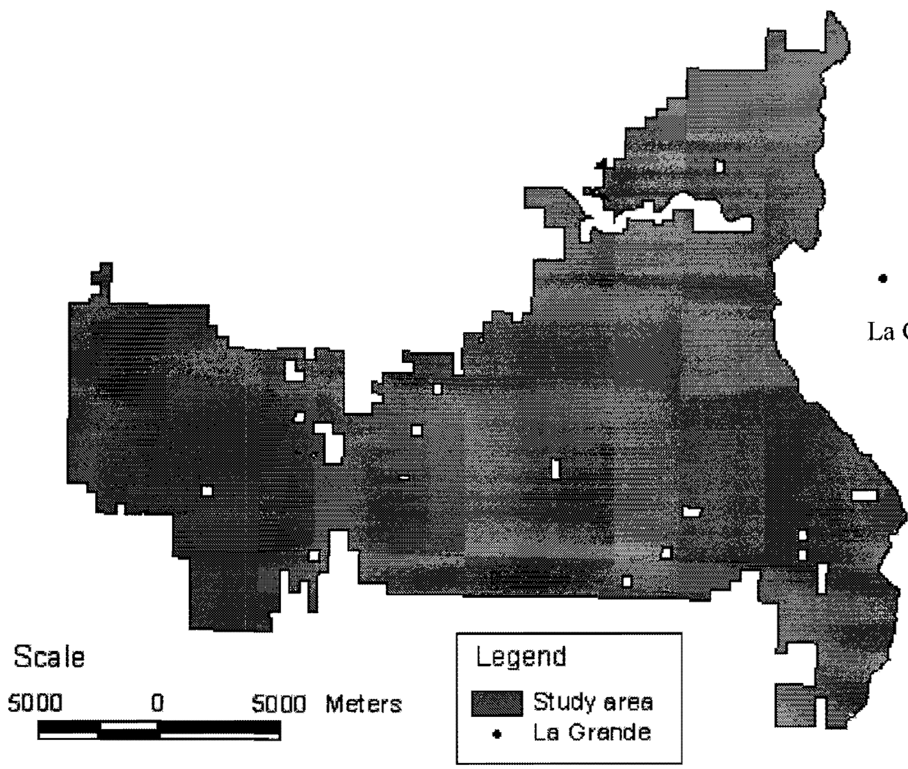
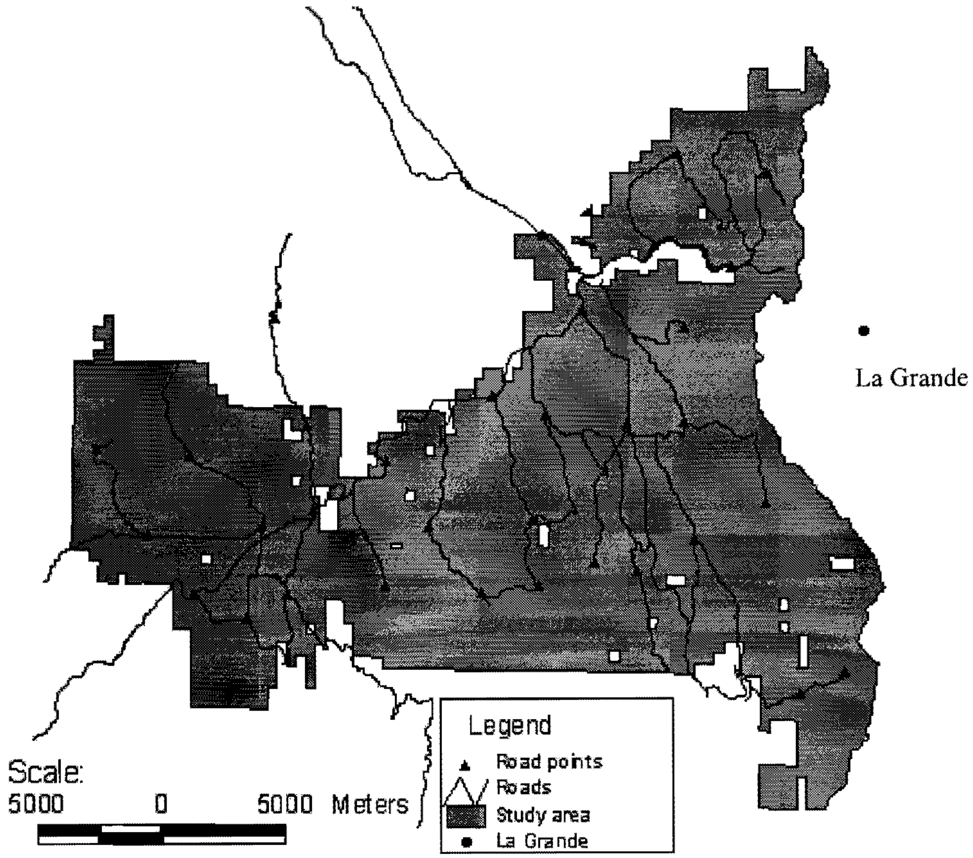


Figure 7. Roads and road entry points used for a 95,063 acre study area on industrial land in eastern Oregon.



The factors that were taken into consideration when calculating a haul cost included the speed of travel on each type of road, length of each road type traveled, the truck costs, including the owning, driver, and operating costs, and whether the log truck was loaded. The distance from each stand to a mapped road was assumed to be a non-graveled spur road, with an average speed limit of 15 MPH for loaded and unloaded trucks. The gravel road travel speed was assumed to average 25 MPH loaded and 30 MPH unloaded. The paved roads were mostly main roads, where the speed limit was assumed 55 MPH. A loaded log truck was assumed to travel these roads at 45 MPH, and an unloaded truck was assumed to travel at 55 MPH.

The cost (fuel, driver, maintenance, and payments) of using a log truck was assumed to be 45 dollars per hour unloaded and 50 dollars per hour loaded. This difference in cost is due to the higher fuel consumption and tire wear of a loaded truck.

The board foot carrying capacities of the trucks were assumed to be different for uneven-aged partial cut or even-aged thinning and even-aged clearcuts. Trucks were assumed to carry 3.5 thousand board feet (MBF) from an uneven-aged partial cut or even-aged thinning, and 4.5 MBF from a clearcut. Clearcuts generally have larger logs with more board feet per cubic foot, allowing for larger truck loads than partial cuts of the same weight. It was assumed that after 2,000 truck loads traveled across a gravel road, regraveling was required to a depth of 1 inch. According to The Bark Place (a local distributor of rock products) a cubic yard of gravel costs $18.99.

A streams GIS database was also obtained from the INLAS project. Streams should have been buffered according to their order and whether they were considered "fish-bearing'. Due to lack of data regarding the fish-bearing status of the streams in the Blue Mountains region, only stream order was used to buffer, and delineate the riparian areas (Table 9). This buffering process was used in an attempt to emulate the Oregon Forest Practices Act (Oregon State Legislature, 2001) riparian management regulations.

Table 9. Stream buffer sizes assumed for riparian management areas in the Blue Mountains region of eastern Oregon.

Order	Buffer size (ft)
1	No Buffer
2	50
3	70
4	100

5 RESULTS

A forest-planning problem where NPV was maximized subject to adjacency and minimum harvest age constraints was solved with a simulated annealing heuristic. The study area consisted of 95,063 acres of industrial land in the Blue Mountains region of eastern Oregon, and 3,840 units were modeled. For each of the three scales of management intentions (fine, medium, coarse), at least 20 separate, independent solutions (forest plans) were developed. The difference within and among the sets of solutions will be described next, in terms of NPV of the resulting plans, the estimated global optimum NPV, timber harvest volume levels, standing timber volume, and great gray owl habitat.

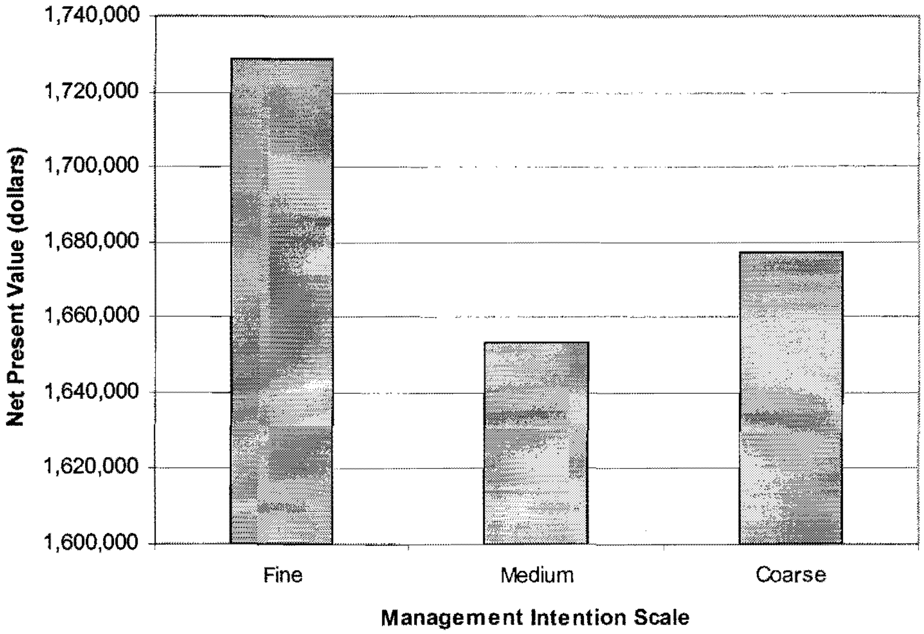
As one might have expected, the fine, medium, and coarse scale management intentions all produced different maximum NPVs of the resulting forest plans (Table 10). While the solutions the heuristics produced were all feasible with respect to the assumptions modeled, there was about a 4% range in the best values generated by each management intention scale (Figure 8).

Of the three management scales, the fine scale produced a solution with the highest NPV, then the coarse scale and medium scales. The best solution from the fine scale runs had NPVs that were about 4% higher than the medium scales and 3% higher than the coarse scales. The medium scale was the lowest due to the

Table 10. Confidence intervals and coefficient of variation from all the solutions generated in the forest plans using three management intention scales.

Management Intention Scale	95% Confidence Intervals (-)	95% Confidence Intervals (+)	Coefficient of Variation
Fine	1728625	1728614	0.00065
Medium	1653152	1653151	0.00008
Coarse	1676851	1673365	0.22231

Figure 8. Net present value from the best solutions generated in forest plans using three different management intention scales.



minimum residual harvest being more restrictive with some species than the fine scale and in some cases the coarse scale as well. The differences in minimum residual volumes were one of the main factors in the higher net revenues produced by the fine scale scenario in the second and third time periods (Figure 9). While the coarse and medium scales were able to produce higher net revenues in the fourth time period, when discounted to the present it was not enough to compensate for the lower revenue in periods 2 and 3. A non-parametric rank sum test indicated that the mean of all three solutions were significantly different (all combinations having a one-sided p-value < 0.0001). The confidence interval (CI) of the means (Table 10), along with the maximum, average and standard deviations (Table 11) further shows that the optimum values of each scale do not overlap other scales at all.

The estimated global optimum NPV for all three management intention scales could not be estimated. The Bestfit software indicated that there was an invalid fit between the data provided (20 solutions from the forest planning model) and a Weibull distribution. No statistics were provided by Bestfit to confirm the result, however one (or more) failure of the test statistics (Anderson-Darling, Chi Squared, Kolmogorov-Smirnov) resulted in a rejection of the use of a Weibull distribution to describe the data's distribution. Upon examination of the results, however, we find that the NPV solution values are concentrated very closely around the best values obtained within each management intention scale. (Figure 10a-c). Therefore the very best objective function value from each

Figure 9. Net revenue from the best solution generated in forest plans using three management intention scales.

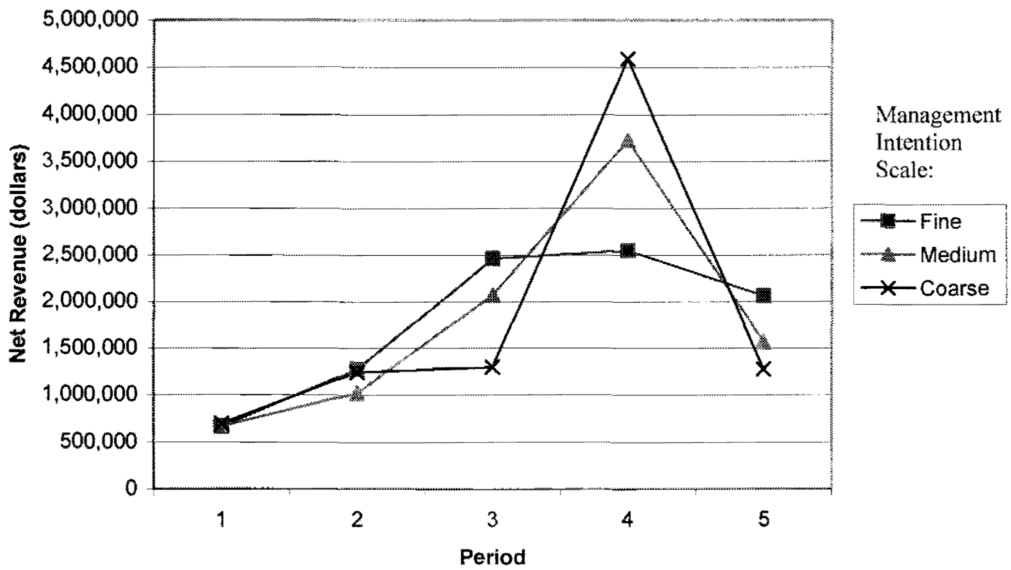


Table 11. Characteristics of the net present value generated in forest plans using three different management intention scales.

Management Scale	Maximum Value (dollars)	Average Value (dollars)	Standard Deviation (dollars)
Fine	1,728,622.35	1,728,619.53	11.16
Medium	1,653,152.02	1,653,151.71	1.29
Coarse	1,677,330.80	1,675,108.33	3723.99

Table 12. Even-aged stand differences between the best solutions of the three management intensity scales.

						Timber Volume				
Scale	Stand Number	Prescription	Site Class	Starting Stand Age (Years)	Species	Period 1 (MBF/acre)	Period 2 (MBF/acre)	Period 3 (MBF/acre)	Period 4 (MBF/acre)	Period 5 (MBF/acre)
Fine	1892	0	low	57	Pine	0	0	0	0	0
	2679	0	low	57	Pine	0	0	0	0	0
	208	11	low	60	Douglas-fir	0	0	0	**1157**	0
Medium	1892	47	low	57	Pine	0	**407**	0	0	0
	2679	47	low	57	Pine	0	**392**	0	0	0
	208	39	low	60	Douglas-fir	0	**984**	0	0	0
Coarse	1892	58	low	57	Pine	**359**	0	0	0	0
	2679	58	low	57	Pine	**345**	0	0	0	0
	208	56	low	60	Douglas-fir	**984**	0	0	0	0

Figure 10a. Distribution of net present values from the fine scale management intensity scale; sorted by value (Run 1 = very best, Run 20 = worst).

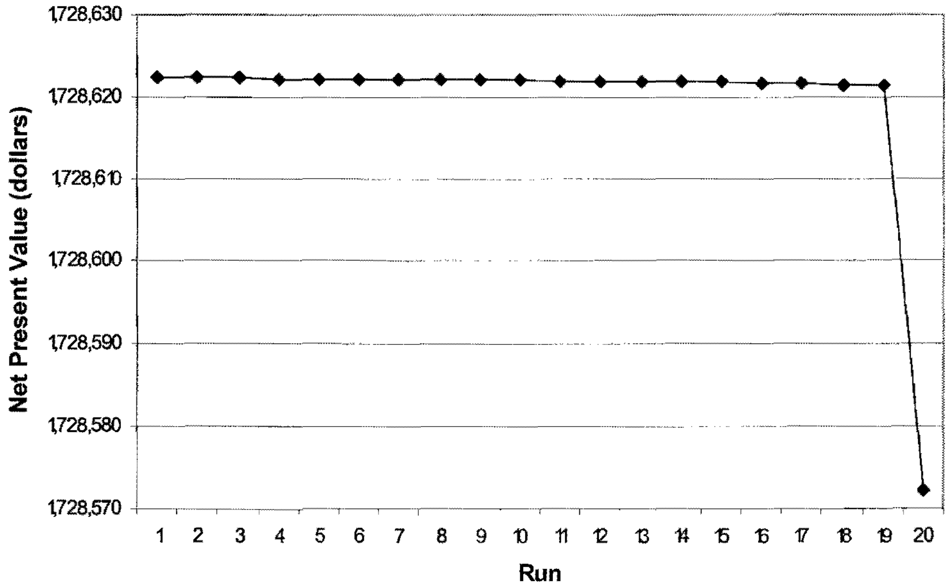


Figure 10b. Distribution of net present values from the medium scale management intensity scale; sorted by value (Run 1 = very best, Run 20 = worst).

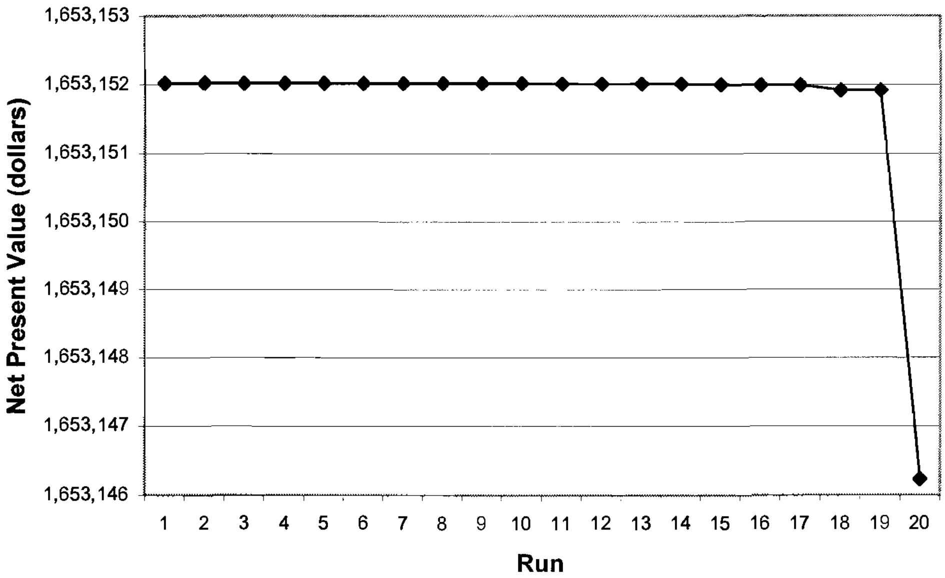
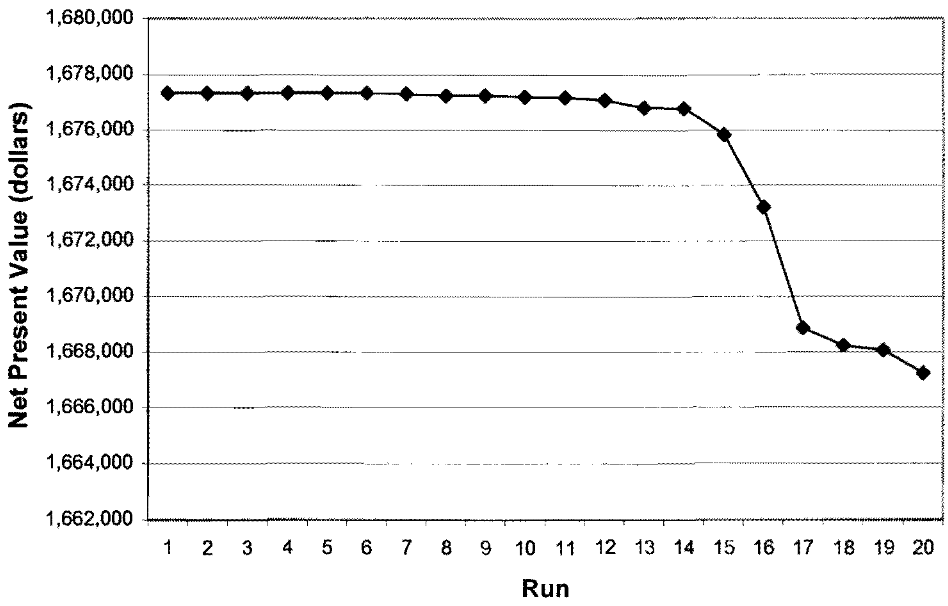


Figure 10c. Distribution of net present values from the coarse scale management intensity scale; sorted by value (Run 1 = very best, Run 20 = worst).



management intention scale will be used as a surrogate for the estimated global optimum value in future discussions.

The differences between the levels of detail in the different management option prescriptions led to disparity of how one stand is managed in each management scale. The fine scale contains more detailed criteria that guide management decision mainly affecting the stands in even-aged harvest regimes. The aggregated minimum harvest ages for the medium and coarse scales can be lower than similar prescriptions of the fine scale, yielding more available area for clearcut harvest in the aggregated scales. An example of this is displayed in Table 12 showing the difference in prescriptions for each scale preformed on the same stand.

Most differences in harvest prescription patterns occurred within pine stands with a low site class, due to the high minimum harvest age of pine on low sites (fine scale: 110 years; medium scale 75 years; coarse scale 65 years) and a majority of the land designated as low site pine forests (Table 13). As can be seen in the first two stand examples of Table 12, under the fine scale these stands cannot be harvested because the initial stand age is 57 years at the beginning of the projection. In the medium scale the stand is the appropriate age to harvest beginning in period three, while the coarse scale has an even lower minimum harvest age allowing the stand to be harvested in period two. The minimum volume requirement may have created even less options for harvesting timber in

Table 13. Amount of acres per site class and species in a GIS vegetation database representing industry land in the Blue Mountains region of Oregon.

Species	High	Medium	Low
		(acres)	
Douglas-fir	489	1,446	18,654
Grand fir	455	225	9,273
Mixed conifer	37	81	946
Pine	302	803	22,177

the fine scale scenario. The third stand example in Table 12 shows harvest in medium and coarse scales scenario occurring much earlier time periods (periods 2 and 3), but because the minimum harvest requirement of 12 MBF restrains stands of less volume from harvesting earlier, this stand was not harvested until it period four in the fine scale scenario. This delay was a common pattern observed.

The lack of even-aged timber harvest volume in the fine scale scenario was over shadowed, however by the abundance of uneven-aged harvest volume. The uneven-aged stands do not have a minimum harvest age, and instead they are constrained by a minimum residual volume requirement. As described earlier, the minimum residual volume level, after cutting 30% of the volume, was determined by examining the average stand in each 10-year age class. In the fine scale scenario, averages were developed by species and site class. In the medium scale scenario the minimum volume to remain was determined by considering the average stand for each species, while in the coarse scale scenario a conglomeration of all the stands was used to arrive at the minimum residual volume (Table 6). Since there were different minimum residual volume requirements for all three management intention scales, the fine scale had much more harvest occurring in uneven-aged management regimes than did the medium and coarse scales in all but the fourth time period (Figure 11). The fine scale prescriptions allowed stands to be harvested earlier and more frequently (see examples in Table 14). The medium scale, using residual harvest volume based

Figure 11. Uneven-aged harvest volume from the best solution of the three management intention scales, over the 50-year planning horizon.

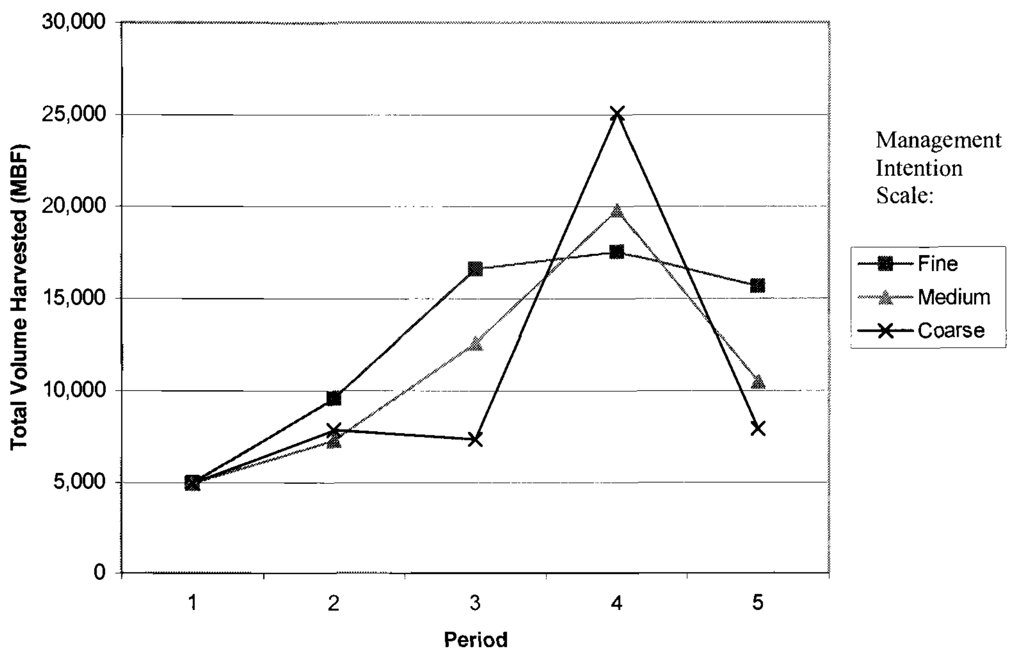


Table 14. Uneven-aged stand differences between the best solutions of the three management intensity scales.

						Timber Volume				
Scale	Stand Number	Prescription	Site Class	Starting Stand Age (Years)	Species	Period 1 (MBF/acre)	Period 2 (MBF/acre)	Period 3 (MBF/acre)	Period 4 (MBF/acre)	Period 5 (MBF/acre)
Fine	1829	30	low	63	Pine	0	**35**	0	0	0
	1433	30	low	57	Pine	0	0	**16**	0	**15**
	858	31	medium	57	Douglas-fir	**3**	0	**3**	0	**3**
	925	31	medium	57	Douglas-fir	**31**	0	**36**	0	**40**
Medium	1829	48	low	63	Pine	0	0	0	**42**	0
	1433	48	low	57	Pine	0	0	**16**	0	0
	858	51	medium	57	Douglas-fir	0	0	**4**	0	**4**
	925	51	medium	57	Douglas-fir	0	0	**47**	0	**48**
Coarse	1829	54	low	63	Pine	0	0	0	**42**	0
	1433	55	low	57	Pine	0	0	**16**	**15**	0
	858	54	medium	57	Douglas-fir	0	0	**4**	0	**4**
	925	57	medium	57	Douglas-fir	0	0	**47**	0	**48**

only on species, tends to provide few options for the low site class stands due to its relatively high residual harvest volume requirement on mixed conifer and pine stands. The coarse scale uses a single minimum residual harvest volume for all sites classes and species. Which tends to be higher than some of the values for low site classes in fine scale.

The amount of harvested volume with each management intention scale is highly correlated with the NPV (Figure 12). The fine scale, for example has higher harvest levels than the other two scales, mainly in the third and fifth time periods. The total volume harvested per period in the fine scale is mainly dictated by the uneven-aged harvest volume (Figure 11). The total volume, in turn, is a condition of the amount of acres harvested. While the even-aged harvest contributes little volume and only harvests a small amount of acres, the fine scale uneven-aged harvested volume is so large it counteracts the small even-age harvest volume (Figure 13). Within the coarse and medium scales, much less uneven-aged acres are harvested than within the fine scale, yet a much larger area of clearcut acres are found (Table 15). The coarse and medium scales both have peak harvest levels in the fourth period. The decline in the fifth period may be due to the lack of harvestable volume in the fifth period, since much was cut in the fourth. However, the decline returns the harvest levels to about the levels obtained in the first three time periods. Although more volume is harvested in even-aged management than the fine scale, the larger area harvested in uneven-aged

Figure 12. Total timber harvest volume per period from the best solution of the three management intention scales, over the 50-year planning horizon.

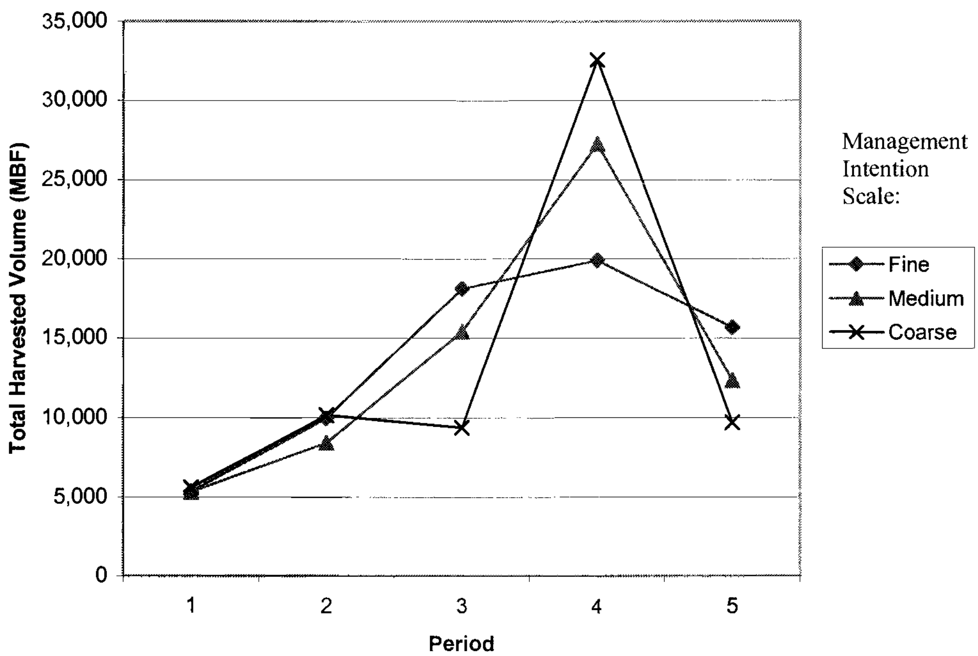


Figure 13. Even-aged harvest volume per period from the best solution of the three management intention scales, over the 50-year planning horizon.

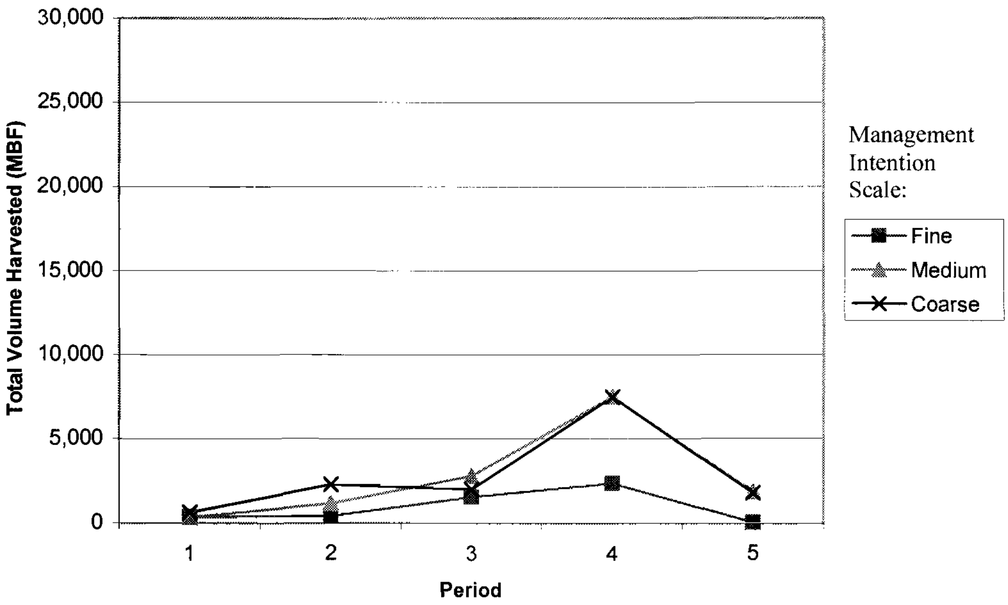


Table 15. Harvested acres in uneven-aged and even-aged management from the best solution located for the three management intensity scales in the Blue Mountains region of Oregon.

Management Intensity Scale	Management Type		
	Uneven-aged	Even-aged	Both
		(acres)	
Fine	10800	259	11059
Medium	9440	1044	10484
Coarse	7545	1044	8589

management neutralizes the total harvest to sustain the total volume and acres harvested at comparable levels. The total timber harvested over the 50-year planning horizon ranges from about 67500 MBF to 69,500 MBF, indicating each scale scheduled about the same level of harvest yet distributed the harvest differently among time periods and management prescriptions. Overall, the resulting level of extraction is approximately 2.5 board feet per acre per year, well below the annual increment of approximately 130 board feet per year. The greatest level of extraction is approximately 60 board feet per acre per year in the fourth time period of the coarse scale scenario. Standing inventory levels (Figure 14 and 15) also indicate a continued build-up in volume over the planning horizon. The low initial inventory levels along with constraints imposed by the management intentions and the assumptions made regarding residual volume levels contributed to these results.

As can be seen in both Figure 13 and Figure 14, both the total standing timber volume and standing timber volume per acre steadily increase throughout the planning horizon when the forest plans are developed under all three management intention scales. The volume begins to curtail its assent in the fifth period in all three management scales and appears to begin to stabilize. So while harvest levels may fluctuate throughout the planning horizon, standing timber inventory generally increases, perhaps because many stands are initially too young to harvest or contain low stocking levels due to prior management decisions. Therefore, many stands in the study area must grow several years (or

Figure 14. Standing timber volume per acre after harvest from the best solution of the three management intention scales over the 50-year planning horizon.

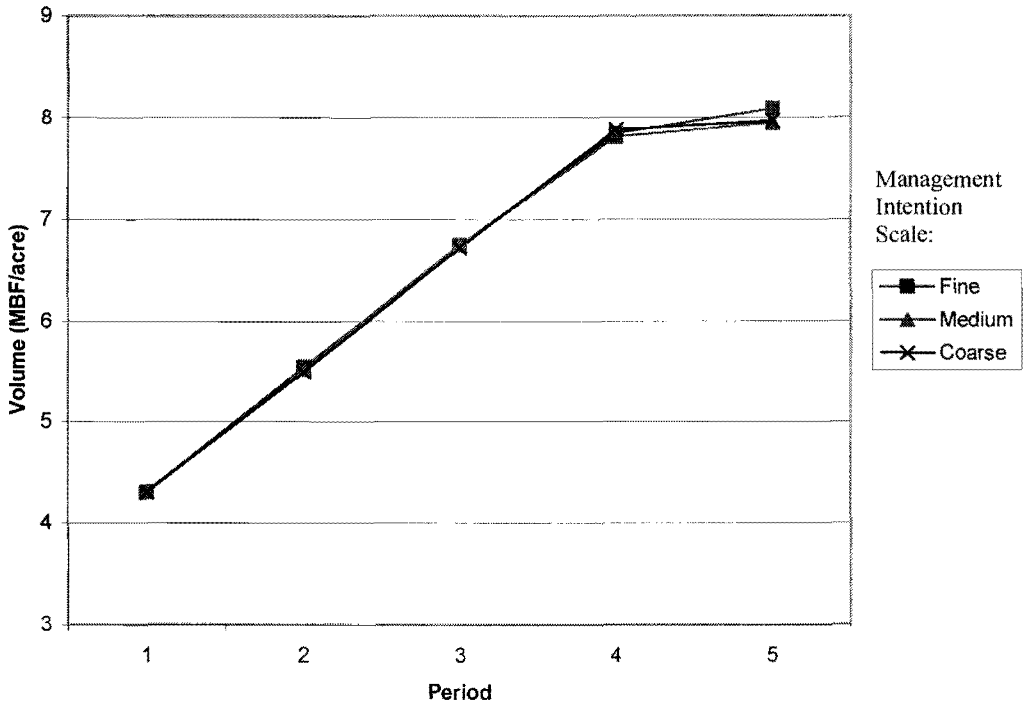
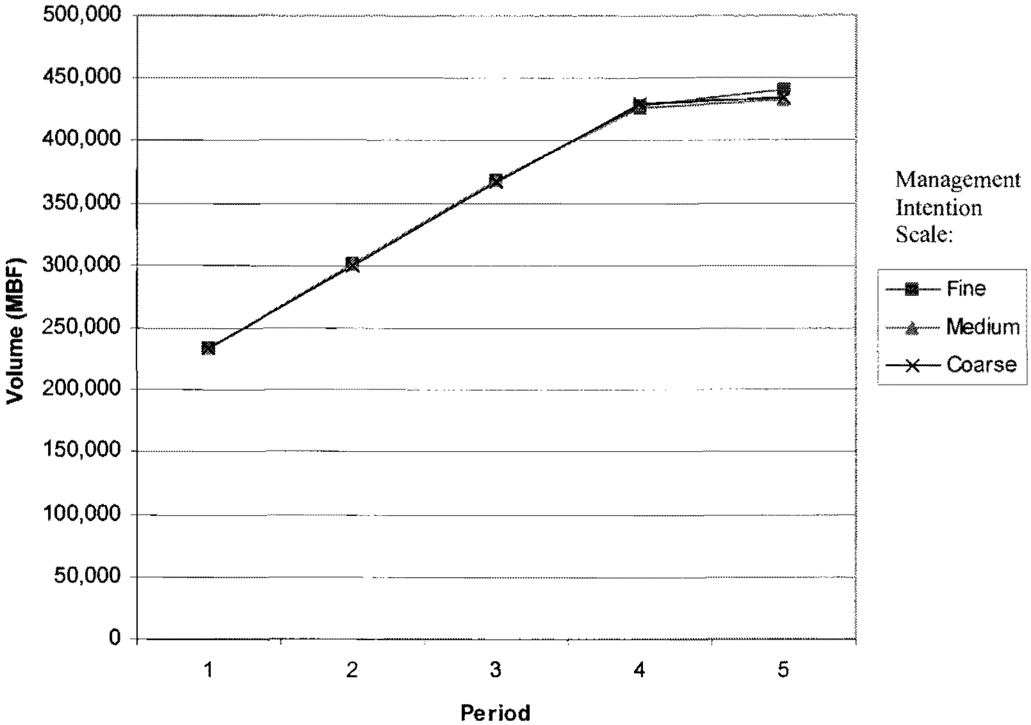


Figure 15. Total standing timber volume after harvest from the best solution of the three management intention scales over the 50-year planning horizon.



decades) before the management intentions being modeled allow extracting some of the volume.

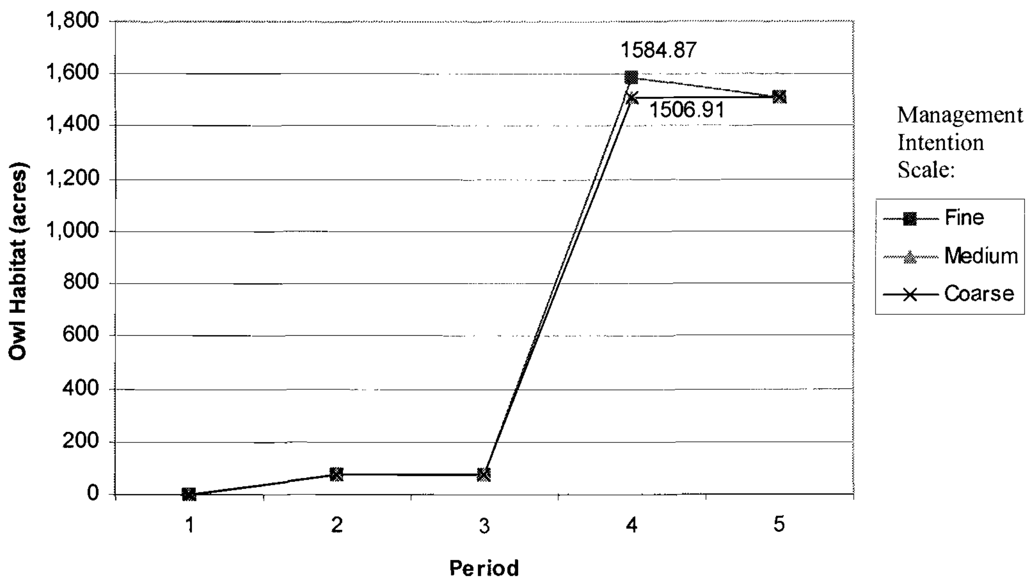
Because of the more precise prescriptions in the fine scale, volume and revenue per acre is larger than the medium and coarse scales in even-aged management (Table 16). The other two scales, more than likely, are allowing clearcutting of lower-stocked, less valuable stands in the early time periods, when there is less standing volume and the stands are not as valuable, decreasing the revenue per acre. The uneven-aged stands harvested in the medium and coarse scales have a greater volume and revenue per acre than the fine scale because of the differences in minimum residual volumes. The medium and coarse scale prescriptions force harvests to occur later in the planning horizon when they meet the minimum residual volumes allowing more timber to be extracted per acre, thus increasing the revenue per acre.

The resulting levels of great gray owl habitat were very similar amongst the three management scales modeled (Figure 16) indicating that changing the management scale modeled did not substantially affect the estimated level of great gray owl habitat estimated. The number of acres forming the owl habitat areas ranged from 0 to 78 acres (about 0.08% of the landscape modeled) in the first 3 periods, then increased to over 1,500 acres (about 2.7% of the landscape) in the last two periods. The fine scale had slightly higher owl habitat levels in the fourth period than the other two scales (about 78 more acres). Since the initial age

Table 16. Per-acre harvest volume and revenues from the best solution of each of three management intention scales.

Management Intensity Scale	Even-aged	
	Volume/acre	Revenue/acre
	(MBF)	($)
Fine	18.21	2307.38
Medium	13.08	1952.08
Coarse	13.59	1997.51
	Uneven-aged	
	Volume/acre	Revenue/acre
	(MBF)	($)
Fine	4.85	590.10
Medium	5.83	743.78
Coarse	7.05	930.36

Figure 16. Owl habitat (from the best solution of each management intention scale).



class distribution of the study area consisted mainly of young stands, owl habitat levels take several years to develop.

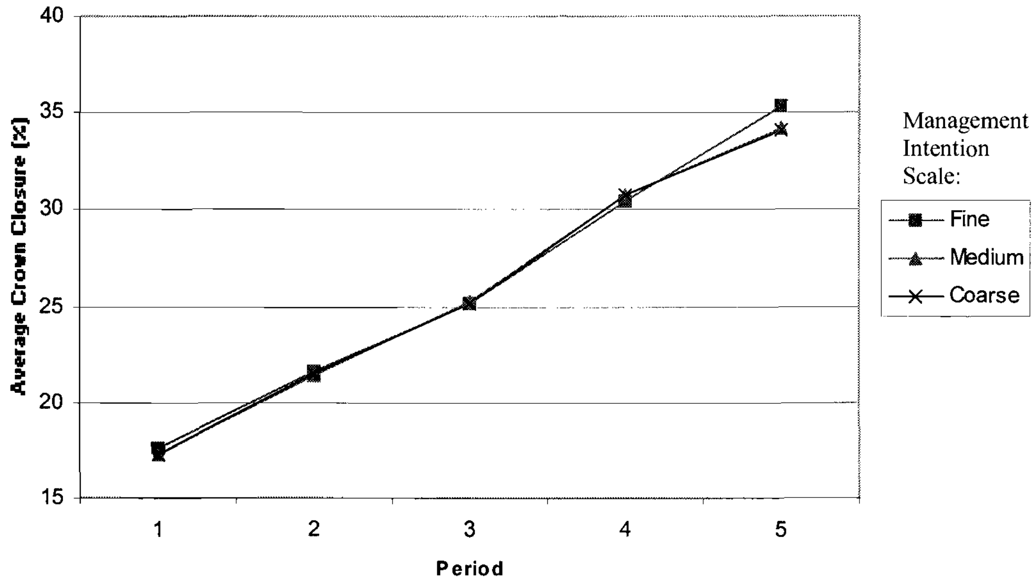
6 DISCUSSION

The objective of this study was to determine, whether different scales of management intentions could produce similar enough results to suggest that the less labor-intensive approach (coarse or medium scale) could be used in lieu of another more detailed approach (fine scale) in forest planning or a similar modeling process. The results provided here, suggest that, from a commodity production standpoint, the fine-scale model should be used. The prescriptions suggested this level of detail is apparently significantly different, in terms of the objective function chosen for the model, from more aggregated detail levels, allowing a landscape to be modeled most appropriately with respect to management behavior. While the differences in NPV between the fine, medium, and coarse scales was only four percent or less, they were statistically significant. In addition, the timing of harvest volume production and hence revenue generation, was different among the scales. The main idea is that if the resources (databases, time, budget) are available to allow modeling at the fine scale, that level of modeling should be undertaken, otherwise the measures of commodity production may not be as efficiently modeled as one had hoped. From a very limited ecological perspective, the choice of management scale modeled did not significantly affect the level of great gray owl habitat on the landscape. The similar levels of owl habitats across forest plans may be strongly affected by the initial condition of the initial landscape, however given the relatively low timber volumes noted (indicating the time required to generate owl habitat on this landscape may be lengthy). Regardless of management scale modeled, the majority of stands in the initial landscape have low crown closure and do not grow fast enough within the planning horizon to reach a 60% closure (Figure 17). Perhaps if the planning horizon were longer, there would be more of a difference in habitat between the scales of management intentions or if another organism was chosen as the ecological measure.

In order to model the survey results as closely as possible, some prescription guidelines were fixed, perhaps at inefficient levels. For example, the survey provided a minimum thinning volume for even-aged thinnings and uneven-aged partial cuts. These minimum thinning volumes dictated how much timber would be removed, yet from a stand management perspective, may have been less than optimal. A stand-level optimization procedure may have suggested management prescriptions much different than those suggested by the survey. Thus, the modeling effort was conservative in this respect by only allowing a minimum percentage to be extracted in each entry.

Two constraints were important in the scheduling process: minimum harvest ages for clearcuts and minimum residual volume levels for partial cuts. Although they were subject to sensitivity tests, the assumptions made in lieu of missing survey data are thought to have played a relatively major role in the

Figure 17. Average crown closure distribution for about 55,000 acres of forested land from the best solutions of three management intensity scales, in the Blue Mountains region of eastern Oregon.



differences observed in management intention scales. In the development of this analysis, several assumptions had to be made, many of which are typical of forest planning efforts (costs, prices, etc.), but a few were directly related to the objective of the study. These were the assumptions about the management intentions, which we incorporated into a forest plan. The Oregon Department of Forestry (ODF) survey results of private industrial forest owners covered options for most of the forest land base in the Blue Mountains region, but not all of it. For instance, the landowners indicated the minimum amount they would harvest using even and uneven-aged management, yet they did not specify the minimum volume a stand must have before it is harvested or thinned. To ascertain that stands with initially low volume were not over thinned in each period the minimum residual volume was developed using the FIA data (described in section 4.3) which represented the Blue Mountains area. This had the largest impact on the results seen and caused the most variation between scales (as described using Table 14).

Further, the owners, through the survey instrument, did not indicate their management intentions on all species and site classes that were represented by the FIA inventory data and the GIS vegetation database that represented the landscape. An example of this is the even-aged Douglas-fir stands on low site classes. In order for every stand in the GIS vegetation database to be available for management, it seemed that some additional prescriptions, beyond those suggested by the survey, needed to be developed. Two options were clear, change the vegetation database or make some assumptions about the prescriptions to fill in the gaps in the data. The latter was chosen, and prescriptions were developed for those species/site class combinations in a fashion similar to the data that was available in the survey (Table 5). The only difference was in the minimum harvest ages for clearcuts and minimum volume requirements on uneven-aged stands (Table 6). We assumed higher minimum harvest ages for the lower site classes. The magnitude of differences from the available ages to the assumed ages was proportional to the available data. Table 4 displays the minimum harvest ages used in the fine scale model for even-aged clearcuts.

Given the differences in the prescriptions available under the three management intention scales it is clear that any one particular stand might be managed differently within each scale. For example, the minimum harvest ages are lower in the coarse and medium scales than in the fine scale. Over a 50-year planning horizon, most low site class stands are not available for clearcut harvest in the fine scale, yet might be available in the medium and coarse scale. This of coarse provides more options for even-aged harvesting in the medium and coarse scales. On the other hand, the lower minimum residual volume requirements in the fine scale scenario allow more harvest within uneven-aged stands than in the medium and coarse scales. Thus, within the fine scale scenario, we find the model to be somewhat conservative with respect to even-aged harvests and liberal with respect to uneven-aged harvests.

A few issues related to the GIS database may have also influenced the results observed, although the magnitude of the impact was not examined. One assumption made indicated that cutting over 120 contiguous acres would not be allowed; some GIS stands however, were over 120 acres in size. Thus, a special exemption had to be made for these stands, since they were not sub-divided prior to forest plan development. The exemption allowed the large stands to be clearcut as long as no surrounding stands had a final harvest in the same time period. Although having a clearcut over 120 acres technically is illegal in Oregon, for modeling purposes it was necessary to allow for the possibility of all suitable even-aged forest to be clearcut. Providing the option of clearcutting a stand over 120 acres may actually simulate real-world dynamics. Rather than the landowner avoiding clearcutting the stand, they may harvest it in portions at different points in time. In total there were 28 even-aged stands that were over 120 acres. Out of these, none were harvestable by clearcutting because they either did not meet the minimum harvest age or the minimum volume requirements.

Another assumption made was that the minimum stand size for harvest activities was not limited. Due to processes where the GIS vegetation, ownership, and stream buffers were combined, many resulting stands were quite small (less than 5 acres). To ensure that all available land had the opportunity to be scheduled, these smaller fragments were not ignored nor blocked together with other stands and were treated as if they were individual stands. There was a total of 167 acres in polygons that were smaller than 1.5 acres, and around 40 of these acres were harvested in each scale. So to some extent, the resulting forest plans may have included harvests that are operationally unreasonable. To counteract these circumstances, stands below a minimum manageable size (1-5ac) could have been eliminated and merged with other neighboring stands, or stands could have been blocked for simultaneous harvest activities.

In keeping with the marked open/closed landscape mosaic of eastern Oregon, many of the "stands" were never considered for harvesting. Much of the land in the study area is described in the GIS vegetation database as "meadow" and "grassland". Also, there are quite a few areas of land that are coded as "admin" (administratively withdrawn). On the ground the "admin" stands are buildings and roads, therefore not having any significance for this modeling purpose. These non-forested areas made up 40,175 acres out of the total 95,063 acres in the landscape that was modeled comprising over 40% of the total area modeled (excluding the exterior owl habitat buffer). No assumption was made regarding natural regeneration of forests into these areas (or the planting of trees).

Finally, the omission of hardwood management from the study is thought to have played a minor role in the results observed between the three management intention scales. Hardwood stands were not assigned management prescriptions in this study. The private industrial landowner surveys indicated that they did not actively manage hardwood resources. Coincidently, the GIS vegetation database did not contain stands where hardwood was the dominant species. The FIA inventory data did, however, contain plots where hardwoods were present, and dominant. This lack in consistency between the two databases resulted in an inability to model hardwood stands, and therefore they were omitted in the study. They are, in fact a minor species in eastern Oregon, thus would have played a minor role in the outcome of the study.

7 CONCLUSION

When considering the development of forest plans, forest planners have a number of decisions to make. One of those decisions relates to data quality, and more specifically, the level of resolution of data to model. In this study I have tried to examine whether three levels of resolution of management intentions (how landowners intend to manage their forest land) might produce different forest plan results. The results I examined included both economic (NPV, harvest volumes, acres treated) and ecological (great gray owl habitat) measures. The ecological measure contained spatial components, thus might have been sensitive to the timing and placement of activities on the landscape.

In order to carry out this study, I developed a harvest scheduling heuristic using simulated annealing, to schedule activities aimed at maximizing NPV while subject to adjacency (green-up), minimum clearcut age, and minimum volume level constraints. The heuristic was applied to a 95,603 acre landscape west of La Grande, Oregon. Within this landscape, management activities were scheduled for 54,888 acres of forested industrial land.

The three levels of management intentions were called the fine scale (where prescriptions were assigned according to ecoregion, species, and site class), the medium scale (ecoregion and species), and the coarse scale (ecoregion). Based on a statistical and quantitative analysis of both the economic and ecological results of the forest plans that were developed, significant differences in the economic results were noted between the three levels of management intentions. No significant differences in the single ecological measure were noted. The level of harvest volume extracted was well below the mean annual increment of forested portion of the landscape due to the initial condition of the forest (average volume per acre about 4 MBF) and the constraints imposed by the planning process (minimum harvest ages for clearcuts and minimum residual volume levels for partial cuts).

The level of detail of management intentions used in forest planning and similar modeling efforts will likely depend on the objective (economic, ecological, social) of the planning effort. However, if the resources (databases, time budget) were available to allow forest planning at the fine scale, that level of modeling may be more appropriate, since the economic, or commodity production, goals are more adequately represented.

BIBLIOGRAPHY

Adams, D. M., R. R. Schillinger, G. Latta, and A. Van Nalts. (2002). "Timber Harvest Projections For Private Land In Western Oregon." Oregon State University, College of Forestry, Forest Research Laboratory, Research Contribution 37. http://www.cof.orst.edu/cof/fr/people/adams.htm. (accessed 7/20/02)

Adams, D., R. Alig, B. McCarl, J.M. Callaway, and S. Winnett (1996). "An Analysis Of The Impacts of Public Timber Harvest Policies On Private Forest Management In The United States." Forest Science 42(3): 343-358

Adams, D., R. Alig, D. Alig, D. Anderson, J. Stevens, and J. Chmelik (1992). "Future Prospects For Western Washington's Timber Supply." Institute of Forest Resources Contribution Number 74. University of Washington, College of Forestry.

Bare, B., B. Lippke, C. Oliver, and S. Zens (1995), "Eastern Washington Timber Supply." CINTRAFORE Special Paper 18. Center for International Trade in Forest Products, University of Washington, College of Forest Resources.

Bettinger, P., J. Sessions, and K. Boston (1997). "Using Tabu Search To Schedule Timber Harvests Subject To Spatial Wildlife Goals For Big Game." Ecological Modeling 94: 111-123.

Bettinger, P., J. Sessions, and K. N. Johnson (1998a). "Ensuring The Compatibility Of Aquatic Habitat And Commodity Production Goals In Eastern Oregon With A Tabu Search Procedure." Forest Science 44(1): 96-112.

Bettinger, P., N. Johnson, and J. Sessions (1998b). "Evaluating The Association Among Alternative Measures Of Cumulative Watershed Effects On A Forested Watershed In Eastern Oregon." Western Journal of Applied Forestry 13(1): 15-22.

Bettinger, P., K. Boston, and J. Sessions (1999a). "Combinatorial Optimization Of Elk Habitat Effectiveness And Timber Harvest Volume." Environmental Modeling and Assessment 4: 1443-153.

Bettinger, P., K. Boston, and J. Sessions (1999b). Intensifying A Heuristic Forest Harvest Scheduling Search Procedure With 2-opt Decision Choices. Canadian Journal of Forest Research. 29:1784-1792.

Bettinger, P., D. Graetz, K. Boston, J. Sessions, W. Chung (2002). "Eight Heuristic Planning Techniques Applied To Three Increasingly Difficult Wildlife Planning Problems." Silva Fennica 36(2): 561-584.

Bettinger, P., and R. Schoonover (2000). "An Accuracy Assessment of Satellite Imagery Developed For Eastern Oregon And Recommendations For Management Intentions Of Private Landowners In Eastern Oregon For Spatial Analysis Purposes" INLAS Accuracy Assessment and Management Intentions Report to the Oregon Department of Forestry.

Boston, K., and P. Bettinger (1999). "An Analysis Of Monte Carlo Integer Programming, Simulated Annealing, And Tabu Search Heuristics For Solving Spatial Harvest Scheduling Problems." Forest Science 45(2): 292-301.

Boston, K., and P. Bettinger (2001). "Development Of Spatially Feasible Forest Plans: A Comparison Of Two Modeling Approaches." Silva Fennica 35(4): 425-435.

Boston, K. D. (1996). Using Tabu Search To Solve Tactical Forest Planning Problems With Spatial Wildlife Habitat Goals And Constraints. Forest Resources. Corvallis, OR, Oregon State University: 265 p.

Brumelle, S., D. Granot, M. Halme, and I. Vertinsky (1998). "A Tabu Search Algorithm For Finding Good Forest Harvest Schedules Satisfying Green-Up Constraints." European J. of Operational Research 106: 408-424.

Burry, Tom. (9/31/01) Personal communication

Bull, E. L. and M. G. Henjum (1990). "Ecology of the Great Gray Owl" USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR 265, Portland OR.

Clark, M. M., R. D. Meller, and T. P. McDonald (2000). "A Three-Stage Heuristic For Harvest Scheduling With Access Road Network Development." Forest Science 46(2): 204-218.

Clements, S. E., and P. L. Dallain (1990). "An Operational , Spatially Constrained Harvest Scheduling Model." Canadian Journal of Forest Resources 20: 1438-1447.

Cochran, P.H. (1979). Gross Yield For Even-aged Stands of Douglas-fir and White or Grand Fir East Of The Cascades In Oregon And Washington. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Or. Research Paper PNW-253. 17p.

Dannenbring, D. G. (1977). "Procedures For Estimating Optimal Solution Values For Large Combinatorial Problems." Management Science 23(12): 1273-1283.

Davis, L. (1987). Genetic Algorithms And Simulated Annealing. London, Pitman: 216.

Davis, L. (1991). Handbook Of Genetic Algorithms. New York, Van Nostrand Reinhold.

Decker, K. L. M., R. E. J. Boerner, and S. J. Morris (1999). "Scale-Dependent Patterns Of Soil Enzyme Activity In A Forested Landscape." Canadian Journal of Forest Resources 29: 232-241.

DeLorme Mapping Company (1991). Oregon Atlas & Gazetteer. Freeport, Main.

Dueck, G. (1993). "New Optimization Heuristics The Great Deluge Algorithm And The Record-To Record Travel." Journal of Computational Physics 104: 86-2-92.

Dueck, G. and T. Scheuer (1990). "Threshold Accepting: A General Purpose Optimization Algorithm Appearing Superior To Simulated Annealing." Journal of Computational Physics 90: 161-175.

Elwood, N. E., and D. W. Rose (1990). "Heuristic Simulation: An Alternative To Linear Programming In Developing Forest Management Schedules." Forest Ecology and Management 35: 303-310.

Glover, F., and M. Laguna (1993). Tabu Search. Modern Heuristic Techniques For Combinatorial Problems. C. R. Reeves. New York, John Wiley & Sons, Inc.: 70-150.

Golden, B. L. (1978). "Point Estimation Of A Global Optimum For Large Combinatorial Problems." Communications in Statistics B7: 361-367.

Golden, B. L. and F. B. Alt (1979). "Interval Estimation Of A Global Optimum For Large Combinatorial Problems." Naval Research logistics Quarterly 26(1): 63-77.

Graetz, D. (2000). "The SafeD Model: Incorporating Episodic Disturbances And Heuristic Programming Into Forest Management Planning For the Applegate River Watershed, Southwestern Oregon." Forest Resources. Oregon State University. p.112

Gustafson, E. J., S. R. Shifley, D. J. Mladenoff, K. K. Nimerfro, and H. S. He (2000). "Spatial Simulation Of Forest Succession And Timber Harvesting Using LANDIS." Canadian Journal of Forest Research 30: 32-43.

Hof, J. G., and L.A. Joyce (1992). “Spatial Optimization For Wildlife And Timber In Managed Forest Ecosystems.” Forest Science 38(3): 489-508.

Hoganson, H. and J. Borges (2000). "Impacts Of The Time Horizon For Adjacency Constraints In Harvest Scheduling." Forest Science 46(2): 176-187.

Holland, J. H. (1975). Adaption in Natural and Artificial Systems. Ann Arbor, Michigan, University of Michigan Press.

Johnson, K. N., J. Sessions, J. Franklin, and J. Gabriel (1998). “Integrating Wildfire Into Strategic Planning For Sierra Nevada Forests.” Journal of Forestry 96: 42-49.

Jones, J. G., B. J Meneghin, and M. W. Kirby (1991). “Formulating Adjacency Constraints In Linear Optimization Models For Scheduling Projects In Tactical Planning.” Forest Science 37(5): 1283-1297.

Kelly, J.W., B.M. Kent, K.N. Johnson, and D.B. Jones (1986). FORPLAN Version 1: Users Guide. USDA Forest Service, Land Management Planning Systems Section, Washington, D.C. 85 pp.

Kirby, M. W., W. A. Hager, and P. Wong (1986). “Simultaneous Planning Of Wildland Management And Transportation Alternatives.” TIMS Stu. Management Science 21: 371-387.

Kirkpatrick, S., Gelatt, Jr., and M. P, Vecchi (1983). “Optimization By Simulated Annealing.” Science 220(4598): 671-680.

Krumland, B., and W. McKillop (1990). Prospects For Supply Of Private Timber In California." Agricultural Experiment Station, University of California, Department of Forestry and Resource Management, Division of Agriculture and Natural Resources. Bulletin 1931.

La Grande Forestry Sciences Laboratory. 2002. INLAS Map Images USDA Forest Service, Pacific Northwest Research Station, Portland. OR. www.fs.fed.us/pnw/La Grande/inlas/inlas-maps.htm (accessed 7/20/02).

Law, A.M. and W.D. Kelton (1991). Simulation modeling and analysis. New York. McGraw-Hill: 759

Lettman, G. (1998). Oregon Forest Management Intentions Survey Oregon Department of Forestry, Salem, OR. 31-41 p.

Liu, G., J. D. Nelson, and C. W. Wardman (2000). "A Target-Oriented Approach To Forest Ecosystem Design - Changing The Rules Of Forest Planning." Ecological Modeling 127: 269-281.

Lockwood, C. and T. Moore (1993). "Harvest Scheduling With Spatial Constraints: A Simulated Annealing Approach." Canadian Journal of Forest Resources 23(3): 468-478.

Los, M. and C. Lardinois (1982). "Combinatorial Programming, Statistical Optimization And The Optimal Transportation Network Problem." Transportation Research 16B(2): 89-124.

Lu, F. and L.O. Eriksson (2000). "Formulation Of Harvest Units With Genetic Algorithms." Forest Ecology and Management 130(1-3): 57-67.

McKenzie, N. J., H. P. Cresswell, P. J. Ryan, and M. Grundy (2000). "Contemporary Land Resource Survey Requires Improvements In Direct Soil Measurement." Commun. Soil Sci. Plant Anal. 31(11-14): 1553-1569.

McRoberts, K. (1971). "A Search Model For Evaluating Combinatorially Explosive Problems." Operations Research 19: 1331-1349.

Meyers, W.H. (1961). Yield Of Even-aged Stands Of Ponderosa Pine. USDA Technical Bulletin No. 630. 59 p.

Mullen, D. S. and R. M. Butler (1999). The Design Of A Genetic Algorithm Based Spatially Constrained Timber Harvest Scheduling Model. *In* Proceedings of the Seventh Symposium on Systems Analysis in Forest Resources. U. F. Service. St. Paul, MN, North Central Experiment Station.

Murray, A. and R. Church. (1994). "Heuristic solution approaches to operational forest planning problems." OR Spektrum 17: 193-203.

Murray, A., and R. Church (1995). "Measuring The Efficacy Of Adjacency Constraint Structure In Forest Planning." Canadian Journal of Forest Resources 25: 1416-1424.

Murray, A., and R. Church (1996a). "Constructing and selecting adjacency constraints." INFOR 34: 232-248

Murray, A., and R. Church (1996b). "Analyzing cliques for imposing adjacency restrictions in forest models." Forest Science 42: 166-175

Murray, A. (1999). "Spatial Restrictions In Harvest Scheduling." Forest Science. 46(1): 45-52.

Murray, A. and S. Snyder (2000). "Spatial Modeling In Forest Management And Natural Resource Planning." Forest Science 46(2): 153-156.

Nelson, J., and, J. D. Brodie (1990). "Comparison Of Random Search Algorithm And Mixed Integer Programming For Solving Area-Based Forest Plans." Canadian Journal of Forest Resources 20: 934-942.

O'Hara, A. J., B. A. Faaland, and B. B. Bare (1989). "Spatially constrained timber harvest scheduling." Canadian Journal of Forest Resources 19: 715-724.

Oregon State Legislature. (2001). Oregon Revised Statutes, chapter 527. http://www.leg.state.or.us/ors/527.html (accessed 7/16/02).

Oregon Department Of Forestry. (2002). Oregon Geospatial Data Clearinghouse: Complete Alphabetical Listing. http://www.sscgis.state.or.us/data/alphalist.html (accessed 7/20/02).

Palisade Corporation (2002). BESTFIT. Newfield, New York.

Reeves, C. R. (1993). Genetic Algorithms. Modern Heuristic Techniques For Combinatorial Problems. John Wiley & Sons, Inc. New York. 320 pp.

Remsoft, Inc. (2001). Woodstock: flexible forest modeling. Remsoft, Inc., Fredericton, N.B. http://www.remsoft.com/forest.woodstock/index.html (accessed 7/19/02)

Richards, E. W. and E. A. Gunn (2000). "A Model And Tabu Search Method To Optimize Stand Harvest And Road Construction Schedules." Forest Science 46(2): 188-203.

Sharer, B. (2000). Heuristic Solution Techniques For A Spatial Harvest Scheduling Problem Involving Wildlife Habitat And Timber Income. Forest Resources. Corvallis, OR, Oregon State University: 101 p.

Shirazi, M. A., L. Boersma, C. B. Johnson, and P. K. Haggerty (2001). "Predicting Physical And Chemical Water Properties From Relationships With

Watershed Soil Characteristics." Journal of Environmental Quality 30: 112-120.

USDA Forest Service (1998a). Spectrum: An Analytical Tool to Support Ecosystem Management. Forest Service. http://www.fs.fed.us/database/ spectrum/spectrum.html (accessed 8/05/05)

USDA Forest Service (1998b). Plot Layout And Referencing. Timberland Inventory Of Eastern Oregon. Pacific Resources Inventory, Monitoring, and Evaluation Program. Pacific Northwest Research Station.

USDA Forest Service. (1990). Appendices-Volume I. Final Environmental Impact Statement, Land and Resource Management Plan, Wallowa-Whitman National Forest. USDA Forest Service, Pacific Northwest Region, Portland, OR. pp. B-30 to B-37.

USDA Forest Service (2002). FVS Software Setup Programs; File: FVS Pacific Northwest Region Blue Mountains Variant. http://www.fs.fed.us/fmsc/fvs/software/setup.php (accessed 7/20/02)

Weintraub, A., G. Jones, A. Magendzo, M. Meacham, and M. Kirby (1994). "A Heuristic System To Solve Mixed Integer Forest Planning Models." Operations Research 42(6).

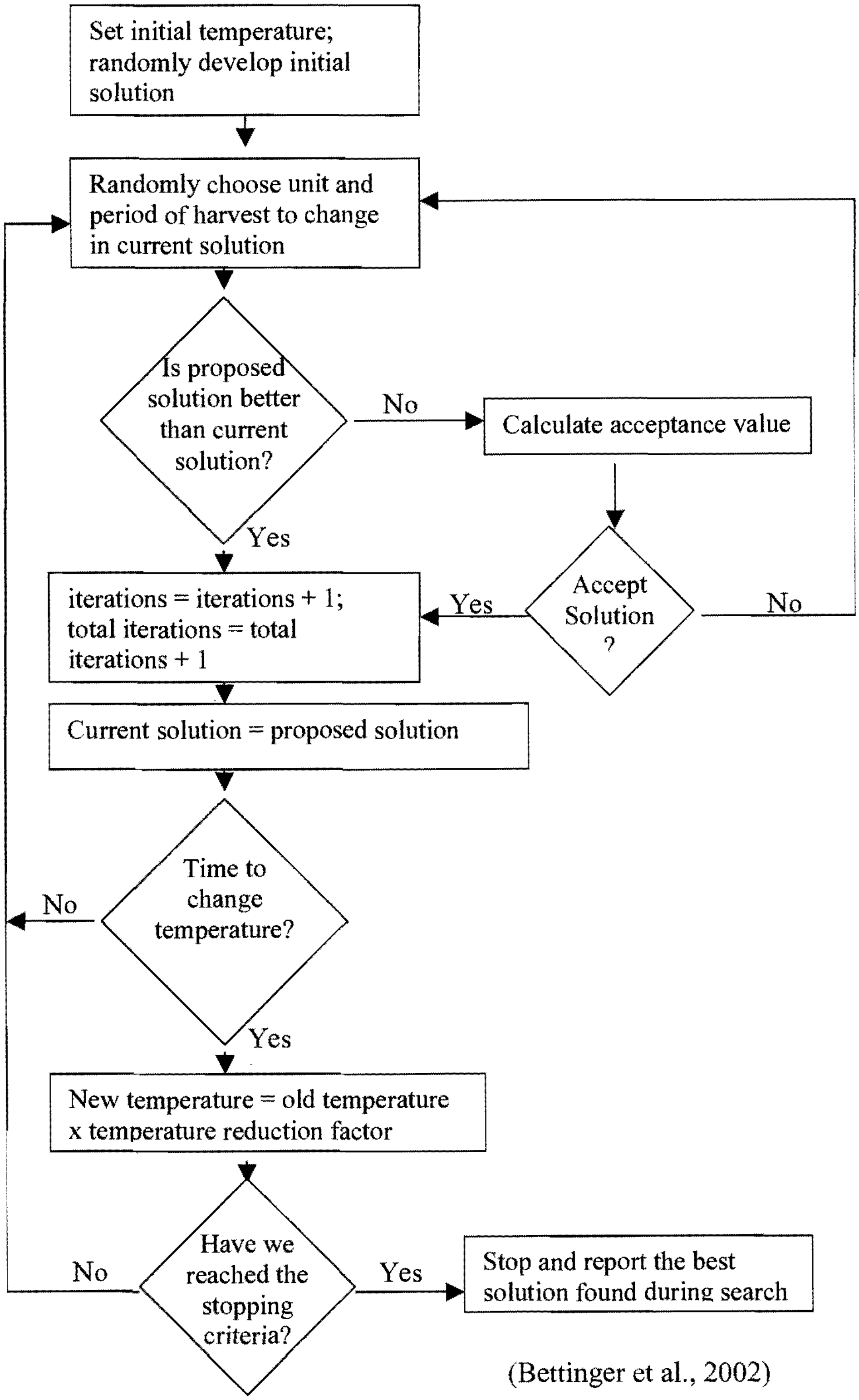
Wykoff, W.R., N.L. Crookston, and A.R. Stage. (1982). User's guide to the stand Prognosis model. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. General Technical Report INT-133. 112 p.

Yoshimoto, A., J. D. Brodie, and J. Sessions (1994). "A New Heuristic To Solve Spatially Constrained Long-Term Harvest Scheduling Problems." Forest Science 40: 365-396.

Zanakis, S. H., and J. R. Evans (1981). "Heuristic "Optimization": Why, When, And How To Use It." Interfaces 11(5): 84-91.

APPENDIX

Appendix A. SIMULATED ANNEALING



(Bettinger et al., 2002)

Appendix B. A PORTION OF THE REPORT BY BETTINGER AND SCHOONOVER (2000) "An accuracy assessment of satellite imagery developed for eastern Oregon, and recommendations for management intentions of private landowners in eastern Oregon for spatial analysis purposes."

II. Overview of Data Categories for Describing the Management Intentions of Industrial and Non-Industrial Private Land in Eastern Oregon

A summary of present and future management intentions was undertaken to develop an understanding of how private industry landowners in eastern Oregon currently manage their land and how they intend to manage their land in the future. The summary was facilitated by two surveys developed and administered by the Oregon Department of Forestry (ODF). Each of the major landowners in eastern Oregon was asked to reply. The results are delineated by the landowner, then by a geographical distinction (ecoregion), then by forest type. Within each of these owner / region / forest type categories, data are summarized by site class and management intensity.

Forest Types

The data was then broken down into forest types within each analysis area. According to the survey form, forest types are differentiated by the predominant species and stocking level greater than 50% in the area. There were at least two forest types in each analysis area for each owner group. The full list of forest types include the following:

Industry:
- Douglas-fir and western larch
- Pine
- Grand fir
- Mixed conifer

Site Classes

The survey of industry landowners requested information by four site classes: 3+ (high), 4 (high), 5 (medium), and 6 (low). The non-industrial survey requested information by three site classes: high (3+ and 4), medium (5), and low (6). Table A describes the productivity and site index measurement descriptions for these classes. Since industry has two site classes in the "high" category, these will be combined into a single High site class. Below is a summary of the site class breakdowns.

Industry:
- High (3+, 4)
- Medium (5)
- Low (6)

Management Intensities

Each of the two surveys requested information for acres to be managed under six management intensities: no harvest (also called reserved), even-aged-low, even-aged medium, even-aged high, uneven-aged low, uneven-aged medium, and uneven-aged high. Low, medium, and high refer to the intensity of management for each silvicultural system. As management intensities move from low to high, a greater emphasis is placed on stocking control and intermediate (between planting and final harvest) stand tending.

The "no harvest" intensity refers to any timberland that may be unavailable for any timber production indefinitely, for reasons such as, but not limited to, urbanization and riparian withdrawals. These are areas where timber harvesting is not completely legally prohibited.

Table B contains an explanation of these management intensity strategies. The columns containing “Plant”, “Genetics”, “Pre-commercial Thinning”, and “Fertilization” further express actions that could take place in the management type. To reiterate, the management intensities we will describe include the following:

Industry:
- Even-aged, high intensity (1)
- Even-aged, medium intensity (2)
- Even-aged, low intensity (3)
- Uneven-aged, high intensity (4)
- Uneven-aged, medium intensity (5)

Uneven-aged, low intensity (6)

III. Summary of Management Intentions

We will present the management intentions of forest industry landowners in eastern Oregon at three different scales. The first, a fine-scale perspective, focuses on forest type, and site class. Subsequent broader-scaled perspectives will examine aggregations of the fine-scale perspective. These broader-scale perspectives may be necessary if GIS and inventory data are of such quality to preclude modeling forest policies at the fine scale.

Fine-Scale Summaries of Survey Data: Owner Group, Analysis Area, Forest Type, and Site Class

The fine-scale summaries we now provide for industry landowners in the Blue Mountains of eastern Oregon are organized as follows:

Owner group	Analysis area	Forest Type	Site Class
(1) Industry	Blue Mountains	Douglas-fir / western larch	High
(2)			Medium
(3)			Low
(4)		Grand fir	High
(5)			Medium
(6)			Low
(7)		Pine	High
(8)			Medium
(9)			Low
(10)		Mixed conifer	High
(11)			Medium
(12)			Low

1. Industry, Blue Mountains, Douglas-fir / western larch, High sites
High sites in the Blue Mountains will be managed under one of six possible management regimes (Table 1). Uneven-aged management prescriptions are being used on 68% of this type of forest land, and even-aged management prescriptions on 32%. The majority of uneven-aged prescriptions use a medium management intensity, with a thinning entry beginning at age 20, and entries

occurring every 20 years thereafter. The majority of even-aged management prescriptions are of a high management intensity, with a thinning at age 50 and planned rotation age of about 70 years.

2. Industry, Blue Mountains, Douglas-fir / western larch, Medium sites
Medium sites in the Blue Mountains will be managed under one of four possible management regimes (Table 2). Uneven-aged management prescriptions are being used on 79% of this type of forest land, and even-aged management prescriptions on 21%. The majority of uneven-aged prescriptions use a medium management intensity, with a thinning entry beginning at age 20, and entries occurring every 20 years thereafter. The majority of even-aged management prescriptions also fairly well split between medium and high management intensities, with each indicating a thinning at age 55 and planned rotation age of about 75 years.

3. Industry, Blue Mountains, Douglas-fir / western larch, Low sites
There were no responses from forest industry landowners for this forest type/site class in the Blue Mountains analysis area (Table 3).

4. Industry, Blue Mountains, Grand fir, High sites
High sites in the Blue Mountains will be managed under one of five possible management regimes (Table 4). Uneven-aged management prescriptions are being used on 33% of this type of forest land, and even-aged management prescriptions on 67%. The majority of uneven-aged prescriptions use a medium management intensity, with a thinning entry beginning at age 30, and entries occurring every 25 years thereafter. The majority of even-aged management prescriptions are of a high management intensity, with a thinning at age 45 and planned rotation age of about 60 years.

5. Industry, Blue Mountains, Grand fir, Medium sites
There were no responses from forest industry landowners for this forest type/site class in the Blue Mountains analysis area (Table 5).

6. Industry, Blue Mountains, Grand fir, Low sites
There were no responses from forest industry landowners for this forest type/site class in the Blue Mountains analysis area (Table 6).

7. Industry, Blue Mountains, Pine, High sites
High sites in the Blue Mountains will be managed under one of six possible management regimes (Table 7). Uneven-aged management prescriptions are being used on 82% of this type of forest land, and even-aged management prescriptions on 18%. The majority of uneven-aged prescriptions use a medium management intensity, with a thinning entry beginning at age 20, and entries occurring every 20 years thereafter. The majority of even-aged management

prescriptions are of a high management intensity. Indications are that these areas are being managed in two different ways, with the majority having a thinning at age 45 and planned rotation age of about 75 years.

<u>8. Industry, Blue Mountains, Pine, Medium sites</u>
Medium sites in the Blue Mountains will be managed under one of six possible management regimes (Table 8). Uneven-aged management prescriptions are being used on 99% of this type of forest land, and even-aged management prescriptions on less than 1%. The majority of uneven-aged prescriptions use a medium management intensity, with a thinning entry beginning at age 20, and entries occurring every 20 years thereafter.

<u>9. Industry, Blue Mountains, Pine, Low sites</u>
Low sites in Blue Mountains will be managed under one of three uneven-aged management prescriptions (Table 9). Stands in this category will be entered every 20 years removing minimum of 1.5 MBF (2 MBF on high management intensity) per acre removed (even with diameter distribution).

<u>10. Industry, Blue Mountains, Mixed conifer, High sites</u>
High sites in the Blue Mountains will be managed under one of seven possible management regimes (Table 10). Uneven-aged management prescriptions are being used on 48% of this type of forest land, and even-aged management prescriptions on 52%. The majority of uneven-aged prescriptions use a low management intensity, with a thinning entry beginning at age 30, and entries occurring every 10 years thereafter. The majority of even-aged management prescriptions are of a high management intensity, with a thinning at age 40 and planned rotation age of about 65 years.

<u>11. Industry, Blue Mountains, Mixed conifer, Medium sites</u>
Medium sites in the Blue Mountains will be managed under one of five possible management regimes (Table 11). Uneven-aged management prescriptions are being used on 76% of this type of forest land, and even-aged management prescriptions on 24%. Although the distribution of acres to management intensities is fairly even, the majority of uneven-aged prescriptions use a medium management intensity, with a thinning entry beginning at age 20, and entries occurring every 20 years thereafter. The majority of even-aged management prescriptions are of a high management intensity, with a thinning at age 45 and 65 and planned rotation age of about 80 years.

<u>12. Industry, Blue Mountains, Mixed conifer, Low sites</u>
Low sites in the Blue Mountains will be managed under one of three possible management regimes (Table 12). Uneven-aged management prescriptions are being used on 64% of this type of forest land, and even-aged management prescriptions on 36%. Only the low management intensity is used for uneven-

aged prescriptions, with a thinning entry beginning at age 20, and entries occurring every 20 years thereafter. The majority of even-aged management prescriptions are of a low management intensity, with no thinning occurring and a planned rotation age of about 90 years.

Broader-Scale Summary of Survey Data: Owner Group, Analysis Area, and Forest Type

Since we are unsure of the quality of the GIS and inventory data we will be using in our policy modeling efforts, we need to develop some options for modeling landowner behavior at a broader perspective. Thus we have aggregated the fine-scale summaries up to two broader scales. Here, we examine the owner groups of each analysis area and the management intentions within each forest type.

Owner group	Analysis area	Forest Type
(13) Industry	Blue Mountains	Douglas-fir / western larch
(14)		Grand fir
(15)		Pine
(16)		Mixed conifer

13. Industry, Blue Mountains, Douglas-fir / western larch

Douglas-fir forest types in the Blue Mountains will be managed under one of seven possible management regimes (Table 55). Uneven-aged management prescriptions are being used on 72% of this type of forest land, and even-aged management prescriptions on 28%. The majority of uneven-aged prescriptions use a medium management intensity, with a thinning entry beginning at age 20, and entries occurring every 20 years thereafter. The majority of even-aged management prescriptions use one of two high management intensities, most having a thinning occurring at age 50 and a planned rotation age of about 70 years.

14. Industry, Blue Mountains, Grand fir

Grand fir forest types in the Blue Mountains will be managed under one of five possible management regimes (Table 56). Uneven-aged management prescriptions are being used on 33% of this type of forest land, and even-aged management prescriptions on 67%. The majority of uneven-aged prescriptions use a medium management intensity, with a thinning entry beginning at age 30, and entries occurring every 25 years thereafter. The majority of even-aged management prescriptions use a high management intensity, with a thinning occurring at age 45 and a planned rotation age of about 60 years.

15. Industry, Blue Mountains, Pine
Pine forest types in the Blue Mountains will be managed under one of six possible management regimes (Table 57). Uneven-aged management prescriptions are being used on 97% of this type of forest land, and even-aged management prescriptions on 3%. The majority of uneven-aged prescriptions use a medium management intensity, with a thinning entry beginning at age 20, and entries occurring every 20 years thereafter. The majority of even-aged management prescriptions use a high management intensity, with a thinning occurring at age 45 and a planned rotation age of about 75 years.

16. Industry, Blue Mountains, Mixed conifer
Mixed conifer forest types in the Blue Mountains will be managed under one of seven possible management regimes (Table 58). Uneven-aged management prescriptions are being used on 54% of this type of forest land, and even-aged management prescriptions on 46%. The majority of uneven-aged prescriptions use a low management intensity, with a thinning entry beginning at age 25, and entries occurring every 10 years thereafter. The majority of even-aged management prescriptions use a high management intensity, with a thinning occurring at age 40 and again at age 50 and a planned rotation age of about 65 years.

Broader-Scale Summary of Survey Data: Owner Group and Analysis Area

In this section of the management intentions report we have now aggregated the fine-scale survey data to the point where we are examining the management intentions of each owner group within each of their respective analysis areas.

Owner group	Analysis area
(17) Industry	Blue Mountains

17. Industry, Blue Mountains
The Blue Mountains analysis area will be managed under one of seven possible management regimes (Table 73). Uneven-aged management prescriptions are being used on 62% of this type of forest land, and even-aged management prescriptions on 38%. The majority of uneven-aged prescriptions use one of two low management intensities. Although the distribution is fairly acres is fairly even in this management intensity, most have a thinning entry beginning at age 30, and entries occurring every 10 years thereafter. The majority of even-aged management prescriptions use a high management intensity, with a thinning occurring at age 40 and again at age 50 and a planned rotation age of about 65 years.

V. Tables and Figures in Support of the Management Intentions Report

The following tables and figures were referenced in the discussion above.
Table A. Productivity and site index measurements for four site classes in the surveys for industry and non-industrial private landowners in eastern Oregon.

Site class	100-yr Douglas-fir Productivity (ft^3/acre/yr)	100-yr ponderosa pine site index (McArdle)	site index (Meyer)	100-yr "any" species site index (Blue Mountains)
3+ (high+)	120+	125+	110+	123+
4 (high)	85-119	105-124	90-109	110-122
5 (medium)	50-84	75-104	65-89	90-109
6 (low)	20-49	<75	<65	<90

Table B. A description of the management intensities used in the survey of industrial and non-industrial private forest landowners in eastern Oregon.

Management Intensity	Description	Plant (Yes/No)	Genetically Pre-improved seedlings (Yes/No)	commercial thinning (Yes/No)	Fertilization (Yes/No)
Uneven-aged Low (Final harvest only)	Custodial management. Periodic overstory removal.	No	No	No	No
Uneven-aged Medium (medium stocking control)	Stocking control coincides with timber harvesting.	No	No	No	No
Uneven-aged High (high stocking control)	Continuous stocking control that coincides with timber harvesting.	No	No	No	No
Even-aged Low (final harvest only)	Harvesting in order to salvage naturally regenerated or low-stocked planted stands.	Yes	No	No	No
Even-aged Medium	Custodial even-aged management.	Yes	Yes	Yes	No
Even-aged High	Stands that have been pre-commercially thinned, and may receive a commercial thinning.	Yes	Yes	Yes	Yes

Table 1. Management prescriptions for industry land in the Blue Mountains analysis area, on high sites of Douglas fir/western larch forest types.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age
Uneven-aged, High (6)	6	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Medium (5)	50	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Low (4)	12	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Even-aged, High (3)	18	enter at age 50, remove 1.5 MBF/acre (minimum), from below.[b]	70
Even-aged, Medium (2)	11	enter at age 45, remove 1.5 MBF/acre (minimum), from below.[c]	65
Even-aged, Low (1)	3	No thinning	

[a] Not indicated in the survey, but assumed here (to be modified as needed).
[b] 99% of acres with commercial thin.
[c] 26% of acres with commercial thin.

Table 2. Management prescriptions for industry land in the Blue Mountains analysis area, on medium sites of Douglas fir/western larch forest types.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age
Uneven-aged, Medium (5)	76	enter at age 20 [a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Low (4)	3	enter at age 20 [a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Even-aged, High (3)	10	enter at age 55, remove 1.5 MBF/acre (minimum), from below.[b]	75
Even-aged, Medium (2)	11	enter at age 55, remove 1.5 MBF/acre (minimum), from below.[c]	75

[a] Not indicated in the survey, but assumed here (to be modified as needed).
[b] 99% of acres with commercial thin.
[c] 26% of acres with commercial thin.

Table 3. Management prescriptions for industry land in the Blue Mountains analysis area, on low sites of Douglas fir/western larch forest types.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age

There were no responses in the survey for this forest type / site class in the Blue Mountains analysis area.

Table 4. Management prescriptions for industry land in the Blue Mountains analysis area, on high sites of grand fir forest types.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age
Uneven-aged, High (6)	9	enter at age 30[a], remove 2 MBF/acre (minimum), even with dbh dist.[a], repeat every 10[a] yrs.	-----
Uneven-aged, Medium (5)	16	enter at age 30[a], remove 2 MBF/acre (minimum), even with dbh dist.[a], repeat every 25[a] yrs.	-----
Uneven-aged, Low (4)	8	enter at age 30[a], remove 1 MBF/acre (minimum), even with dbh dist.[a], repeat every 25[a] yrs.	-----
Even-aged, High (3)	64	enter at age 45, remove 2 MBF/acre (minimum), from below.[b]	60
Even-aged, Medium (2)	3	enter at age 45, remove 2 MBF/acre (minimum), from below.[c]	60

[a] Not indicated in the survey, but assumed here (to be modified as needed).
[b] 40% of acres with commercial thin.
[c] 10% of acres with commercial thin.

Table 5. Management prescriptions for industry land in the Blue Mountains analysis area, on medium sites of grand fir forest types.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age

There were no responses in the survey for this forest type / site class in the Blue Mountains analysis area.

Table 6. Management prescriptions for industry land in the Blue Mountains analysis area, on low sites of grand fir forest types.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age

There were no responses in the survey for this forest type / site class in the Blue Mountains analysis area.

Table 7. Management prescriptions for industry land in the Blue Mountains analysis area, on high sites of pine forest types.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age
Uneven-aged, High (6)	14	enter at age 20 [a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Medium (5)	55	enter at age 20 [a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Low (4)	13	enter at age 20 [a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Even-aged, High (3)	10	enter at age 45, remove 1.5 MBF/acre (minimum), from below.[b]	75
Even-aged, High (3)	6	enter at age 50, remove 1.5 MBF/acre (minimum), from below, repeat at age 70.[b]	85
Even-aged, Medium (2)	2	enter at age 45, remove 1.5 MBF/acre (minimum), from below.[c]	65

[a] Not indicated in the survey, but assumed here (to be modified as needed).
[b] 99% of acres with commercial thin.
[c] 90% of acres with commercial thin.

Table 8. Management prescriptions for industry land in the Blue Mountains analysis area, on medium sites of pine forest types.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age
Uneven-aged, High (6)	25	enter at age 20 [a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Medium (5)	64	enter at age 20 [a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Low (4)	10	enter at age 20 [a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Even-aged, High (3)	<1	enter at age 55, remove 1.5 MBF/acre (minimum), from below, Repeat at age 75.[b]	95
Even-aged, Medium (2)	<1	enter at age 70, remove 1.5 MBF/acre (minimum), from below.[c]	95
Even-aged, Low (1)	<1	No thinning	95

[a] Not indicated in the survey, but assumed here (to be modified as needed).
[b] 90% of acres with commercial thin.
[c] 80% of acres with commercial thin.

Table 9. Management prescriptions for industry land in the Blue Mountains analysis area, on low sites of pine forest types.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age
Uneven-aged, High (6)	16	enter at age 20[a], remove 2 MBF/acre (minimum), even with dbh dist., repeat every 20[a] yrs.	-----
Uneven-aged, Medium (5)	70	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Low (4)	14	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----

[a] Not indicated in the survey, but assumed here (to be modified as needed).

Table 10. Management prescriptions for industry land in the Blue Mountains analysis area, on high sites of mixed conifer forest types.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age
Uneven-aged, High (6)	16	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Medium (5)	2	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Medium (5)	3	enter at age 50[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 50 yrs.	-----
Uneven-aged, Low (4)	27	enter at age 30[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 10 yrs.[b]	-----
Even-aged, High (3)	46	enter at age 40, remove 1.5 MBF/acre (minimum), from below, repeat at age 50.[c]	65
Even-aged, Medium (2)	4	enter at age 45, remove 1.5 MBF/acre (minimum), from below.[c]	65
Even-aged, Medium (2)	2	No thinning	65

[a] Not indicated in the survey, but assumed here (to be modified as needed).
[b] 99% of acres with commercial thin.
[c] 54% of acres with commercial thin.

Table 11. Management prescriptions for industry land in the Blue Mountains analysis area, on medium sites of mixed conifer forest types.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age
Uneven-aged, High (6)	24	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Medium (5)	35	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Low (4)	17	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Even-aged, High (3)	20	enter at age 45, remove 1.5 MBF/acre (minimum), from below, repeat at age 65.[b]	80
Even-aged, Medium (2)	4	enter at age 60, remove 1.5 MBF/acre (minimum), from below.[c]	80

[a] Not indicated in the survey, but assumed here (to be modified as needed).
[b] 99% of acres with commercial thin.
[c] 90% of acres with commercial thin.

Table 12. Management prescriptions for industry land in the Blue Mountains analysis area, on low sites of mixed conifer forest types.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age
Uneven-aged, Low (4)	64	enter at age 20[a], remove 1.5 MBF/acre (minimum), from above, repeat every 20 yrs.	-----
Even-aged, High (3)	13	enter at age 50, remove 1.5 MBF/acre (minimum), from below, repeat at age 70.[b]	90
Even-aged, Low (1)	23	No thinning	90

[a] Not indicated in the survey, but assumed here (to be modified as needed).
[b] No data to indicate acres with commercial thin.

Table 13. Management prescriptions for industry land in the Blue Mountains analysis area, of Douglas-fir / western larch forest types.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age
Uneven-aged, High (6)	4	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Medium (5)	59	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Low (4)	9	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Even-aged, High (3)	6	enter at age 45, remove 1.5 MBF/acre (minimum), from below.[b]	65
Even-aged, High (3)	9	enter at age 50, remove 1.5 MBF/acre (minimum), from below.[b]	70
Even-aged, Medium (2)	11	enter at age 50, remove 1.5 MBF/acre (minimum), from below.[c]	70
Even-aged, Low (1)	2	No thinning	70[a]

[a] Not indicated in the survey, but assumed here (to be modified as needed).
[b] 99% of acres with commercial thin.
[c] 26% of acres with commercial thin.

Table 14. Management prescriptions for industry land in the Blue Mountains analysis area, of grand fir forest type.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age
Uneven-aged, High (6)	9	enter at age 30[a], remove 2 MBF/acre (minimum), even with dbh dist.[a], repeat every 10 [a] yrs.	-----
Uneven-aged, Medium (5)	16	enter at age 30[a], remove 2 MBF/acre (minimum), even with dbh dist.[a], repeat every 25 [a] yrs.	-----
Uneven-aged, Low (4)	8	enter at age 30 [a], remove 1 MBF/acre (minimum), even with dbh dist.[a], repeat every 25 [a] yrs.	-----
Even-aged, High (3)	64	enter at age 45, remove 2 MBF/acre (minimum), from below.[b]	60
Even-aged, Medium (2)	3	enter at age 45, remove 2 MBF/acre (minimum), from below.[c]	60

[a] Not indicated in the survey, but assumed here (to be modified as needed).
[b] 40% of acres with commercial thin.
[c] 10% of acres with commercial thin.

Table 15. Management prescriptions for industry land in the Blue Mountains analysis area, of pine forest type.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age
Uneven-aged, High (6)	23	enter at age 20[a], remove 2 MBF/acre (minimum), even with dbh dist.[a], repeat every 20[a] yrs.	-----
Uneven-aged, Medium (5)	63	enter at age 20[a], remove 2 MBF/acre (minimum), even with dbh dist.[a], repeat every 20[a] yrs.	-----
Uneven-aged, Low (4)	11	enter at age 20[a], remove 1 MBF/acre (minimum), even with dbh dist.[a], repeat every 20[a] yrs.	-----
Even-aged, High (3)	2	enter at age 45, remove 1.5 MBF/acre (minimum), from below.[b]	75
Even-aged, Medium (2)	<1	enter at age 65, remove 1.5 MBF/acre (minimum), from below.[c]	90
Even-aged, Low (1)	<1	No thinning	95

[a] Not indicated in the survey, but assumed here (to be modified as needed).
[b] 95% of acres with commercial thin.
[c] 85% of acres with commercial thin.

Table 16. Management prescriptions for industry land in the Blue Mountains analysis area, of mixed conifer forest type.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age
Uneven-aged, High (6)	15	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Medium (5)	5	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----
Uneven-aged, Medium (5)	3	enter at age 50[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 50 yrs.	-----
Uneven-aged, Low (4)	31	enter at age 25 [a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 15 yrs.	-----
Even-aged, High (3)	38	enter at age 40, remove 1.5 MBF/acre (minimum), from below, repeat at age 50.[b]	65
Even-aged, Medium (2)	3	enter at age 45, remove 1.5 MBF/acre (minimum), from below.[c]	65
Even-aged, Low (1)	5	No thinning	90

[a] Not indicated in the survey, but assumed here (to be modified as needed).

[b] 99% of acres with commercial thin.

[c] 72% of acres with commercial thin.

Table 17. Management prescriptions for industry land in the Blue Mountains analysis area.

Management intensity	Percent of acres	Thinning prescription	Planned rotation age min	mean	max
Uneven-aged, High (6)	16	enter at age 20[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 20 yrs.	-----		
Uneven-aged, Medium (5)	19	enter at age 20[a], remove 2 MBF/acre (minimum), even with dbh dist., repeat every 20[a] yrs.	-----		
Uneven-aged, low (4)	14	enter at age 30[a], remove 1.5 MBF/acre (minimum), even with dbh dist., repeat every 10 yrs.	-----		
Uneven-aged, low (4)	13	enter at age 20[a], remove 1.5 MBF/acre (minimum), from above, repeat every 20 yrs.	-----		
Even-aged, High (3)	31	enter at age 40, remove 1.5 MBF/acre (minimum), from below, repeat at age 50.[b]	65		
Even-aged, Medium (2)	3	enter at age 45, remove 1.5 MBF/acre (minimum), from below.[c]	65		
Even-aged, Low (1)	4	No thinning	90		

[a] Not indicated in the survey, but assumed here (to be modified as needed).
[b] 90% of acres with commercial thin.
[c] 55% of acres with commercial thin.

Appendix C. BLUE MOUNTAINS SURVEY

Table 1. MANAGEMENT OF EXISTING STANDS OF TIMBERLAND
BLUE MOUNTAINS

Instructions for completing Table 1: For each forest type, site class and management prescription (where appropriate)

Column e: enter the number of timberland acres (in 000's).

Column f: enter the percent of acres in this prescription that will be commercially thinned (for even-aged management).

Column g: enter the age or ages of the planned commercial thins or the re-entry cycle if the prescription is an uneven aged prescription or an overstory removal.

Column h: enter the minimum volume that must be removed if a commercial thinning or a selective harvest is to occur.

Column i: enter if the harvest is from above, below, or equal (i.e. d/D ratio >1, <1, or =1).

Column j: enter the planned rotation age for this prescription (even-aged management).

NOTE: Do not include nonstocked acres or double count acres in Table 1.

Table 1a.
Ecoregion: **Blue Mountains**

Forest Type: **Douglas-fir/Western Larch***

]] (: (	Even or Uneven-...	Management Prescription Description			% acres that will be or have been commer-cially thinned	Age of thins or re-entry cycle for Selective harvest or overstory removal	Minimum Vol. cut in commercial thin or Selective Harvest (MBF)	Harvest from: Above=A Below=B Equal=E	For Even-aged Mgt. Planned Rotation Age
:	b	c	d	e	f	g	h	i	j
Cubic Foot Site Classes 3+ (from site class table)									
(	NA	Voluntary-No Harvest	None						
	Even	Final Regeneration Harvest Only	Low						
:	Even	Let Grow	Medium						
:	Even	Stocking Control	High						
·	Uneven	Commercial Harvest Only	Low						
:	Uneven	Medium Stocking Control	High						
(	Uneven	High Stocking Control	High						
Total Medium-High Site Timberland Acres									

*50% or more of stocking (e.g. volume or basal area) is Douglas-fir or larch

Cubic Foot Site Class 4 (from site class table)									
(	NA	Voluntary-No Harvest	None						
	Even	Final Regeneration Harvest Only	Low						

	Even or Uneven-	Management Prescription Description			% acres that will be or have been commer-cially thinned	Age of thins or re-entry cycle for Selective harvest or overstory removal	Minimum Vol. cut in commercial thin or Selective Harvest (MBF)	Harvest from: Above=A Below=B Equal=E	For Even-aged Mgt. Planned Rotation Age
	b	c	d	e	f	g	h	i	j
	Even	Let Grow	Medium						
	Even	Stocking Control	High						
	Uneven	Commercial Harvest Only	Low						
	Uneven	Medium Stocking Control	High						
	Uneven	High Stocking Control	High						
Total Medium-Low Site Timberland Acres									
Cubic Foot Site Class 5 (from site class table)									
	NA	Voluntary-No Harvest	None						
	Even	Final Regeneration Harvest Only	Low						
	Even	Let Grow	Medium						
	Even	Stocking Control	High						
	Uneven	Commercial Harvest Only	Low						
	Uneven	Medium Stocking Control	High						
	Uneven	High Stocking Control	High						

	Even or Uneven-…	Management Prescription Description			% acres that will be or have been commer-cially thinned	Age of thins or re-entry cycle for Selective harvest or overstory removal	Minimum Vol. cut in commercial thin or Selective Harvest (MBF)	Harvest from: Above=A Below=B Equal=E	For Even-aged Mgt. Planned Rotation Age
	b	c	d	e	f	g	h	i	j
Total Low Site Timberland Acres									
Cubic Foot Site Class 6 (from site class table)									
	NA	Voluntary-No Harvest	None						
	Even	Final Regeneration Harvest Only	Low						
	Even	Let Grow	Medium						
	Even	Stocking Control	High						
	Uneven	Commercial Harvest Only	Low						
	Uneven	Medium Stocking Control	High						
	Uneven	High Stocking Control	High						
Total Very Low Site Timberland Acres									
Total Timberland Acres In This Ecoregion/Forest Type									

Table 1b.
Ecoregion: **Blue Mountains** Forest Type: **Pine***

Prescriptic	Even or Uneven-Aged Mgt.	Management Prescription Description	Mgt.	Tim	Commercial Thins and/or Selective Harvest/and or Overstory Removal				For Even-aged Mgt. Planned Rotation Age
					% acres that will be or have been comme r-cially thinned	Age of thins or re-entry cycle for Selective harvest or overstory removal	Minimum Vol. cut in commercial thin or Selective Harvest (MBF)	Harvest from: Above= A Below= B Equal= E	
a	b	c	d	e	f	g	h	i	j
Cubic Foot Site Classes 3+ (from site class table)									
0	NA	Voluntary-No Harvest	None						
1	Even	Final Regeneration Harvest Only	Low						
2	Even	Let Grow	Medium						
3	Even	Stocking Control	High						
4	Uneven	Commercial Harvest Only	Low						
5	Uneven	Medium Stocking Control	High						
6	Uneven	High Stocking Control	High						
Total Medium-High Site Timberland Acres									
Cubic Foot Site Class 4 (from site class table)									
0	NA	Voluntary-No Harvest	None						
1	Even	Final Regeneration Harvest Only	Low						

Prescriptic	Even or Uneven-Aged Mgt.	Management Prescription Description	Mgt.	Tim	Commercial Thins and/or Selective Harvest/and or Overstory Removal: % acres that will be or have been commer-cially thinned	Age of thins or re-entry cycle for Selective harvest or overstory removal	Minimum Vol. cut in commercial thin or Selective Harvest (MBF)	Harvest from: Above= A Below= B Equal= E	For Even-aged Mgt. Planned Rotation Age
a	b	c	d	e	f	g	h	i	j
2	Even	Let Grow	Medium						
3	Even	Stocking Control	High						
4	Uneven	Commercial Harvest Only	Low						
5	Uneven	Medium Stocking Control	High						
6	Uneven	High Stocking Control	High						
Total Medium-Low Site Timberland Acres									

*50% or more of stocking (e.g. volume or basal area) is pine

Cubic Foot Site Classes 5 (from site class table)									
0	NA	Voluntary-No Harvest	None						
1	Even	Final Regeneration Harvest Only	Low						
2	Even	Let Grow	Medium						
3	Even	Stocking Control	High						
4	Uneven	Commercial Harvest Only	Low						
5	Uneven	Medium Stocking Control	High						

Prescriptic	Even or Uneve n-Aged Mgt.	Management Prescription Description	Mgt.	Tim	Commercial Thins and/or Selective Harvest/and or Overstory Removal				For Even-aged Mgt. Planned Rotation Age
					% acres that will be or have been comme r-cially thinned	Age of thins or re-entry cycle for Selective harvest or overstory removal	Minimum Vol. cut in commerc ial thin or Selective Harvest (MBF)	Harvest from: Above= A Below= B Equal= E	
a	b	c	d	e	f	g	h	i	j
6	Uneve n	High Stocking Control	High						
Total Low Site Timberland Acres									
Cubic Foot Site Class 6 (from site class table)									
0	NA	Voluntary-No Harvest	None						
1	Even	Final Regeneratio n Harvest Only	Low						
2	Even	Let Grow	Medium						
3	Even	Stocking Control	High						
4	Uneve n	Commercial Harvest Only	Low						
5	Uneve n	Medium Stocking Control	High						
6	Uneve n	High Stocking Control	High						
Total Very Low Site Timberland Acres									
Total Timberland Acres In This Ecoregion/Forest Type									

Table 1c.

Ecoregion: **Blue Mountains** Forest Type: **Grand Fir***

z	Even or Uneven-Aged Mgt.	Management Prescription Description			Commercial Thins and/or Selective Harvest/and or Overstory Removal				For Even-aged Mgt. Planned Rotation Age
					% acres that will be or have been commer-cially thinned	Age of thins or re-entry cycle for Selective harvest or overstory removal	Minimum Vol. cut in commercial thin or Selective Harvest (MBF)	Harvest from: Above= A Below= B Equal= E	
a	b	c	d	e	f	g	h	i	j
Cubic Foot Site Classes 3+ (from site class table)									
0	NA	Voluntary-No Harvest	None						
1	Even	Final Regeneration Harvest Only	Low						
2	Even	Let Grow	Medium						
3	Even	Stocking Control	High						
4	Uneven	Commercial Harvest Only	Low						
5	Uneven	Medium Stocking Control	High						
6	Uneven	High Stocking Control	High						
Total Medium-High Site Timberland Acres									
Cubic Foot Site Class 4 (from site class table)									
0	NA	Voluntary-No Harvest	None						
1	Even	Final Regeneration Harvest Only	Low						
2	Even	Let Grow	Medium						
3	Even	Stocking	High						

z	Even or Uneven-Aged Mgt.	Management Prescription Description			Commercial Thins and/or Selective Harvest/and or Overstory Removal				For Even-aged Mgt. Planned Rotation Age
					% acres that will be or have been commercially thinned	Age of thins or re-entry cycle for Selective harvest or overstory removal	Minimum Vol. cut in commercial thin or Selective Harvest (MBF)	Harvest from: Above= A Below= B Equal= E	
a	b	c	d	e	f	g	h	i	j
		Control							
4	Uneven	Commercial Harvest Only	Low						
5	Uneven	Medium Stocking Control	High						
6	Uneven	High Stocking Control	High						
Total Medium-Low Site Timberland Acres									

*50% or more of stocking (e.g. volume or basal area) is grand fir (or white fir)

Cubic Foot Site Class 5 (from site class table)									
0	NA	Voluntary-No Harvest	None						
1	Even	Final Regeneration Harvest Only	Low						
2	Even	Let Grow	Medium						
3	Even	Stocking Control	High						
4	Uneven	Commercial Harvest Only	Low						
5	Uneven	Medium Stocking Control	High						
6	Uneven	High Stocking Control	High						

z	Even or Uneven-Aged Mgt.	Management Prescription Description			Commercial Thins and/or Selective Harvest/and or Overstory Removal				For Even-aged Mgt. Planned Rotation Age
					% acres that will be or have been comme-rcially thinned	Age of thins or re-entry cycle for Selective harvest or overstory removal	Minimum Vol. cut in commercial thin or Selective Harvest (MBF)	Harvest from: Above= A Below= B Equal= E	
a	b	c	d	e	f	g	h	i	j
Total Low Site Timberland Acres									
Cubic Foot Site Class 6 (from site class table)									
0	NA	Voluntary-No Harvest	None						
1	Even	Final Regeneration Harvest Only	Low						
2	Even	Let Grow	Medium						
3	Even	Stocking Control	High						
4	Uneven	Commercial Harvest Only	Low						
5	Uneven	Medium Stocking Control	High						
6	Uneven	High Stocking Control	High						
Total Very Low Site Timberland Acres									
Total Timberland Acres In This Ecoregion/Forest Type									

Table 1d.
Ecoregion: **Blue Mountains** Forest Type: **Mixed Conifer***

Prescrip	Even or Uneven-Aged Mgt.	Management Prescription Description			Commercial Thins and/or Selective Harvest/and or Overstory Removal				For Even-aged Mgt. Planned Rotation Age
					% acres that will be or have been commer-cially thinned	Age of thins or re-entry cycle for Selective harvest or overstory removal	Minimum Vol. cut in commercial thin or Selective Harvest (MBF)	Harvest from: Above=A Below=B Equal=E	
a	b	c	d	e	f	g	h	i	j
Cubic Foot Site Classes 3+ (from site class table)									
0	NA	Voluntary-No Harvest	None						
1	Even	Final Regeneration Harvest Only	Low						
2	Even	Let Grow	Medium						
3	Even	Stocking Control	High						
4	Uneven	Commercial Harvest Only	Low						
5	Uneven	Medium Stocking Control	High						
6	Uneven	High Stocking Control	High						
Total Medium-High Site Timberland Acres									
Cubic Foot Site Class 4 (from site class table)									
0	NA	Voluntary-No Harvest	None						
1	Even	Final Regeneration Harvest Only	Low						
2	Even	Let Grow	Medium						
3	Even	Stocking Control	High						
4	Uneve	Commercial	Low						

Prescrip	Even or Uneven-Aged Mgt.	Management Prescription Description			Commercial Thins and/or Selective Harvest/and or Overstory Removal				For Even-aged Mgt. Planned Rotation Age
					% acres that will be or have been commer-cially thinned	Age of thins or re-entry cycle for Selective harvest or overstory removal	Minimum Vol. cut in commercial thin or Selective Harvest (MBF)	Harvest from: Above=A Below=B Equal=E	
a	b	c	d	e	f	g	h	i	j
	n	Harvest Only							
5	Uneven	Medium Stocking Control	High						
6	Uneven	High Stocking Control	High						
Total Medium-Low Site Timberland Acres									

*Less than 50% of stocking (e.g. volume or basal area) is Douglas-fir/Larch, or pine, or grand fir

Cubic Foot Site Class 5 (from site class table)									
0	NA	Voluntary-No Harvest	None						
1	Even	Final Regeneration Harvest Only	Low						
2	Even	Let Grow	Medium						
3	Even	Stocking Control	High						
4	Uneven	Commercial Harvest Only	Low						
5	Uneven	Medium Stocking Control	High						
6	Uneven	High Stocking Control	High						
Total Low Site Timberland Acres									
Cubic Foot Site Classes 6 (from site class table)									
0	NA	Voluntary-No Harvest	None						
1	Even	Final Regeneration	Low						

Prescrip	Even or Uneven-Aged Mgt.	Management Prescription Description			Commercial Thins and/or Selective Harvest/and or Overstory Removal				For Even-aged Mgt. Planned Rotation Age
					% acres that will be or have been commer-cially thinned	Age of thins or re-entry cycle for Selective harvest or overstory removal	Minimum Vol. cut in commercial thin or Selective Harvest (MBF)	Harvest from: Above=A Below=B Equal=E	
a	b	c	d	e	f	g	h	i	j
		Harvest Only							
2	Even	Let Grow	Medium						
3	Even	Stocking Control	High						
4	Uneven	Commercial Harvest Only	Low						
5	Uneven	Medium Stocking Control	High						
6	Uneven	High Stocking Control	High						
Total Very Low Site Timberland Acres									
Total Timberland Acres In This Ecoregion/Forest Type									