CINTRAFOR

Working Paper

51

EVALUATING THE COST AND EFFECTIVENESS OF FOREST STAND STRUCTURE MANAGEMENT ALTERNATIVES TO RESTORE ENVIRONMENTAL VALUES

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Evaluating the Cost and Effectiveness of Forest Stand Structure Management Alternatives to Restore Environmental Values

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Center for International Trade in Forest Products
and
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Executive Summary

Economic incentives and regulations are two means of achieving environmental outputs from managed forest lands. While regulations generally create disincentives for resource managers by increasing costs and reducing output, incentive mechanisms may allow forest managers the flexibility and creativity to find the lowest cost means of providing environmental outputs. If properly formulated, incentives will equitably distribute the costs of increased environmental outputs.

This paper discusses the need to measure the costs and benefits associated with alternative management policies as prerequisite for an effective incentive system. Measuring the costs and benefits in a systematic manner will allow public officials and resource managers to agree upon realistic levels of compensation and expected benefits.

An illustrative model has been developed to demonstrate how a measurement system could work. The model uses a spreadsheet to project forest growth through time under different management scenarios. The data represents western Washington even aged commercial timberland for all owners in terms of age class by acres. The present distribution is skewed towards younger age classes as the result of past timber production policies.

Alternative management scenarios are examined for environmental benefits and costs. Management scenarios illustrated include combinations of: (a) wildlife thinning (thinning with extended rotation) for the 30-39 year age class; (b) a variable percentage of the area clear cut in the 60-69 year age class; and (c) and a variable percentage of the area clear cut in the 100-109 year age class. Scenarios are input as proportions of acres in the age class to receive each treatment. These combinations illustrate the relative impact of thinning, short rotations, long rotations and set asides.

In each decade a marginal cost is measured as the difference in net revenue between the scenario being projected and an assumed profit maximizing scenario. These costs are summed

and discounted over a 150 year (15 decade) planning horizon. As such only direct operating costs are measured. An incentive mechanism could also consider indirect costs.

An environmental index is calculated on the basis of stand structure distribution. Revenue loss for management alternatives are compared to progress in shifting the stand structure from the present distribution towards a target distribution over the 150 horizon. Restoration of a target stand structure distribution is used as proxy for the potential environmental benefits. Alternative indexes or variable(s) could also be used to measure environmental output.

For each forest management alternative considered, the marginal cost and stand structure shift are calculated and shown in Figure 3. Results show that a level of wildlife thinning from 20 to 60 percent combined with a modest reduction in the acres clearcut at 60 years characterize the more efficient solutions. Extending the rotation age or increasing the amount of set asides are extremely costly. The cost effectiveness of the solution is also shown to depend on the rate of the shift towards the target stand distribution; a greater rate will increase costs, while a slower rate will reduce costs. The limitations and assumptions of this model include the impact of a discount rate, which is assumed to be a real rate of 5 percent. The model is not spatially explicit.

This paper demonstrates an approach to measure both the incremental costs and benefits that could be tied to environmental targets and linked to an economic incentive approach for increasing environmental outputs for managed forest lands. An effective system must identify management alternatives that impact forest dynamics in ways that contribute the most to both timber and environmental goals.

Acknowledgements

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I. INTRODUCTION

The current debate over forest management policy is often characterized as a choice between nature and economic growth, simplified even further to owls versus jobs. However, a more insightful perspective of this issue considers *who* pays, *how much* and for *what.* Forest management policies and practices designed to increase the flow of environmental amenities will add direct operating costs that have previously been external to the process of wood production. Costs will vary depending on the desired level of environmental outputs and the type of modified silvicultural practices used (Lippke and Oliver 1993). This project develops a conceptual approach for measuring and comparing the costs and environmental benefits of alternative silvicultural strategies. In other words, the focus of this study is to consider the relationship between *how much* are the costs and *what* is produced.

The issue of who will pay the added costs of more environmentally sensitive forest management is one of equity. Where liability is not a factor, logic suggests that all of the beneficiaries of improved environmental conditions should pay the costs in equitable proportions. Traditionally, regulations have been employed to ensure a certain environmental condition or level of standards with only the environmental objective in mind. However, regulations in the form of environmental constraints create disincentives to resource managers by increasing costs and reducing marketable outputs. If producing incremental environmental outputs at levels mandated by regulations were commercially profitable, the regulations would not be necessary (Lippke 1992). A primary reason why it is not profitable to produce many environmental amenities is the lack of efficient market mechanisms to reimburse landowners for the increased marginal costs associated with producing the additional environmental outputs.

An incentives approach to stimulating the production of environmental values provides a public policy alternative to regulation through motivating landowners and forest managers to adopt specific environmental and non-timber goals. Incentive mechanisms[1], such as tax credits, substitute for normal market responses by transferring payments to landowners for achieving environmental goals. Incentives also allow timber producers the flexibility to find

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[1] For a more detailed discussion of incentive options see Lippke and Oliver (1993).

the lowest cost, and thus most economically efficient, means of achieving environmental goals.

In order to construct and evaluate potential incentive mechanisms for producing non-timber outputs from commercial timberland in western Washington, it is first necessary to be able to measure a large array of increased environmental outputs and the marginal costs associated with providing each one. The objective of this paper is to demonstrate that a system and criteria for measuring the environmental benefits and economic costs associated with alternative silvicultural systems is prerequisite for an effective method of realizing environmental goals. From an economic theory perspective, the problem can be thought of as the allocation of scarce means (the forest land base) to competing ends (environmental and commodity objectives). A variety of silvicultural alternatives exist which must be evaluated on the basis of estimated costs and benefits, in order to identify the strategies that provide the most benefits for the least costs.

The quantitative procedures presented here are intended to be illustrative rather than final, providing a framework for an ongoing research. For example, this paper uses stand structure distributions as a measurement of environmental output. The idea of using stand structures as a proxy measure of environmental outputs is being more thoroughly developed in other projects (Carey et al. 1994) and the treatment here is necessarily preliminary and simplistic. Observers have pointed out that stand structure may not adequately account for other environmental factors such as species diversity, water flow/quality and carbon sequestration, although Carey et al. (1994) suggest structures are a good representation for diversity. However, habitat suitability indexes have been developed which are linked to stand structures (Adams et al. 1992). Likewise, reduced timber output would not be the only economic cost associated with restricting timber harvests. These possible limitations draw attention to the purpose of this paper. Costing incentives is complicated by the fact that identifying and measuring the environmental benefits is a difficult process. Exploring mechanisms to better measure these costs and sort through the many alternatives en route to benefits is therefore both constructive and necessary.

Since forests change over time, the benefits of alternative management practices may not be realized for years or decades, while the investments and costs are likely to be more immediate. The costs and benefits must be estimated over long periods of time. This project uses an EXCEL spreadsheet model to project the growth of tree stands for 150 years, subdivided by decades. The forest stands are categorized by ten year age class and measured in acres of each class or strata. The model operates on the simple assumption that, except for certain management alternatives, each decade the area of each age class moves in the next decade to a structure characterized as being 10 years older. For example, suppose there are 450,000 acres of 50-59 year old stands in the fourth decade. Then in the fifth decade there will be 450,000 acres of 60-69 year old stands as they have grown 10 years over the decade.

Although this is not a sophisticated method for projecting tree growth and leaves out the impact of some disturbances it serves to *highlight the issues involved* for costing incentives. A detailed description of the model will be given in the next section. Section three will outline the results of several model runs. The paper concludes with a discussion of the results.

II. OUTLINE OF THE MODEL

A. The forest management alternatives

The forest management alternatives evaluated by this model are combinations of three different silvicultural prescriptions applicable for the Douglas fir forests of the study region. The intensity of each prescription can be varied on the basis of percentage of acres to be treated. The *first* option is to clearcut stands uniformly at 60 to 69 years of age. This is assumed to approximate the present economically optimal rotation age for these forests. This option represents forest management as practiced in the region in the absence of significant regulatory costs for environmental protection.

Second, a wildlife thin option commercially thins stands at 30 to 39 years, and increases the rotation age, to allow for stand diversification and increased growth. This option creates greater forest biodiversity by moving forest structures from the stem exclusion stage to structures characteristic of older forests. Stem exclusion stands predominate in western Washington and are characterized by young trees, closed canopies, and little or no understory. Left alone, these stands may require decades to produce valuable timber and quality wildlife habitat (Oliver 1992). The full effectiveness of this method for producing habitat benefits is the subject of ongoing research (Oliver 1994, Carey et al. 1994).

The decision rules demonstrated here were selected to conservatively demonstrate the principle of alternative management in accelerating the time when younger stands take on desirable age-dependent characteristics. In order to model the effects of wildlife thinning, the stands that are thinned at 30 years are reclassified in the following decades as being in the 50 year age class rather than the 40 year age class (as with the 30 year stands which are not thinned). The idea is that by thinning these stands the density change causes them to take on the characteristics of older forests at a younger age. This representation is a simplification of the concepts presented in Carey et. al. (1994), which outlines much more specific commercial and wildlife thinning regimes for western Washington. A ten year aging was considered a conservative minimum benefit from thinning for the present analysis.

The term "wildlife thin" is used here because the final harvest of the all of the thinned stands is either delayed until they reach the 100-109 year age class, or they are set aside from harvest. Whereas the purpose of a commercial thin is to increase stand value prior to harvest, the wildlife thin creates structures to be used as habitat and may not be harvested at the economically optimal rotation age.

The *third* option allows for the harvest age to be extended until the stands reach 100 to 109 years of age. Beginning in the fourth decade stands that were thinned are not available for cutting when they reach the 60-69 year age class. These stands only become available to be cut when they reach the 100-109 year age class. Stands that were not thinned and not harvested at 60-69 years can be harvested when they reach the 100-109 year age class. Stands that are not cut at 100-109 years are allowed to grow to an old growth condition and effectively become set asides. Wildlife thinning, extended rotations and set asides are forest structure modifications assumed to increase environmental benefits of an invested value.

The model has been designed such that each of these silvicultural options can be applied to a selected percentage of the acres in the respective age class. For example, if there are 300,000 acres of 30-39 year old stands, the thinning prescription could be applied to any percentage of these acres. The same principle also applies to the two clearcut options. If each prescription is limited to an integer-valued percentage there are 101^3 different combinations of the three silvicultural options, constituting 101^3 different management alternatives which can be evaluated by this model. However, in this paper only variations of 4 main strategies are explored: (a) optimal timber rotation; (b) wildlife thinning with a longer rotation; (c) extending the rotation age; and (d) setting aside acres from harvest.

To "run" the model merely requires specifying each treatment level and the spreadsheet calculates the outputs as described above. A wide array of management alternatives were arbitrarily chosen to approximate the full range of trade offs. Table I shows the 12 projected alternative management scenarios (labelled A-L) in terms of the percentages of acres treated by wildlife thinning, clear cutting at 60-69 years, and clear cutting at 100-109 years.

Table I: Alternative management scenarios.

Scenario	Wildlife Thinning (% of acres in 30-39 year age class)	Clearcut at 60 years (% of acres not thinned)	Clearcut at 100 (% of all acres in age class)
A	0 percent	85 percent	85 percent
B	20	85	85
C	0	88	30
D	0	72	69
E	0	0	100
F	25	40	35
G	0	68	54
H	56	68	54
I	10	20	60
J	40	88	30
K	0	72	39
L	32	72	39

Alternatives A and B produce a high volume of wood, while alternatives F and I significantly reduce the volume of wood produced and presumably increase the amount of environmental benefits. Several cases were specified without thinning in order to evaluate the cost effect of the wildlife thinning (thinning and extending the rotation). Alternative E shows the effect of only extending the rotation age.

B. Measuring the costs of management alternatives

The cost of implementing each alternative is developed as a marginal cost derived as the loss in net revenue between the management alternative being evaluated and a base case designed to maximize profits (see "Assumptions" section below). Costs in this sense are fairly narrowly defined as the direct operating costs paid by the land managers. The opportunity costs such as the loss of the soil expectation value from a subsequent rotation when a harvest age is extended are not computed. As a result, the costs calculated in this paper are likely to underestimate the actual total costs of the forest management alternatives considered. While the direct operating costs are not intended to be inclusive of all the costs paid by all parties, this marginal cost demonstrates that a relative level of compensation is required for each alternative in order to make the landowners indifferent to that alternative. The indirect costs and benefits to secondary employment and community tax bases are not considered.

The average net revenue for each treatment in each decade is calculated as the difference between the output revenues and the logging and regeneration costs (for the clearcut options). In this case, average refers to the average annual value for each year of a given decade. The revenues are the sum of the wood value (price/MBF x MBF produced) and the value added revenue which is equivalent to the logging costs. The result is that the average net revenue for each treatment in each decade equals the wood value less the regeneration costs.

The average net revenue for each of the three options are calculated and summed in each decade to give a total average net revenue (TANR) in each decade[2]. The average marginal

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[2] The acronyms used here as abbreviations are found in the equations below, but were not necessary for the spreadsheets in the appendices where longer abbreviations have been used.

cost (AMC) is given by subtracting the base case TANR (BTANR) from alternative TANR (ATANR) for each decade. In order to calculate this cost on a per unit basis, the AMC is divided by the average timber volume (ALTVOL in BF) produced in each decade under the alternative being evaluated. This gives an AMC for each decade expressed in \$/MBF harvested under the given alternative.

To account for the time value of money, the average marginal costs for each decade are discounted and expressed in present value terms. The present value factors for each decade are approximate and represent the midpoint of the decade. Thus the AMC for decade t is expressed as:

$$AMC_t=(\frac{ATANR_t-BTANR_t}{ALTVOL_t})\cdot(\frac{1}{1+i})^{5+k_t} \qquad \textbf{(1)}$$

where t=1,2,3,...,15 and k_t=0,10,20,...,140. Note, k_t+5 is an index used to represent the midpoint of each decade. Thus, these present value marginal costs are weighted by the discount factors and are dependent upon the discount rate, i, as in ordinary financial analysis.

In order to make the \$/MBF cost more easily comparable to current costs, the discount factors are used as weights to compute a discount weighted marginal cost rather than a net present value of all future marginal costs. By dividing the sum of discounted decadal costs from equation (1) by the sum of the factors (weights which discount each decade) we obtain a discount (present value) weighted marginal cost (MC). These calculations are shown in the following equation:

$$MC=\frac{\Sigma_t(AMC_t)}{\Sigma_t(\frac{1}{1+i})^{5+k_t}} \qquad \textbf{(2)}$$

where t and k_t are as above.

Thus, the present analysis is reduced to a cost-minimization problem. The estimated marginal cost is used to compare alternative levels of long-term stand structure shifts as discussed below.

C. Measuring the environmental benefits of management alternatives

Perhaps the most difficult problem addressed by this study has been to construct a measure or method of measuring environmental quality and/or outputs. There are multiple environmental outputs derived from the area of stands in each age class. These different outputs may be associated with different environmental values. The issue is so complex that there may never be an exact or "true" measure. Specific variables such as the mean number of wildlife and/or plant species per acre may be most appropriate for specific objectives such as maximizing species diversity, but variables do not exist for measuring the overall environmental benefits of forest management. The best index of "environmental quality" may need to be a function of numerous variables which can be measured in the field and projected over time.

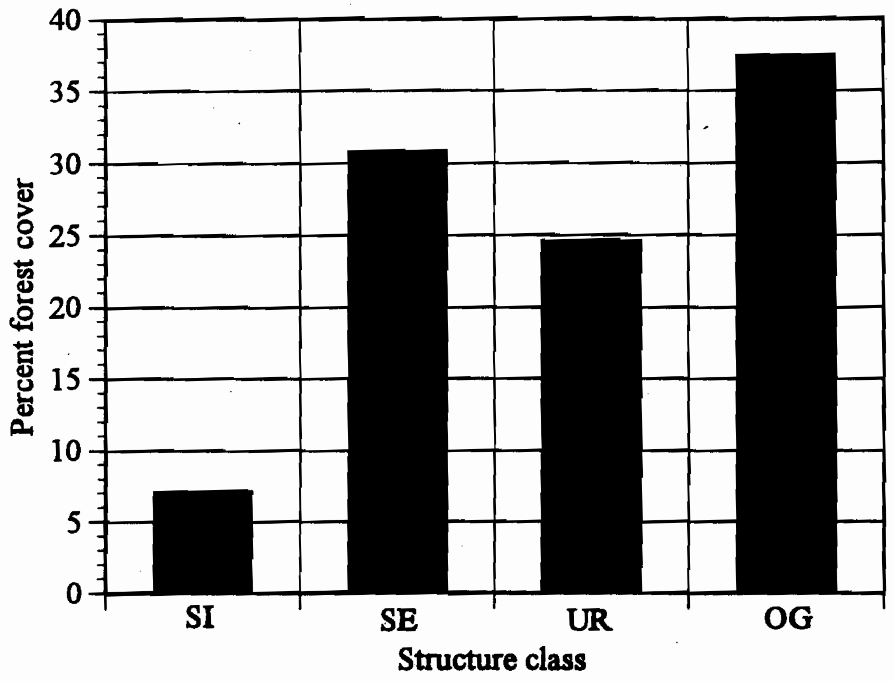
This study uses the distribution of forest stand structures as the measurable criteria for evaluating each alternative. A stand structure can be measured by the number of acres in each decadal age class, or the number of acres in each broader forest class. The four forest classes considered in this paper are stand initiation, stem exclusion, understory reinitiation and old growth (Oliver and Larson, 1990). The definition of stand structure itself does not provide a specific metric for its measurement. A stand structure distribution alone-perhaps measured by standard deviation-does not allow different structures to be compared because there is no scale for stand structure deviation. However, having a "target" structure allows stand structure to be scaled. This is done by using the beginning structure together with the "target" structure to parameterize an index. It must be strongly emphasized that the "target" is not necessarily the goal. In this case, the "target" structure serves as a benchmark against which all management alternatives being considered can be evaluated relative to the "target."

A major problem is selecting a "target" structure. Like a measure for environmental quality, it is not likely that there will ever be a single "true target" structure. Instead, proposed "target" structures can be tested on the basis of logic, scientific evidence and, most importantly, political consensus. Further, a given change in stand structure can lead to both positive and negative environmental outputs. The changes measured by this index are relative to the present stand structure distribution shown below.

The benchmark structure identified for this study is an estimate of the historical norm. The assumption underlying this "target" is that the "natural state" of the forests that existed before the period of economic expansion brought on by European settlers provides the highest level of environmental benefits. Ripple (1994) argues prelogging forest landscape patterns in Oregon should be used as a basis for ecosystem management. While it is highly unlikely that managed forests will ever achieve such a historic stand distribution, this "target" nevertheless serves as a measurable upper bound.

Estimating the mean historical stand distribution is another problem. For this project two stand histories were combined using weighted average of time spanned to estimate the historical norm for the westside Cascade region (see Figure 1 and Appendix I). The Olympic data set covers a 300 year range with decadal samples, while the Oregon data spans 8 decades with only 3 observations. The weighted average gives more weight to the time spanned than the number of samples as trees grow relatively slowly.

Constructing the stand structure index involves equating the estimated historical distribution of the structure classes shown in Figure 1 with the decadal age classes projected in this model. To do this, stand structure is divided into four broad classes. Early or stand initiation stands (SI) were delimited as 0-19 years; mid-seral or stem exclusion (SE) stands as 20-79 years; single story late-seral or understory reinitiation (UR) stands as 80-199 years; and multi-story late-seral or old growth (OG) as 200+ years.



Source: Franklin and Dyrness (1973); Teensma, et al. (1991).

Figure 1: Estimated mean historical stand distribution for the westside Cascades--average of two regions from 1600 to 1920.

Based on this classification a measure of deviation from the historical distribution (norm) can be calculated for the present forest distribution and the projected distributions in each decade. A measure of total absolute deviation of a stand in period *t* is defined as:

$$TADH_t = |SI_t - 486.5| + |SE_t - 2103.9| + |UR_t - 1682.3| + |OG_t - 2560.3| \qquad (3)$$

where $TADH_t$ is a measure, in acres, of the total absolute deviation of the stand structures in decade *t* from the estimated historical norm. The constants in (3) represent the historical norm percentages of acres of each structure class for the total area used for this project. The data is described in more detail below.

Finally, it is assumed that a greater amount of environmental benefit (as related to stand structure) will be realized at the end of the projection period. Therefore the environmental index is specified as the percentage shift from the present absolute deviation towards the historical norm (zero deviation) that occurs over the 150 year projection period. Thus the shift to the historical norm by the 15th decade is calculated as follows:

$$Shift = \left(\frac{TADH_{t=1} - TADH_{t=15}}{TADH_{t=1}}\right) \cdot 100 \tag{4}$$

where $TADH_{t=1} = 6063$, $TADH_{t=15}$ is estimated by the model for each management scenario to be evaluated.

D. The data

Stand structure data by ten year age class was obtained for the 6.8 million acres of commercially managed even aged stands in western Washington for all ownerships in 1991 (MacLean et al. 1992). This distribution was used as the baseline distribution for all of the model runs. Figure 2 shows the 1991 stand structure in terms of the four classes used to classify the historical distribution (Figure 1)[3]. Note that there has been a substantial shift away from the older more diverse structures shown in Figure 1 to the younger structures shown in Figure 2. This is the consequence of the short rotations used in the economic production of timber for commodity markets.

Although the stand distributions vary across ownerships, many of the newly emerging concepts of ecosystem and landscape management transcend property lines by focusing on forested regions (or ecosystems) as a whole. However, appropriate management regimes may need to vary from owner to owner depending on distribution. In the data for this study, the national forests occupy almost all of the stands greater than 120 years, while the majority of forest industry stands are less than 60 years (Appendix II). Uneven aged stands were not considered in the present study. Such forests require additional parameters to characterize stand structure and, as such, are beyond the context of the present study.

The conversion factors measuring board feet, revenue and prices per acre were interpolated

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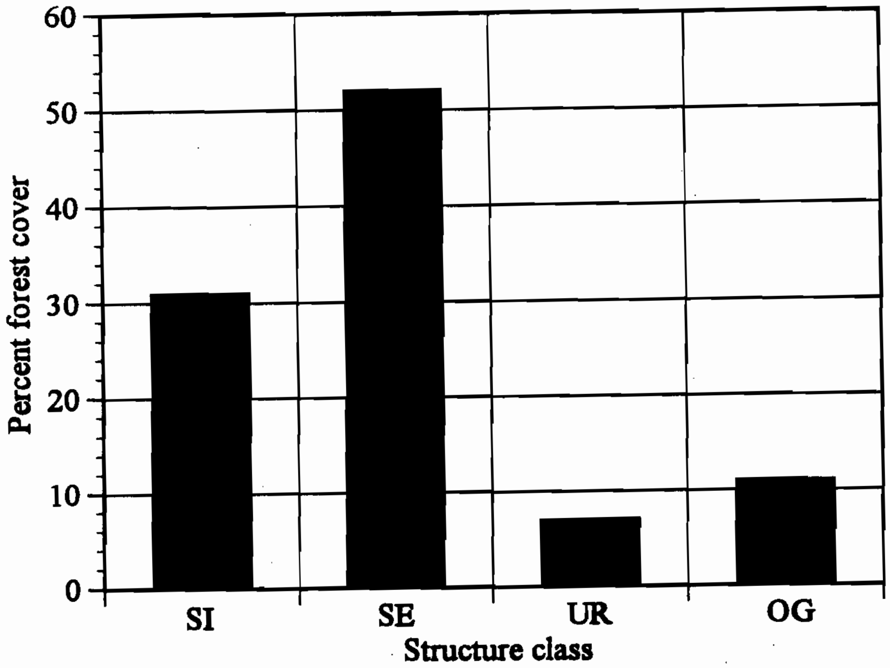
[3] Figure 5 shows the 1991 stand structure by ten year age class which is introduced later so that it can be more easily compared to the projected distributions.



Source: MacLean, et al. (1992).

Figure 2: Western Washington stand distribution by structure class for all owners in 1991.

from Chambers (1993). This data are shown at the bottom of each model run (see Appendices), and in Table II. Finally, the results of this model are dependent upon the discount rate. Here it is assumed to be an annual real rate of 5 percent.

E. Assumptions and limitations

1. The base case. The base case produces a revenue stream from a 60 year cyclical rotation without thinning. Additional revenue is produced from cutting all of the 70-100 year stands in the first four decades. In specifying a base case, the objective was to choose a scenario that best resembles a typical profit maximizing and/or high volume forest management policy. This case was also chosen so that the costs associated with alternative scenarios could be best contrasted with commercial management policies. The base case calculations are shown in Appendix III.

Table II: Coefficients used in the model.

	Price/MBF	Cost/MBF	MBF/AC	Cost/AC
Wildlife Thin at 30-39 years	127	175	2.22	389
Clearcut at 60-69 years	240	134	40.00	5360
site prep				100
plant				300
Clearcut at 100-109 years	271	134	82.20	11015
site prep				100
plant				300

2. Actual forest stand dynamics. The model was designed to provide a hypothetical example for measuring the costs and benefits of alternative management scenarios. Stand dynamic characteristics, such as species, species competition, mortality and disturbances are not explicitly modelled, although they are implicit in the conversion factors. The risk of loss to exogenous disturbance is ignored, although the older stands under longer rotations may be more susceptible to natural disturbance patterns.

Natural disturbances are an integral part of all forested landscapes. Thus, in using the historical mean stand distribution as a "target" distribution, it should be noted that the percentage of each forest structure will naturally vary widely over time. Disturbances, such as fires, prevention of fires, and windstorms, range from small to large, and with infrequent to frequent occurrences depending on the type of disturbance and geographic factors involved (Oliver 1993). The effect of disturbances is to alter the stand structure distribution over time. An example of this variation can be found in the data used to estimate the mean "target" distribution for this model (see Appendix I). By taking the mean as a benchmark, the natural dynamic variation of stand structures over time is lost.

III. MODEL RESULTS

The marginal cost and percent stand structure shift projected for each alternative are shown in Table III and are plotted in Figure 3.

Table III: Model results for each scenario.

Scenario	Marginal cost/MBF	Percent shift in stand structure towards historical norm
A	$33	13 percent
B	24	29
C	72	35
D	79	40
E	916	43
F	303	47
G	111	59
H	83	61
I	509	61
J	52	62
K	113	63
L	94	64

A. The base case

The model run shown in Appendix III shows a MC of zero dollars because the base case treatments were specified as the commercial management option used to calculate the incremental differences with other alternative treatments. The shift to the historical norm (the "target") is negative, which implies that under the base scenario the age class distribution will become more skewed over time (further away from the "target"), but at no additional cost. The average annual baseline timber volume produced is 3404 MMBF.

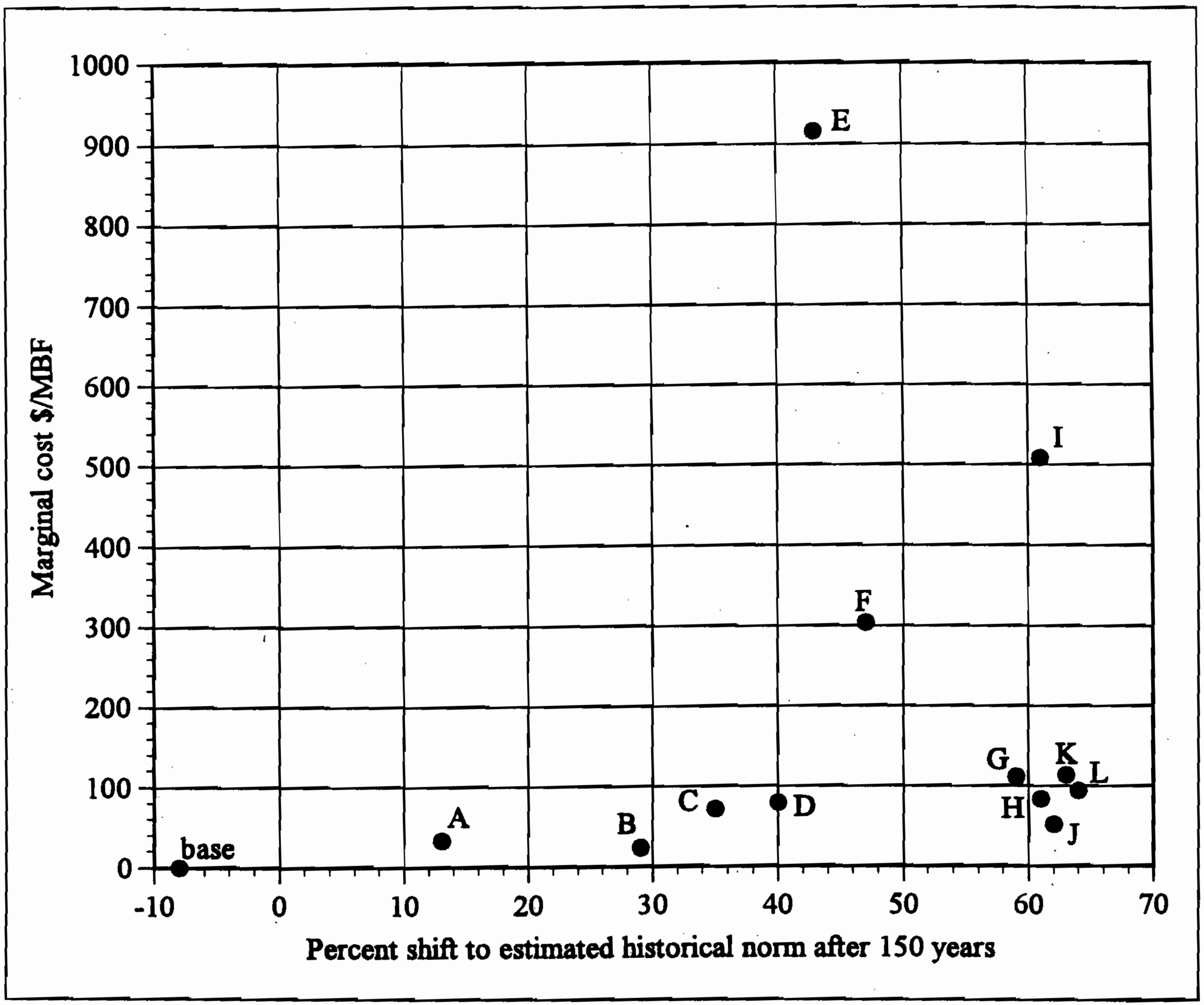


Figure 3: Estimated marginal cost and shift in stand structure by scenario.

B. The alternative management scenarios

The marginal costs can vary widely for a given shift in forest structure. As an extreme, the marginal cost of alternative E is $916/MBF for a 43 percent stand restructuring towards the historical norm, while alternative F provides a 47 percent shift for $303/MBF. Both alternatives H and I provide a 61 percent shift. However the cost differs from $83 to $509/MBF, respectively.

The most efficient solutions will lie along the low cost envelope curve of all the possible solutions. The points along this envelope will meet the conditions of Pareto optimality. In Figure 3 this curve intersects alternatives B, J and L, increasing rapidly from J to L. The model results for alternatives B and J can be found in Appendices IV and V, respectively. Each of these alternatives employed a mixture of thinning rotations while retaining a high percentage of short rotations for timber production.

Figure 4 shows only the lower cost scenarios. Inspection of Figure 4 and Table I shows that the thinning treatment is associated with the lowest cost solutions; generally not exceeding $100/MBF. Each of the three most efficient solutions include wildlife thinning treatments on more than 20 percent of the acres in the 30-39 year age class for each decade.

Three pairs of scenarios were designed to measure the effect of the wildlife thinning option by controlling for the two clearcut options. In each pair one alternative has a level of thinning, while the second does not and the two clearcut options are the same for both. The pairs are scenarios A & B, G & H, and K & L. Scenarios A, G and K do not include thinning. In Figure 4, vectors have been drawn to show the cost effect of removing the thinning option.

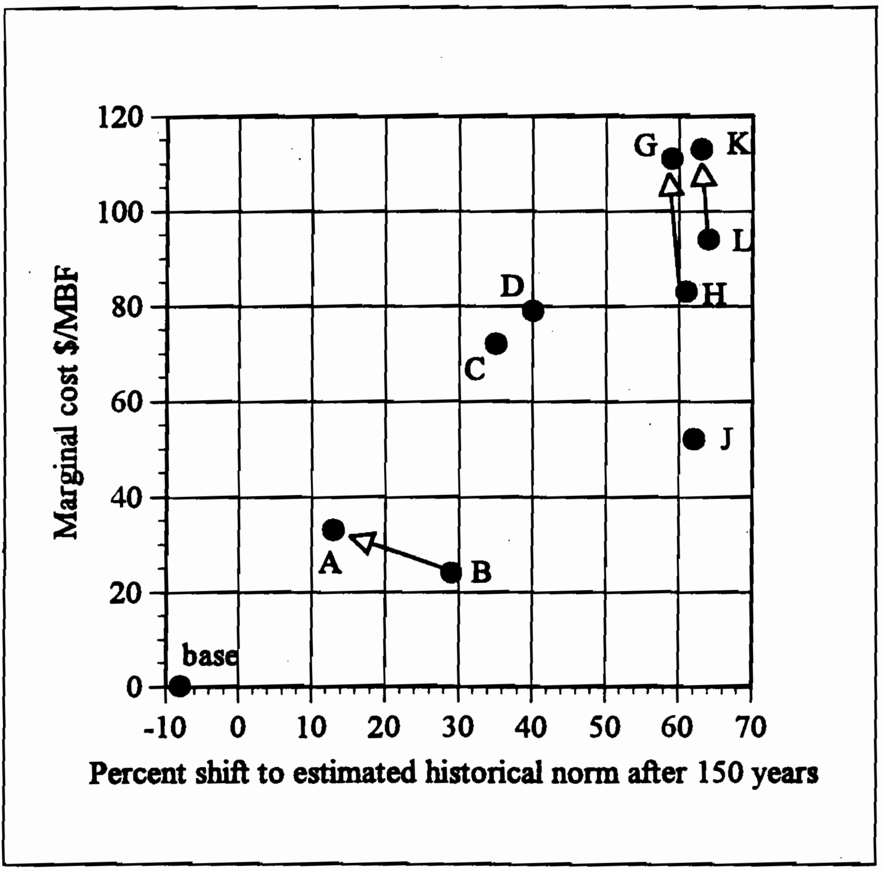
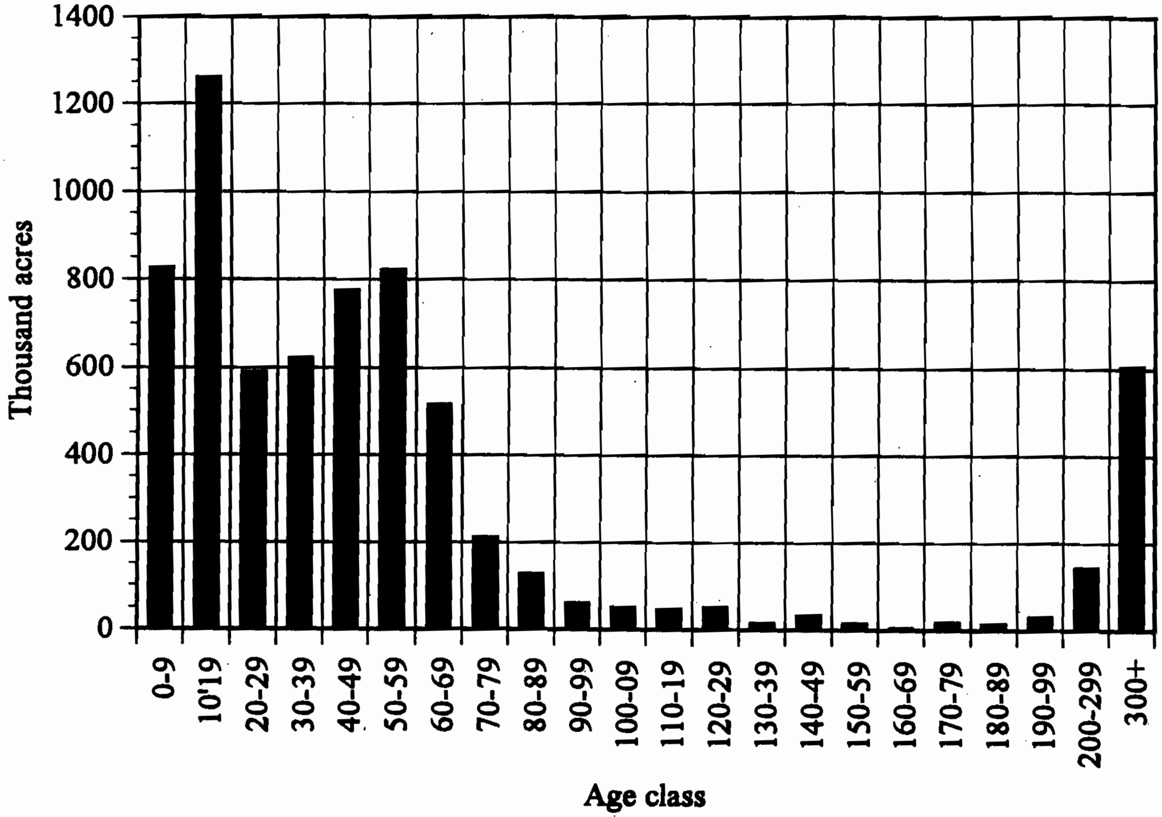


Figure 4: Scenario results comparing thinning and no thinning regimes.

Eliminating the 20 percent level of thinning between alternatives B and A increases costs from 24 to 33 $/MBF, and the stand structure shift index declines from 29 to 13 percent of the estimated historical norm. For the other two pairs, eliminating thinning has little effect on the shift index, but a greater effect on the marginal cost. The removal of the 56 percent thin from alternative H increases costs from 83 to 111 $/MBF (scenario G), but only reduces the shift index from 61 to 59 percent. Removing the 32 percent thin from alternative L increases the marginal cost from 94 to 113 $/MBF (scenario K), only reducing the shift index from 64 to 63 percent.

Graphs of the stand distributions by ten year age class can also be used to help evaluate the stand structure shifts produced by each alternative management scenario. Figure 5 shows the 1991 age class distribution of even aged timberland in western Washington for all owners. As mentioned above, this data was used as the initial condition for all scenarios modelled.



Source: MacLean, et al. (1992).

Figure 5: Area distribution of even-aged western Washington timberland by age class for all owners in 1991.

Figures 6 and 7 show the projected stand structure distributions at 150 years for scenarios B and J, respectively. These scenarios are considered in detail because they are the two lowest cost alternatives.

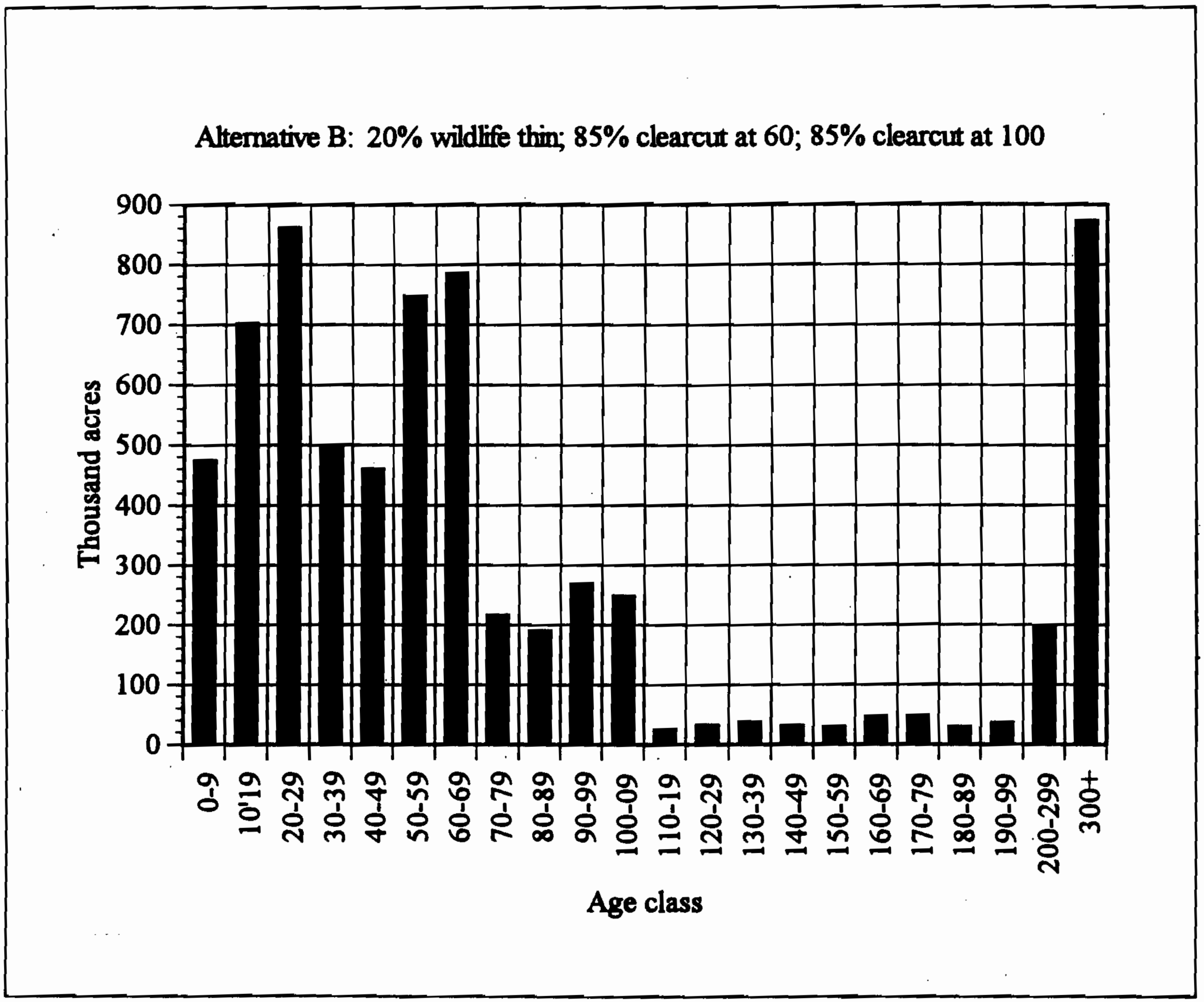


Figure 6: Projected stand distribution for alternative B at 150 years.

Alternative B actually increases the average annual volume harvested in each decade to 3771 MMBF over the base level of 3403 MMBF. This increased wood supply also leads to an increase in net revenue, explaining the lower marginal cost of this scenario. On the other hand, the scenario J harvest volume is reduced to 2929 MMBF.

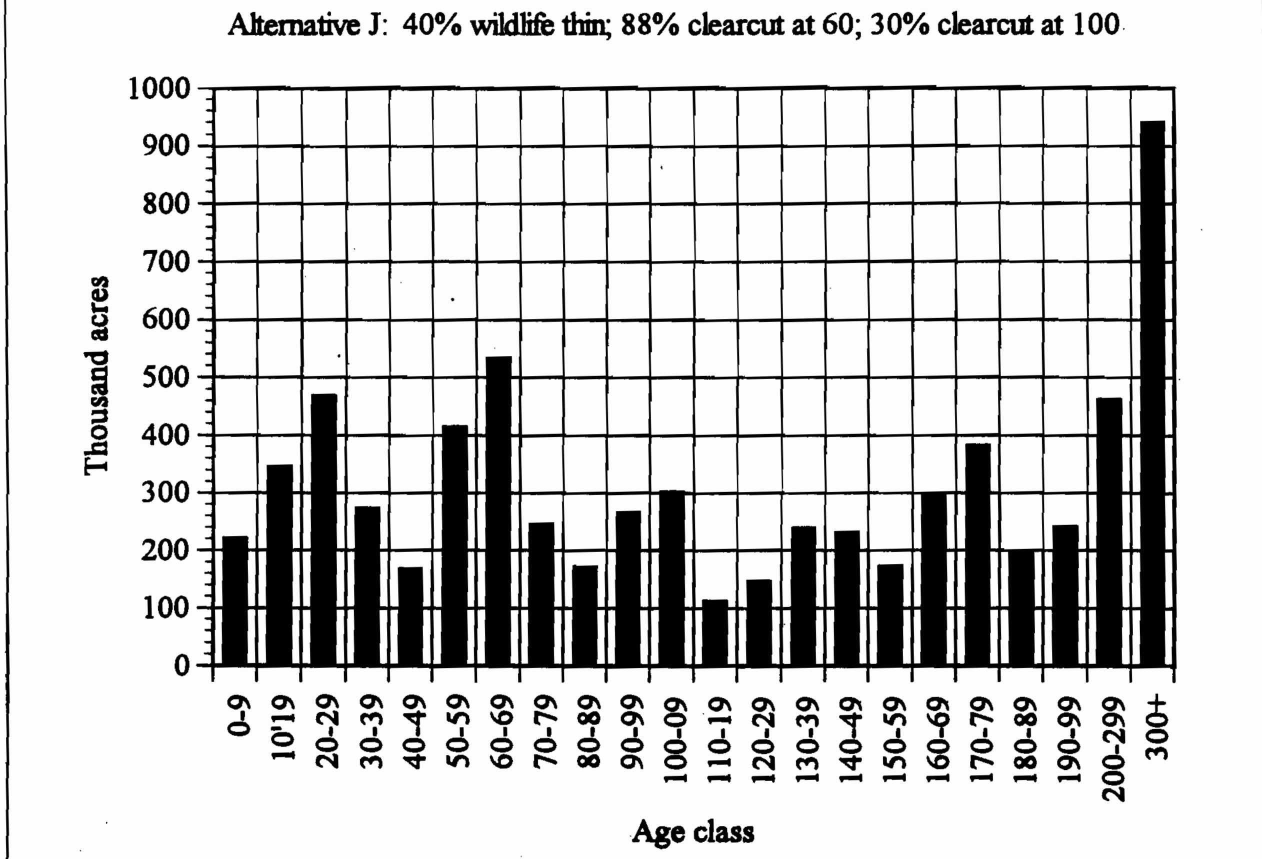


Figure 7: Projected stand distribution for alternative J at 150 years.

Figure 8 compares the projected age class distributions of scenarios B and J with the initial distribution and the historical norm. Thus, this Figure shows the past, present and possible future age class distributions for western Washington in terms of forest structure.

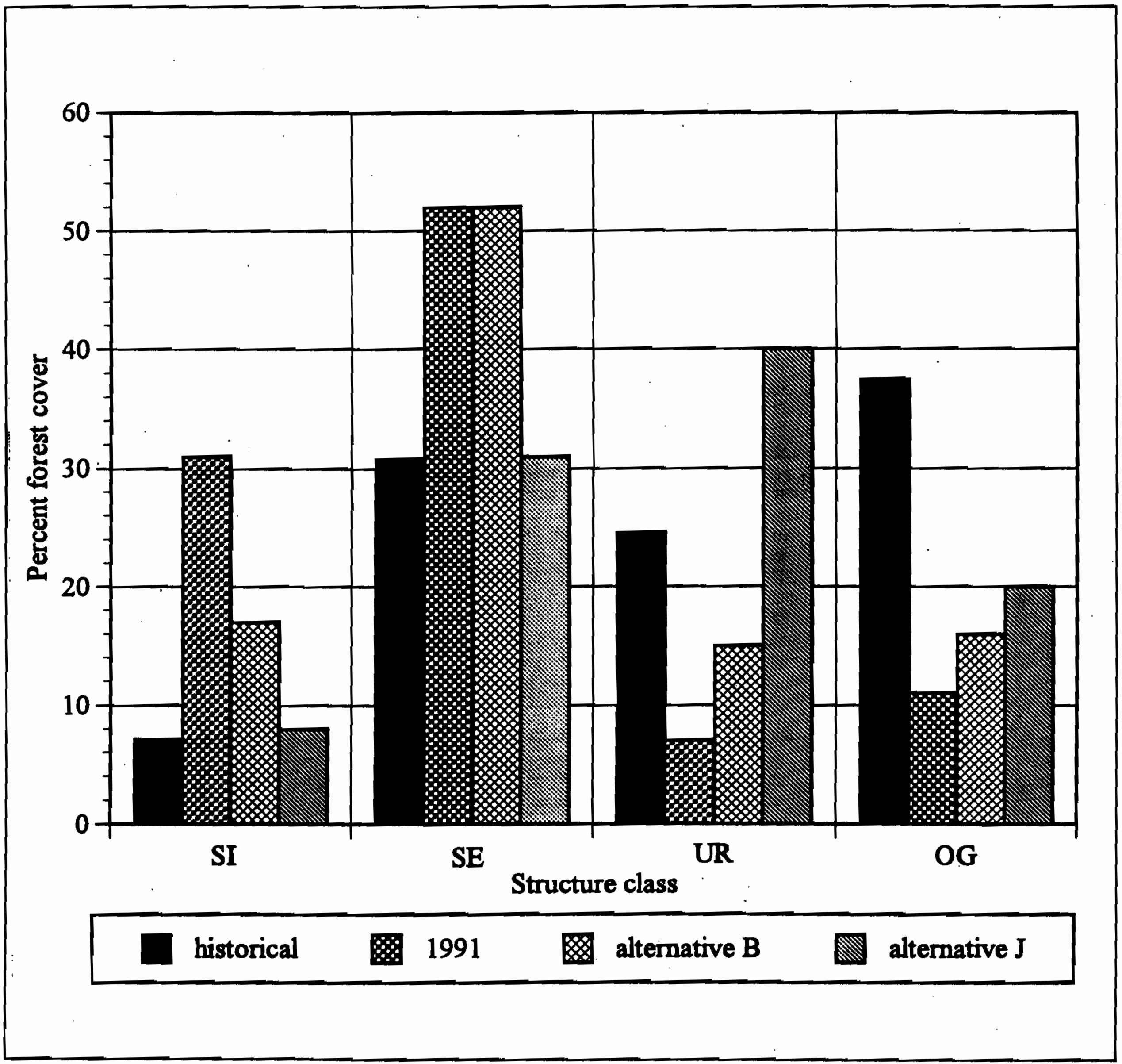


Figure 8: Comparison of structure class distributions for historic, current and projections of scenarios B and J.

Figure 8 shows how the two scenarios lead to differing effects on the age class distribution. Alternative B actually has no effect on the area of stem exclusion stands. Instead, this alternative increases the area of understory reinitiation stands and old growth stands by reducing the area of the stand initiation class. Alternative J significantly reduces the area of stand initiation and stem exclusion stands, to approximately the historical levels. Many of these stands are moved into the understory reinitiation stage, to a level exceeding the historical norm. The area of old growth is increased, but remains less than the historical norm. These results are partially dependent on the 150 year time horizon used for this analysis. If the analysis were extended for another 50 years, more of the understory reinitiation stands would be expected to move into the old growth stage.

IV. DISCUSSION OF IMPORTANT LIMITATIONS

The approach to measuring the timber opportunity costs of stand structure modification outlined in this analysis is significant in that it recognizes that forest structures do change over time, as does the cost of holding the structures. The costs as measured in this analysis use a 5 percent real discount rate. If an actual forest management modification incentive mechanism were to be designed following this approach, a sensitivity analysis could be carried out relative to key parameters such as the discount rate. An actual analysis should also be carried out for the specific acres under consideration.

Although this analysis accounts for time in an absolute sense, the results illustrated so far do not show the effect of the rate at which age class distributions change. For example, this influence can be observed by comparing scenarios H and J. While both alternatives achieve the same level of stand modification (within one percentage point) after 150 years, this is not true after only 60 years. Using equation (4) and the outputs shown in Appendices V and VI, the stand structure shift index can be computed for these alternatives at 60 years. The shift at 60 years for scenario H is 49 percent, while for scenario J it is 39 percent. At 150 years, scenario J clearly provides the same amount of stand structure shift as scenario H, but at a lower marginal cost, 52 $/MBF compared to 83 $/MBF, respectively. However, scenario J achieves the 150 year change at a slower rate, due to the higher level of harvesting at 60 years. Thus, a trade off exists between the rate of stand structure modification and the estimated marginal cost.

This analysis is not spatially explicit. The impact of given stand disturbances and the appropriateness of different silvicultural treatments will vary with geography. The quality of wildlife habitat and the costs of harvesting also depend on spatial configuration. As this is an aspatial analysis, these effects are not considered. In addition, forest land ownership varies across space, and as mentioned above, current stand structures also vary across ownership. Thus, changing the distribution of an entire landscape may require varying treatments across ownerships.

Finally, the costs as measured by this model are direct. However, indirect costs will be associated with each alternative. For example, an intensive thinning regime will require more labor, hence higher costs, than a clearcut only scenario. Although the wildlife thinning alternatives will increase costs, they may also increase job growth and tax revenue. While these may be of little benefit to the land manager, they are of value to the economic region and therefore provide additional benefits to those who would be expected to pay for incentives.

V. CONCLUSIONS

This analysis models the incremental timber implications associated with various forest management scenarios designed to change forest stand structure. There is a positive correlation between forest structure change, as measured by a percent shift to the historical norm over a fixed 150 year time horizon, and the marginal cost of stimulating the shift, where marginal cost is a present value weighted average marginal cost of an alternative relative to baseline management practices. In other words, stand modifications cost more than traditional timber management regimes. The study further shows that forest management alternatives which include thinning for wildlife are likely to be more cost effective than those without, given a change in forest management policies. By comparison, longer rotations and set asides alone are substantially more costly.

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APPENDIX I

HISTORIC NORMS

	Soleduck HUC - percent stand structure				Oregon Coast Range			
	Early	mid seral	ss I seral	ms I seral	Early	mid seral	ss I seral	ms I seral
1600	0	64	8	28				
1610	0	62	10	28				
1620	0	62	10	28				
1630	0	62	10	28				
1640	0	62	10	28				
1650	0	62	10	28				
1660	0	56	16	28				
1670	0	56	16	28				
1680	0	22	50	28				
1690	0	22	50	28				
1700	0	22	50	28				
1710	25	18	21	36				
1720	22	21	21	36				
1730	22	21	21	36				
1740	6	37	21	36				
1750	0	43	21	36				
1760	0	43	19	38				
1770	0	43	19	38				
1780	0	43	19	38				
1790	0	43	19	38				
1800	0	43	19	38				
1810	0	25	33	42				
1820	0	25	33	42				
1830	0	25	33	42				
1840	0	25	33	42				
1850	0	25	33	42	35.80	2.20	22.00	40.00
1860	0	23	35	42				
1870	0	23	35	42				
1880	0	4	54	42				
1890	0	4	54	42	28.90	19.60	5.20	46.30
1900	2	4	52	42				
1910								
1920					10.50	19.80	19.80	49.90
Mean	2.48	35.16	26.94	35.42	25.07	13.87	15.67	45.40
Std dev	6.93	18.81	14.75	5.98	13.08	10.10	9.13	5.01
		Weighted Avg (by total time span)						
Mean	7.12	30.79	24.62	37.47				
Std dev	8.19	17.02	13.60	5.78				

Source: Franklin and Dyrness (1973); Teensma, et al. (1991)

APPENDIX II

Area of timberland by stand age and owner for western Washington, 1991

Age Class	NF	other public	Forest Ind	other private	Total
0-9	102	113	490	121	826
10-19	109	234	768	150	1261
21-29	92	70	386	42	590
30-39	107	126	331	57	621
40-49	73	171	407	124	775
50-59	97	261	289	175	822
60-69	87	170	162	96	515
70-79	65	53	35	58	211
80-89	54	33	11	29	127
90-99	33	3	12	11	59
100-109	36	0	12	3	51
110-119	35	7	3	0	45
120-129	37	7	7	0	51
130-139	11	0	0	3	14
140-149	30	3	0	0	33
150-159	14	0	0	0	14
160-169	4	0	0	0	4
170-179	14	3	0	0	17
180-189	14	0	0	0	14
190-199	31	0	0	0	31
200-299	131	9	0	3	143
300+	593	7	0	6	606
Total area (000 ac)	1769	1270	2913	878	6830
Tot abs dev balance 1991	5060	5639	6527	5951	
Tot abs dev historical 1991	5064	5563	5463	5955	

Source: MacLean, et al. (1992)

note: totals calculated by the spreadsheet
may not add due to round-off error

Appendix III: Base Scenario

Age Class	t=0	t=10	t=20	t=30	t=40	t=50	t=60	t=70	t=80	t=90	t=100	t=110	t=120	t=130	t=140	t=150
0-9	827	566	882	903	832	590	1260	827	566	882	903	832	590	1260	827	566
10-19	1260	827	566	882	903	832	590	1260	827	566	882	903	832	590	1260	827
21-29	590	1260	827	566	882	903	832	590	1260	827	566	882	903	832	590	1260
30-39	621	590	1260	827	566	882	903	832	590	1260	827	566	882	903	832	590
40-49	776	621	590	1260	827	566	882	903	832	590	1260	827	566	882	903	832
50-59	822	776	621	590	1260	827	566	882	903	832	590	1260	827	566	882	903
60-69	515	822	776	621	590	1260	827	566	882	903	832	590	1260	827	566	882
70-79	211	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80-89	127	211	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90-99	60	127	211	0	0	0	0	0	0	0	0	0	0	0	0	0
100-109	51	60	127	211	0	0	0	0	0	0	0	0	0	0	0	0
110-119	46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
120-129	51	46	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130-139	14	51	46	0	0	0	0	0	0	0	0	0	0	0	0	0
140-149	33	14	51	46	0	0	0	0	0	0	0	0	0	0	0	0
150-159	14	33	14	51	46	0	0	0	0	0	0	0	0	0	0	0
160-169	4	14	33	14	51	46	0	0	0	0	0	0	0	0	0	0
170-179	17	4	14	33	14	51	46	0	0	0	0	0	0	0	0	0
180-189	14	17	4	14	33	14	51	46	0	0	0	0	0	0	0	0
190-199	31	14	17	4	14	33	14	51	46	0	0	0	0	0	0	0
200-299	143	160	158	159	147	146	165	162	197	223	201	181	163	147	132	119
300+	606	620	636	652	668	683	697	714	730	750	772	792	810	826	841	854
Total area (000 ac)	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833
Tot abs dev balance	7632	7734	7854	8108	8530	8530	8530	8530	8530	8530	8530	8530	8530	8530	8530	8530
Tot abs dev historic	6063	5743	5863	6117	6539	6539	6539	6539	6539	6539	6539	6539	6539	6539	6539	6539
Acres WT@30/10yr (000 ac)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acres CC@60/10yr (000)		515	822	776	621	590	1260	827	566	882	903	832	590	1260	827	566
Acres CC@100/10yr(000)		51	60	127	211	0	0	0	0	0	0	0	0	0	0	0
Tot Acres CC/10yr (000)		566	882	903	832	590	1260	827	566	882	903	832	590	1260	827	566
WT Vol/10yr MMBF		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg WT Cost/yr (000)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg WT Rev/yr (000)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg WT VA Rev/yr (000)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg Net WT Rev/yr (000)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CC60 V/10yr MMBF		20600	32880	31040	24840	23600	50400	33080	22640	35280	36120	33280	23600	50400	33080	22640
Avg CC60 Cost/yr (000)		276040	440592	415936	332856	316240	675360	443272	303376	472752	484008	445952	316240	675360	443272	303376
Avg Regen Cost/yr (000)		20600	32880	31040	24840	23600	50400	33080	22640	35280	36120	33280	23600	50400	33080	22640
Avg CC60 Rev/yr (000)		494400	789120	744960	596160	566400	1209600	793920	543360	846720	866880	798720	566400	1209600	793920	543360
Avg VA Rev/yr (000)		276040	440592	415936	332856	316240	675360	443272	303376	472752	484008	445952	316240	675360	443272	303376
Avg Net CC60 Rev/yr (000)		473800	756240	713920	571320	542800	1159200	760840	520720	811440	830760	765440	542800	1159200	760840	520720
CC100 V/10y MMBF		4192	4932	10439	17344	0	0	0	0	0	0	0	0	0	0	0
Avg CC100 Cost/yr (000)		56175	66089	139888	232412	0	0	0	0	0	0	0	0	0	0	0
Avg Regen Cost/yr (000)		2040	2400	5080	8440	0	0	0	0	0	0	0	0	0	0	0
Avg CC100 Rev/yr (000)		113609	133657	282908	470028	0	0	0	0	0	0	0	0	0	0	0
Avg VA Rev/yr (000)		56175	66089	139888	232412	0	0	0	0	0	0	0	0	0	0	0
Avg Net CC100 Rev/yr 000		111569	131257	277828	461588	0	0	0	0	0	0	0	0	0	0	0
Alt Tot Vol/10yr MMBF		24792	37812	41479	42184	23600	50400	33080	22640	35280	36120	33280	23600	50400	33080	22640
Avg Tot Vol/yr MMBF		2479	3781	4148	4218	2360	5040	3308	2264	3528	3612	3328	2360	5040	3308	2264
Alt Tot Avg Net Rev/yr (000)		585369	887497	991748	1032908	542800	1159200	760840	520720	811440	830760	765440	542800	1159200	760840	520720
Base Tot Vol/10yr MMBF		24792	37812	41479	42184	23600	50400	33080	22640	35280	36120	33280	23600	50400	33080	22640
Avg Tot Vol/yr MMBF		2479	3781	4148	4218	2360	5040	3308	2264	3528	3612	3328	2360	5040	3308	2264
Base Tot Avg Net Rev/yr 000		585369	887497	991748	1032908	542800	1159200	760840	520720	811440	830760	765440	542800	1159200	760840	520720
ALT-ECON MGT (Avg/yr 000)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(Cstdiff/Alt vol)*pvf(av/yr)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Discount Factors		0.78	0.48	0.30	0.18	0.11	0.07	0.04	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00
				Sum of weights =		2.03		Interest rate =		0.05						
RESULTS:																
Sum = Marginal Cost =		0.00	$/MBF													
Shift to even balance		-12														
Shift to historical norm		-8														
Alt Avg MMBF/yr		3403														
Base Avg MMBF/yr		3403														
Prescriptions/10yr	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Frac WT @ 30-39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Frac CC@60 not CW	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Frac CC @ 100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Price/MBF	Cost/MBF	MBF/Ac	Rev/Ac	Cst/Ac											
WT@30	127	175	2.22	282	389		Avg Ac WT/yr (0-150yr interval, 000 acres)					0				
CC@60	240	134	40.00	9600	5360		Avg Ac CC@60/yr (0-150yr interval, 000 acrs)					118				
site prep					100		Avg Ac CC@100/yr (0-150yr interval, 000 acs)					4				
plant					300											
CC@100	271	134	82.20	22276	11015											
site prep					100											
plant					300											

Appendix IV: Scenario B

Age Class	t=0	t=10	t=20	t=30	t=40	t=50	t=60	t=70	t=80	t=90	t=100	t=110	t=120	t=130	t=140	t=150
0-9	827	481	750	768	602	467	962	767	491	784	791	575	494	861	702	474
10-19	1260	827	481	750	768	602	467	962	767	491	784	791	575	494	861	702
21-29	590	1260	827	481	750	768	602	467	962	767	491	784	791	575	494	861
30-39	621	590	1260	827	481	750	768	602	467	962	767	491	784	791	575	494
40-49	776	497	472	1008	662	385	600	614	481	373	769	613	393	627	633	460
50-59	822	900	615	724	1173	758	535	753	734	575	566	923	712	549	786	748
60-69	515	822	900	615	724	1173	758	535	753	734	575	566	923	712	549	786
70-79	211	77	123	241	193	323	317	195	208	243	212	166	248	269	190	216
80-89	127	211	77	123	241	193	323	317	195	208	243	212	166	248	269	190
90-99	60	127	211	77	123	241	193	323	317	195	208	243	212	166	248	269
100-109	51	60	127	211	77	123	241	193	323	317	195	208	243	212	166	248
110-119	46	8	9	19	32	12	18	36	29	48	47	29	31	37	32	25
120-129	51	46	8	9	19	32	12	18	36	29	48	47	29	31	37	32
130-139	14	51	46	8	9	19	32	12	18	36	29	48	47	29	31	37
140-149	33	14	51	46	8	9	19	32	12	18	36	29	48	47	29	31
150-159	14	33	14	51	46	8	9	19	32	12	18	36	29	48	47	29
160-169	4	14	33	14	51	46	8	9	19	32	12	18	36	29	48	47
170-179	17	4	14	33	14	51	46	8	9	19	32	12	18	36	29	48
180-189	14	17	4	14	33	14	51	46	8	9	19	32	12	18	36	29
190-199	31	14	17	4	14	33	14	51	46	8	9	19	32	12	18	36
200-299	143	160	158	159	147	146	165	162	197	223	209	197	196	208	199	198
300+	606	620	636	652	668	683	697	714	730	750	772	793	813	832	853	873
Total area (000 ac)	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833
Tot abs dev balance	7632	7565	7420	7181	7154	6831	6585	6577	6489	6392	6328	6329	6227	6154	6134	5984
Tot abs dev historica	6063	5728	5675	5645	5522	5269	4833	4608	4545	4678	4729	4637	4659	4576	4400	4301
Acres WT@30/10yr (000 ac)		124	118	252	165	96	150	154	120	93	192	153	98	157	158	115
Acres CC@60/10yr (000)		438	699	765	523	615	997	644	455	640	624	488	481	784	605	467
Acres CC@100/10yr(000)		43	51	108	179	66	105	205	164	274	269	166	177	207	181	141
Tot Acres CC/10yr (000)		481	750	768	602	467	962	767	491	784	791	575	494	861	702	474
WT Vol/10yr MMBF		273	260	554	364	212	330	338	265	205	423	337	216	345	348	253
Avg WT Cost/yr (000)		4782	4543	9702	6368	3704	5773	5910	4633	3595	7404	5905	3779	6038	6091	4429
Avg WT Rev/yr (000)		3470	3297	7041	4621	2688	4189	4289	3362	2609	5373	4285	2743	4382	4420	3214
Avg WT VA Rev/yr (000)		4782	4543	9702	6368	3704	5773	5910	4633	3595	7404	5905	3779	6038	6091	4429
Avg Net WT Rev/yr (000)		3470	3297	7041	4621	2688	4189	4289	3362	2609	5373	4285	2743	4382	4420	3214
CC60 V/10yr MMBF		17510	27948	30607	20903	24616	39896	25766	18184	25611	24968	19539	19238	31370	24196	18682
Avg CC60 Cost/yr (000)		234634	374503	410131	280103	329854	534601	345263	243664	343190	334577	261823	257783	420363	324230	250337
Avg Regen Cost/yr (000)		17510	27948	30607	20903	24616	39896	25766	18184	25611	24968	19539	19238	31370	24196	18682
Avg CC60 Rev/yr (000)		420240	670752	734563	501677	590764	957494	618381	436413	614668	599243	468936	461702	752889	580710	448365
Avg VA Rev/yr (000)		234634	374503	410131	280103	329854	534601	345263	243664	343190	334577	261823	257783	420363	324230	250337
Avg Net CC60 Rev/yr (000)		402730	642804	703956	480774	566168	917599	592615	418229	589057	574274	449397	442464	721519	556513	429683
CC100 V/10y MMBF		3563	4192	8873	14743	5397	8615	16811	13451	22554	22121	13657	14510	17012	14843	11568
Avg CC100 Cost/yr (000)		47749	56175	118905	197550	72326	115441	225264	180248	302224	296419	183001	194435	227954	198891	155014
Avg Regen Cost/yr (000)		1734	2040	4318	7174	2627	4192	8180	6546	10975	10764	6646	7061	8278	7223	5629
Avg CC100 Rev/yr (000)		96567	113609	240472	399524	146271	233466	455571	364532	611214	599475	370099	393222	461012	402235	313499
Avg VA Rev/yr (000)		47749	56175	118905	197550	72326	115441	225264	180248	302224	296419	183001	194435	227954	198891	155014
Avg Net CC100 Rev/yr 000		94833	111569	236154	392350	143645	229274	447390	357987	600239	588710	363453	386161	452734	395012	307870
Alt Tot Vol/10yr MMBF		21347	32400	40035	36010	30225	48840	42914	31900	48371	47512	33533	33964	48727	39387	30503
Avg Tot Vol/yr MMBF		2135	3240	4003	3601	3023	4884	4291	3190	4837	4751	3353	3396	4873	3939	3050
Alt Tot Avg Net Rev/yr (000)		501033	757670	947151	877745	712501	1151062	######	779578	1191905	#####	817136	831368	1178635	955946	740768
Base Tot Vol/10yr MMBF		24792	37812	41479	42184	23600	50400	33080	22640	35280	36120	33280	23600	50400	33080	22640
Avg Tot Vol/yr MMBF		2479	3781	4148	4218	2360	5040	3308	2264	3528	3612	3328	2360	5040	3308	2264
Base Tot Avg Net Rev/yr 000		585369	887497	991748	1032908	542800	1159200	760840	520720	811440	830760	765440	542800	1159200	760840	520720
ALT-ECON MGT (Avg/yr 000)		-84335	-129828	-44597	-155163	169701	-8138	283454	258858	380465	337598	51696	288568	19435	195106	220048
(Cstdiff/Alt vol)*pvf(av/yr)		-30.95517	-19.2746	-3.28954	-7.81168	6.2488	-0.11385	2.7706	2.0896	1.24349	0.6896	0.09185	0.31079	0.00896	0.06829	0.06106
Discount Factors		0.78	0.48	0.30	0.18	0.11	0.07	0.04	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00
				Sum of weights =		2.03		Interest rate =		0.05						
RESULTS:																
Sum = Marginal Cost =		-23.60	$/MBF													
Shift to even balance		22														
Shift to historical norm		29														
Alt Avg MMBF/yr		3771														
Base Avg MMBF/yr		3403														
Prescriptions/10yr	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Frac WT @ 30-39	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Frac CC@60 not CW	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Frac CC @ 100	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
	Price/MBF	Cost/MBF	MBF/Ac	Rev/Ac	Cst/Ac											
WT@30	127	175	2.22	282	389		Avg Ac WT/yr (0-150yr interval, 000 acres)					21				
CC@60	240	134	40.00	9600	5360		Avg Ac CC@60/yr (0-150yr interval, 000 acrs)					92				
site prep					100		Avg Ac CC@100/yr (0-150yr interval, 000 acs)					23				
plant					300											
CC@100	271	134	82.20	22278	11015											
site prep					100											
plant					300											

Appendix V: Scenario J

Age Class	t=0	t=10	t=20	t=30	t=40	t=50	t=60	t=70	t=80	t=90	t=100	t=110	t=120	t=130	t=140	t=150
0-9	827	469	741	721	391	330	695	539	332	555	507	281	273	469	347	223
10-19	1260	827	469	741	721	391	330	695	539	332	555	507	281	273	469	347
21-29	590	1260	827	469	741	721	391	330	695	539	332	555	507	281	273	469
30-39	621	590	1260	827	469	741	721	391	330	695	539	332	555	507	281	273
40-49	776	373	354	756	496	281	445	433	235	198	417	323	199	333	304	168
50-59	822	1024	609	858	1087	684	578	733	589	367	476	633	456	421	536	417
60-69	515	822	1024	609	858	1087	684	578	733	589	367	476	633	456	421	536
70-79	211	62	99	342	281	546	422	247	330	342	208	160	302	266	171	246
80-89	127	211	62	99	342	281	546	422	247	330	342	208	160	302	266	171
90-99	60	127	211	62	99	342	281	546	422	247	330	342	208	160	302	266
100-109	51	60	127	211	62	99	342	281	546	422	247	330	342	208	160	302
110-119	46	36	42	89	148	43	69	239	196	383	295	173	231	239	146	112
120-129	51	46	36	42	89	148	43	69	239	196	383	295	173	231	239	146
130-139	14	51	46	36	42	89	148	43	69	239	196	383	295	173	231	239
140-149	33	14	51	46	36	42	89	148	43	69	239	196	383	295	173	231
150-159	14	33	14	51	46	36	42	89	148	43	69	239	196	383	295	173
160-169	4	14	33	14	51	46	36	42	89	148	43	69	239	196	383	295
170-179	17	4	14	33	14	51	46	36	42	89	148	43	69	239	196	383
180-189	14	17	4	14	33	14	51	46	36	42	89	148	43	69	239	196
190-199	31	14	17	4	14	33	14	51	46	36	42	89	148	43	69	239
200-299	143	160	158	159	147	146	165	162	197	223	237	255	318	434	434	460
300+	606	620	636	652	668	683	697	714	730	750	772	796	821	853	896	940
Total area (000 ac)	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833
Tot abs dev balance	7632	7539	7378	6999	6671	6253	5857	5402	5009	4613	4137	3926	3528	3016	2798	2566
Tot abs dev historic	6063	5672	5584	5463	4907	4382	3397	3369	3267	3175	3103	3019	2841	2546	2694	2321
Acres WT@30/10yr (000 ac)		248	236	504	331	187	297	288	156	132	278	216	133	222	203	112
Acres CC@60/10yr (000)		453	723	901	536	755	956	602	508	645	518	323	419	557	401	371
Acres CC@100/10yr(000)		15	18	38	63	19	30	102	84	164	126	74	99	103	63	48
Tot Acres CC/10yr (000)		469	741	721	391	330	695	539	332	555	507	281	273	469	347	223
WT Vol/10yr MMBF		546	519	1109	728	412	652	634	344	290	611	474	292	489	446	247
Avg WT Cost/yr (000)		9563	9086	19404	12736	7215	11417	11103	6024	5083	10701	8302	5106	8553	7810	4322
Avg WT Rev/yr (000)		6940	6594	14082	9243	5236	8285	8058	4372	3689	7766	6025	3706	6207	5668	3136
Avg WT VA Rev/yr (000)		9563	9086	19404	12736	7215	11417	11103	6024	5083	10701	8302	5106	8553	7810	4322
Avg Net WT Rev/yr (000)		6940	6594	14082	9243	5236	8285	8058	4372	3689	7766	6025	3706	6207	5668	3136
CC60 V/10yr MMBF		18128	28934	36059	21423	30202	38255	24063	20333	25809	20735	12909	16755	22266	16055	14823
Avg CC60 Cost/yr (000)		242915	387721	483189	287064	404701	512622	322440	272463	345840	277849	172982	224513	298370	215133	198625
Avg Regen Cost/yr (000)		18128	28934	36059	21423	30202	38255	24063	20333	25809	20735	12909	16755	22266	16055	14823
Avg CC60 Rev/yr (000)		435072	694426	865413	514145	724838	918129	577505	487994	619414	497641	309819	402112	534393	385313	355747
Avg VA Rev/yr (000)		242915	387721	483189	287064	404701	512622	322440	272463	345840	277849	172982	224513	298370	215133	198625
Avg Net CC60 Rev/yr (000)		416944	665491	829354	492723	694637	879873	553443	467661	593605	476906	296910	385357	512127	369258	340924
CC100 V/10y MMBF		1258	1480	3132	5203	1524	2432	8422	6922	13476	10395	6090	8145	8428	5139	3950
Avg CC100 Cost/yr (000)		16853	19827	41966	69724	20421	32595	112853	92760	180581	139289	81601	109138	112936	68860	52934
Avg Regen Cost/yr (000)		612	720	1524	2532	742	1184	4098	3369	6558	5058	2963	3963	4101	2501	1922
Avg CC100 Rev/yr (000)		34083	40097	84872	141008	41300	65920	228233	187596	365205	281696	165029	220719	228400	139261	107052
Avg VA Rev/yr (000)		16853	19827	41966	69724	20421	32595	112853	92760	180581	139289	81601	109138	112936	68860	52934
Avg Net CC100 Rev/yr 000		33471	39377	83348	138476	40558	64736	224135	184227	358647	276638	162066	216756	224299	136761	105130
Alt Tot Vol/10yr MMBF		19932	30933	40300	27354	32138	41340	33119	27600	39576	31741	19473	25191	31183	21640	19020
Avg Tot Vol/yr MMBF		1993	3093	4030	2735	3214	4134	3312	2760	3958	3174	1947	2519	3118	2164	1902
Alt Tot Avg Net Rev/yr (000)		457355	711462	926784	840441	740431	952895	785635	656260	955941	761309	465001	605819	742633	511687	449190
Base Tot Vol/10yr MMBF		24792	37812	41479	42184	23600	50400	33080	22640	35280	36120	33280	23600	50400	33080	22640
Avg Tot Vol/yr MMBF		2479	3781	4148	4218	2360	5040	3308	2264	3528	3612	3328	2360	5040	3308	2264
Base Tot Avg Net Rev/yr 000		585369	887497	991748	1032908	542800	1159200	760840	520720	811440	830760	765440	542800	1159200	760840	520720
ALT-ECON MGT (Avg/yr 000)		-128014	-176035	-64963	-392466	197631	-206305	24795	135540	144501	-69451	-300439	63019	-416567	-249153	-71530
(Cstdiff/Alt vol)*pvf(av/yr)		-50.3218	-27.3738	-4.76033	-26.0112	6.8442	-3.40978	0.314	1.2646	0.57724	-0.212	-0.9193	0.09151	-0.3	-0.1587	-0.0318
Discount Factors		0.78	0.48	0.30	0.18	0.11	0.07	0.04	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00
				Sum of weights =		2.03		Interest rate =		0.05						
RESULTS:																
Sum = Marginal Cost =		-51.48	$/MBF													
Shift to even balance		66														
Shift to historical norm		62														
Alt Avg MMBF/yr		2937														
Base Avg MMBF/yr		3403														
Prescriptions/10yr	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Frac WT @ 30-39	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Frac CC@60 not CW	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Frac CC @ 100	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
	Price/MBF	Cost/MBF	MBF/Ac	Rev/Ac	Cst/Ac											
WT@30	127	175	2.22	282	389		Avg Ac WT/yr (0-150yr interval, 000 acres)					35				
CC@60	240	134	40.00	9600	5360		Avg Ac CC@60/yr (0-150yr interval, 000 acrs)					87				
site prep					100		Avg Ac CC@100/yr (0-150yr interval, 000 acs)					10				
plant					300											
CC@100	271	134	82.20	22276	11016											
site prep					100											
plant					300											

Appendix VI: Scenario H

Age Class	t=0	t=10	t=20	t=30	t=40	t=50	t=60	t=70	t=80	t=90	t=100	t=110	t=120	t=130	t=140	t=150
0-9	827	378	591	596	300	266	519	569	339	603	524	267	287	381	306	204
10-19	1260	827	378	591	596	300	266	519	569	339	603	524	267	287	381	306
21-29	590	1260	827	378	591	596	300	266	519	569	339	603	524	267	287	381
30-39	621	590	1260	827	378	591	596	300	266	519	569	339	603	524	267	287
40-49	776	273	260	554	364	166	260	262	132	117	228	251	149	265	231	117
50-59	822	1124	604	965	1018	575	497	594	430	281	407	547	440	487	559	380
60-69	515	822	1124	604	965	1018	575	497	594	430	281	407	547	440	487	559
70-79	211	165	263	596	418	789	641	328	384	417	252	191	328	392	270	385
80-89	127	211	165	263	596	418	789	641	328	384	417	252	191	328	392	270
90-99	60	127	211	165	263	596	418	789	641	328	384	417	252	191	328	392
100-109	51	60	127	211	165	263	596	418	789	641	328	384	417	252	191	328
110-119	46	23	28	58	97	76	121	274	192	363	295	151	177	192	116	88
120-129	51	46	23	28	58	97	76	121	274	192	363	295	151	177	192	116
130-139	14	51	46	23	28	58	97	76	121	274	192	363	295	151	177	192
140-149	33	14	51	46	23	28	58	97	76	121	274	192	363	295	151	177
150-159	14	33	14	51	46	23	28	58	97	76	121	274	192	363	295	151
160-169	4	14	33	14	51	46	23	28	58	97	76	121	274	192	363	295
170-179	17	4	14	33	14	51	46	23	28	58	97	76	121	274	192	363
180-189	14	17	4	14	33	14	51	46	23	28	58	97	76	121	274	192
190-199	31	14	17	4	14	33	14	51	46	23	28	58	97	76	121	274
200-299	143	160	158	159	147	146	165	162	197	223	224	230	265	336	378	461
300+	606	620	636	652	668	683	697	714	730	750	772	794	817	844	877	915
Total area (000 ac)	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833	6833
Tot abs dev balance	7632	7358	6968	6650	6422	6268	5903	5448	5255	4830	4154	3925	3729	3188	2956	2974
Tot abs dev historica	6063	5696	5432	5043	4078	3463	3397	3369	3267	3175	3183	3073	2956	2762	2618	2368
Acres WT@30/10yr (000 ac)		348	330	706	463	212	331	334	168	149	291	319	190	338	294	149
Acres CC@60/10yr (000)		350	559	764	410	656	692	391	338	404	293	191	277	.372	299	331
Acres CC@100/10yr(000)		28	32	69	114	89	142	322	226	426	346	177	208	225	136	103
Tot Acres CC/10yr (000)		378	591	596	300	266	519	569	339	603	524	267	287	381	306	204
WT Vol/10yr MMBF		765	727	1552	1019	465	729	735	369	327	639	701	417	743	646	329
Avg WT Cost/yr (000)		13389	12720	27166	17830	8144	12750	12855	6462	5725	11190	12275	7301	12997	11304	5752
Avg WT Rev/yr (000)		9716	9231	19714	12940	5910	9253	9329	4690	4154	8121	8908	5299	9432	8203	4174
Avg WT VA Rev/yr (000)		13389	12720	27166	17830	8144	12750	12855	6462	5725	11190	12275	7301	12997	11304	5752
Avg Net WT Rev/yr (000)		9716	9231	19714	12940	5910	9253	9329	4690	4154	8121	8908	5299	9432	8203	4174
CC60 V/10yr MMBF		14008	22358	30566	16419	26253	27677	15651	13528	16160	11702	7632	11084	14884	11972	13235
Avg CC60 Cost/yr (000)		187707	299603	409588	220015	351796	370866	209727	181280	216539	156803	102265	148521	199442	160425	177350
Avg Regen Cost/yr (000)		14008	22358	30566	16419	26253	27677	15651	13528	16160	11702	7632	11084	14884	11972	13235
Avg CC60 Rev/yr (000)		336192	536602	733591	394056	630083	664237	375631	324681	387831	280841	183161	266008	357209	287328	317642
Avg VA Rev/yr (000)		187707	299603	409588	220015	351796	370866	209727	181280	216539	156803	102265	148521	199442	160425	177350
Avg Net CC60 Rev/yr (000)		322184	514243	703024	377637	603829	636561	359979	311153	371671	269140	175530	254924	342325	275356	304407
CC100 V/10y MMBF		2264	2663	5637	9366	7315	11676	26459	18547	35008	28432	14558	17060	18517	11177	8473
Avg CC100 Cost/yr (000)		30335	35688	75539	125503	98023	156456	354548	248529	469101	380986	195080	228610	248132	149776	113544
Avg Regen Cost/yr (000)		1102	1296	2743	4558	3580	5682	12875	9025	17035	13835	7084	8302	9011	5439	4123
Avg CC100 Rev/yr (000)		61349	72175	152770	253815	198240	316415	717033	502622	948705	770501	394627	462337	501819	302905	229630
Avg VA Rev/yr (000)		30335	35688	75539	125503	98023	156456	354548	248529	469101	380986	195080	228610	248132	149776	113544
Avg Net CC100 Rev/yr 000		60247	70879	150027	249257	194681	310733	704158	493597	931670	756665	387443	454035	492808	297466	225507
Alt Tot Vol/10yr MMBF		17037	25749	37756	26804	34034	40081	42845	32445	51494	40773	22891	28561	34144	23795	22037
Avg Tot Vol/yr MMBF		1704	2575	3776	2680	3403	4008	4284	3244	5149	4077	2289	2856	3414	2380	2204
Alt Tot Avg Net Rev/yr (000)		392147	594353	872766	639834	804420	956546	######	809440	1307496	#####	571880	714258	844565	581025	534089
Base Tot Vol/10yr MMBF		24792	37812	41479	42184	23600	50400	33080	22640	35280	36120	33280	23600	50400	33080	22640
Avg Tot Vol/yr MMBF		2479	3781	4148	4218	2360	5040	3308	2264	3528	3612	3328	2360	5040	3308	2264
Base Tot Avg Net Rev/yr 000		585369	887497	991748	1032908	542800	1159200	760840	520720	811440	830760	765440	542800	1159200	760840	520720
ALT-ECON MGT (Avg/yr 000)		-193221	-293144	-118982	-393074	261620	-202654	312627	288720	496056	203166	-193560	171458	-314635	-179815	13369
(Cstdiff/Alt vol)*pvf(av/yr)		-88.86252	-54.7631	-9.30603	-26.586	8.5554	-3.45466	3.0607	2.2916	1.52293	0.4836	-0.5038	0.21959	-0.2069	-0.1042	0.00513
Discount Factors		0.78	0.48	0.30	0.16	0.11	0.07	0.04	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00
				Sum of weights =		2.03		Interest rate =		0.05						
RESULTS:																
Sum = Marginal Cost =		-82.66	$/MBF													
Shift to even balance		61														
Shift to historical norm		61														
Alt Avg MMBF/yr		3203														
Base Avg MMBF/yr		3403														
Prescriptions/10yr	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Frac WT @ 30-39	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
Frac CC@60 not CW	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Frac CC @ 100	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
	Price/MBF	Cost/MBF	MBF/Ac	Rev/Ac	Cst/Ac											
WT@30	127	175	2.22	282	389		Avg Ac WT/yr (0-150yr interval, 000 acres)					46				
CC@60	240	134	40.00	9600	5360		Avg Ac CC@60/yr (0-150yr interval, 000 acrs)					63				
site prep					100		Avg Ac CC@100/yr (0-150yr interval, 000 acs)					26				
plant					300											
CC@100	271	134	82.20	22276	11015											
site prep					100											
plant					300											