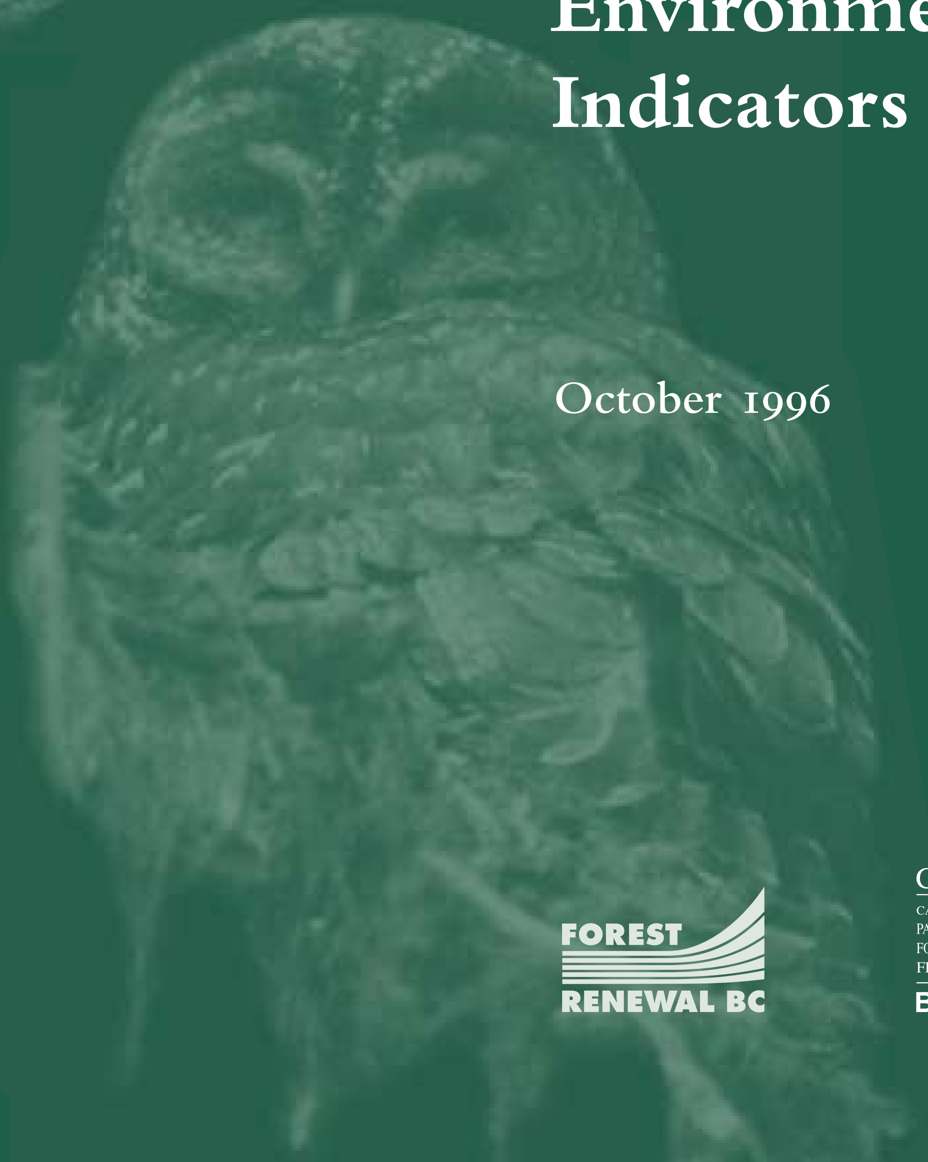
Stand Tending Impacts on Environmental Indicators



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FOREST RENEWAL BC

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PARTNERSHIP AGREEMENT ON
FOREST RESOURCE DEVELOPMENT:
FRDA II

BC

STAND TENDING IMPACTS ON ENVIRONMENTAL INDICATORS

Prepared for

Silviculture Practices Branch
B.C. Ministry of Forests
3rd Floor, 31 Bastion Square
Victoria, B.C. V8W 3E7

Prepared by

Julee A. Greenough and Werner A. Kurz
ESSA Technologies Ltd.
Suite 300, 1765 West 8th Avenue
Vancouver, B.C. V6J 5C6

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For additional copies and/or further information about the Canada-British Columbia Partnership Agreement on Forest Resource Development: FRDA II, contact:

Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5
(604) 363-0600

or

B.C. Ministry of Forests
Research Branch
31 Bastion Square
Victoria, B.C. V8W 3E7
(604) 387-6719

Executive Summary

"Stand tending" refers to a variety of forest treatments—including juvenile spacing, fertilizing, pruning, and commercial thinning—that can be used to enhance timber production. British Columbia's Forest Renewal Plan puts an "immediate priority" on substantially increased investment in these treatments (Government of British Columbia 1994a, pages 7 and 19). The current study examines the environmental implications of these treatments.

Stand tending changes the structure of a stand, and so has implications for many other forest values. The same changes that are positive for some wildlife species are expected to be negative for others. Cougars, for example, prefer stands with more open canopies but hoary bats prefer closed canopies (Ritcey *et al.* 1988). Quantitative data on these environmental costs and benefits are needed in order to optimize the level of investment in stand tending and to direct that investment where it will do the greatest good.

One difficulty in obtaining the necessary data is that the effects of a stand treatment may change in the years following treatment, and may persist for a century or more after treatment. Simulation models provide a means to overcome this difficulty. Existing stand simulation models can take as input the initial stand conditions and management actions, and then project the expected changes in stand structure. What is needed is a means to link the forecast changes in stand structure to changes in other environmental values, such as habitat quality for the cougars and bats mentioned above. The current study shows by example how this link can be developed and applied.

In this study, the Tree and Stand Simulator (TASS; Mitchell 1975) was used to forecast the changes in stand structure following stand tending. A literature search and interviews with 46 resource experts in British Columbia were used to identify 25 environmental indicators that are sensitive to changes in stand structure, and to quantify the structural dependencies of these indicators. This information was then coupled to the TASS output to show how the environmental indicators were expected to change over time under 89 different stand tending regimes. Some 'highlights' of this analysis are presented here; the full report is available elsewhere (Greenough *et al.* 1995).[1]

The results show the expected trade-offs: most stand tending regimes improve some environmental values at the expense of others. For example, spacing a stand can increase the production of understorey vegetation (because of increased light availability at ground level), but reduces the number of snags

1 Greenough, J.A., W.A. Kurz, and C.L. Murray. 1995. The environmental impacts of incremental silviculture. B.C. Min. For., Silv. Branch, Victoria, B.C. Contract report.

produced for decades afterwards (because suppressed trees that would have later died have been removed from the stand). There are some notable exceptions to the rule, however. For example, compared to the untended condition, many of the stand treatments tested improve habitat quality for *both* the cougar and the hoary bat mentioned above, in spite of the opposing canopy cover preferences of these species. Note that the net effect of a treatment will depend not just on stand conditions after treatment, but also on the rotation length—harvest age—chosen with that treatment.

A number of the indicators employed in this study were designed to represent "old-growth" dependent values (e.g., spotted owl habitat quality, minimum habitat conditions for pileated woodpeckers, and an index of "functional maturity"). The analysis of these indicators suggests that no stand tending regime can provide all of the required old-growth values under short rotation cycles. However, the analysis also suggests that appropriate stand tending regimes, in combination with extended rotation lengths, could provide these values sooner than would otherwise have been the case.

The existence of environmental trade-offs means that no one type of stand or stand treatment can provide for the needs of all wildlife species. This means that the 'best treatment option' from an economic perspective should not be uniformly applied to all stands. It also means that management planning for the maintenance of biodiversity must be done at a landscape-level, and not just on a stand-by-stand basis. This report describes two examples that show how stand-level environmental indicators can contribute to the necessary landscape-level analyses.

Comparative analyses of the impacts of different stand tending regimes, as are presented here, can be used not just to choose between different regimes, but to design novel regimes. Some of the results presented here are for regimes designed specifically to meet environmental goals that were not met by any of the conventional regimes initially tested.

This study serves as an illustration of how environmental indicators can be coupled with stand simulation models to provide quantitative data on the expected impact of stand tending. This approach could form the basis of a new decision support tool that would help managers assess the environmental and economic trade-offs inherent in integrated resource management. The approach offers an objective, scientifically credible, and reproducible means of impact assessment. The indicators presented here as examples should be refined and updated as more information becomes available. As is discussed in the final section of the report, future analyses would particularly benefit from the development of more accurate models of understorey vegetation and snags, and more sophisticated landscape-level models.

Acknowledgements

The environmental indicators used in this analysis were developed in consultation with 46 resource experts working in British Columbia. These people, who are listed in Appendix 1, also provided thoughtful comments that form the basis of section 4 and some other parts of the discussion. They should be thanked for their commitment to comprehensive resource management.

The study benefited from the guidance of a “core group” consisting of Nancy Densmore, Tony Hamilton, Dean Mills, Jeff Stone, and Ralph Winter. The efforts of this core group were important in setting the scope of the study and developing the list of expert contacts.

All of the TASS (Tree and Stand Simulator) data used in this analysis were provided by Ken Polsson and Jeff Stone at the B.C. Ministry of Forests, Research Branch. Both Jeff and Ken were exceptionally obliging in meeting the needs of this study. Ken developed a special TASS output format to provide the data required for the calculation of environmental indicators. In order to help devise tending regimes for expected “environmental benefits,” Ken also adapted the simulation model so that the timing and level of thinning could be contingent on canopy closure targets. Jeff adapted a model of snag dynamics to convert the dead tree list generated by TASS into estimates of the number and size of standing snags, and the volume of coarse woody debris input in different size class. Moreover, both Jeff and Ken worked to provide the requested information on the shortest possible timeline.

Earlier versions of this report have been reviewed by Nancy Densmore, Tony Hamilton, Dean Mills, Jeff Stone, Tom Sullivan, Oliver Thomae, and Les Peterson. Their comments have helped improve this version of the report.

Carol Murray and Ian Parnell helped conduct telephone interviews with the resource experts who were consulted on this project. Ian also helped organize the literature search. The report and some of the figures were produced by Kelly Robson.

Thanks are extended to Nancy Densmore of the Silviculture Practices Branch and to TM Communications of Victoria for compiling and producing this publication.

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1 Introduction

"Stand tending" refers to a variety of treatments that can be used to enhance timber production. These treatments include the *spacing* of juvenile trees (pre-commercial thinning), *commercial thinning* of older trees, *fertilizing*, and *pruning*. As a result of enhanced timber production and reduced losses to forest disease agents, stand tending activities may help alleviate the expected decline in timber availability and compensate for the removal of operable land elsewhere. British Columbia's Forest Renewal Plan puts an immediate priority on substantially increased investment in stand tending operations (Government of British Columbia 1994a, pages 7 and 19).

However, B.C.'s new Forest Practices Code (Government of British Columbia 1994b, 1995a) places many requirements on the development of stand tending regimes. Such silvicultural systems must, for example, be designed to achieve the "objectives for biological diversity contained in the forest development plan for the area" (*Operational Planning Regulation*, Section 43(c)), or other approved objectives for fish and wildlife habitat where such plans are not in place (see the *Biodiversity Guidebook* and the *Forest Development Plan Guidebook* that accompany the Code; Government of British Columbia, 1995b, 1995c). Under this Code, there will be a continuing need for objective, quantitative, scientifically credible, and reproducible methods to predict the environmental impact of different silvicultural regimes. The current study, funded under the Canada-British Columbia Partnership Agreement on Forest Resource Development (FRDA II), was designed to address this need.

1.1 Overstorey Response to Stand Tending

Table 1 summarizes the effect of different stand tending treatments on overstorey development and stand structure. By reducing stand density, spacing and commercial thinning both reduce competition between trees for light, water, and soil nutrients. This results in reduced mortality and an increased growth rate for the remaining trees (see Figure 1).

Pruning, the removal of all branches below a specified height, is like thinning in that it opens the canopy and reduces competition for light. However, operational pruning removes a sufficiently large portion of the crown of each tree that diameter growth is reduced for some time.

Fertilizing, on the other hand, reduces competition for nutrients. This results in an increased rate of tree growth, especially on nutrient-poor sites. However, because fertilizing increases the growth rate without reducing stand density, fertilization leads to increased canopy closure and an accelerated rate of tree mortality (compared to an otherwise similar unfertilized stand).

TABLE 1. A characterization of overstorey response to stand tending treatments. "+" indicates that an overstorey characteristic is increased by the treatment, and "-" indicates that it is decreased. "0" indicates that density is not immediately affected by the treatment, although later density values would reflect any treatment-induced change in the mortality rate.

	Spacing	Commercial thinning	Pruning	Fertilizing
Density (stems/ha)	–	–	0	0
Canopy closure (%)	–	–	–	+
Diameter growth rate (cm)	+	+	–	+
Mortality rate (% of stems/yr)	–	–	0	+

FIGURE 1. Stand tending can affect many characteristics of the forest. The two photos here both show stands of 44-year-old Douglas-fir near Campbell River on Vancouver Island. The stand in the top photo is untended, while the stand in the lower photo has been thinned since age 21 to maintain tree density at 50% of the basal area of the untreated stand. Trees are generally larger in the thinned stand, even though the thinning method used here was not biased with respect to tree size. As suggested by the fallen snag across the centre of the top photo, however, more dead wood is produced in the unthinned stand. Note too how the understorey vegetation differs between the two stands.

Photos: B.C. Ministry of Forests, from the Sayward 'LOGS' study.

1.2 Environmental Implications of Stand Tending

Although its purpose is to influence the growth and mortality rates of commercial trees, stand tending has implications for many other forest values. Many of these implications are expected to be positive. Opening the canopy, for example, allows more light to reach the ground and could encourage greater forage production. The occurrence of most vertebrate species is considered to depend more on the occurrence of particular structural attributes and vegetation species than on stand age *per se* (see Steventon 1994 and references therein). Thus stand tending could potentially be used to create desired structural characteristics and alleviate habitat supply problems. Accelerating the growth of trees could allow the stand to function more like old growth at an earlier age.

However, the same changes that are positive for some forest values can be negative for many others. For example, Table 2 shows how different species of carnivore are affected when a pole-sapling stand is thinned from dense to moderate canopy cover (as occurs during juvenile spacing). Opening the canopy clearly does not benefit in the short term those species that prefer a closed canopy. Moreover, stand tending may have direct environmental effects other than its effect on overstorey characteristics.

Table 2. Impact of thinning on some carnivore species in the dry interior of B.C. The table shows the expected impact on individual species if a "pole-sapling" stand (i.e., a stand in which the mean tree diameter is less than 25 cm at breast height) of Douglas-fir–lodgepole pine is thinned from dense canopy cover to moderate cover (i.e., 100% cover down to 26–65% cover). Species in the "unaffected" column are those that are not expected to experience any net cost or benefit immediately; changes in stand development may affect later use of the stand. The classification of each species considers both its feeding and reproductive requirements. The table is based on information in the *Wildlife Habitat Handbook* (Ritcey *et al.* 1988). It lists all carnivore species that are included in the handbook and use Douglas-fir–lodgepole pine stands.

Habitat quality decreased	Habitat quality unaffected	Habitat quality improved
Marten Fisher Lynx	Gray wolf Grizzly bear Ermine	Coyote Black bear Long-tailed weasel Cougar Bobcat

TASS: The Tree & Stand Simulator

The Tree and Stand Simulator (TASS; Mitchell 1975) models the fate of each individual tree in a single-species, even-aged sample plot created by either natural regeneration or planting (typically a one hectare plot). To do this, the model simulates the three-dimensional shape of the crown of each tree. Each crown may grow and contract asymmetrically in response to competition with other crowns. Every year, the model adds a layer of new foliage to each crown, and older layers of foliage become progressively less productive until they are eventually shed. The model uses the amount of foliage remaining on each tree to calculate how much new wood growth will be added to that tree's stem. Growth is reduced if the volume of foliage on the tree becomes too small to support the full potential wood growth.

The model simulates the 'random' mortality of seedlings and young trees during root establishment. It also creates random 'genetic variation' in the height growth and crown size of trees, so that some trees will grow better than others. The lower branches of each tree die-back as they are shaded by other branches, and trees stop growing and may eventually 'die' when their crown is over-topped by adjacent crowns.

Permanent sample plot data (14 000 data points) have been used to calibrate TASS for a variety of tree species growing on different quality sites (as measured by site index). The model is also equipped to simulate the effect of different stand tending regimes, and has been validated (see Mitchell and Cameron 1985, and Kellogg 1989 for further details). The model output describes in detail the overstorey component of stand vegetation; it lists stand density, percent canopy closure, tree height and diameter distributions, crown dimensions, foliage volume, bole characteristics, and tree mortality rates. Through model extensions, TASS can describe the volume of lumber that could be obtained from each tree, and the quality of that lumber (e.g., proportion of high- density, mature wood, and the number and size of knots).

Clearly, quantitative data on the environmental impacts of stand tending are needed in order to optimize the level of investment in stand tending and direct that investment where it will be of greatest benefit. The next section outlines how this study was designed to provide some of the necessary data.

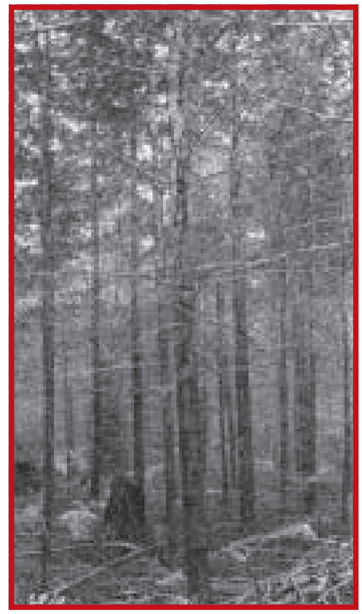
1.3 Design of the Current Study

Although the general overstorey response to stand tending is qualitatively predictable, quantifying the impact of any stand treatment is complicated by the fact that the magnitude of the effect on each stand will depend on the intensity of treatment, whether other treatments are also applied to the stand, and the character of the stand before treatment. Furthermore, the magnitude of effect will change over time following treatment (see Figure 2 for example). For these reasons, the current study employs a stand simulation model to predict the overstorey response.

The particular model chosen for this study was TASS (Mitchell 1975), the Tree and Stand Simulator in use at the B.C. Ministry of Forests. Readers who are unfamiliar with TASS may wish to refer to the sidebar here for a brief introduction.

Basically, TASS is a model that takes as input some initial stand conditions (e.g., site index, tree species, initial stand density, height and diameter distribution) and management actions, and then outputs the expected change in stand structure over time (see Figure 3). As shown in Figure 4, what is needed to

Figure 2. Assessing the impact of stand tending is complicated by the fact that the apparent effects change as the treated stands develop over time. The two photos here provide an example of how a single stand has evolved following treatment. The top photo shows a 19-year-old Douglas-fir stand near Cowichan Lake on Vancouver Island. The photo was taken in 1930, one year after the first of several thinning operations had removed the smallest trees in the stand. Note that the forest floor is covered with fine woody debris created by the thinning, and very little understorey vegetation is apparent. The size of the remaining trees would, of course, have changed little in the one year since the thinning. The bottom photo shows the same stand in 1994, at the age of 83. By this time, the trees are much larger and a rich understorey has developed.



Photos: B.C. Ministry of Forests, from the Schenstrom plots, Mesachie Lake.

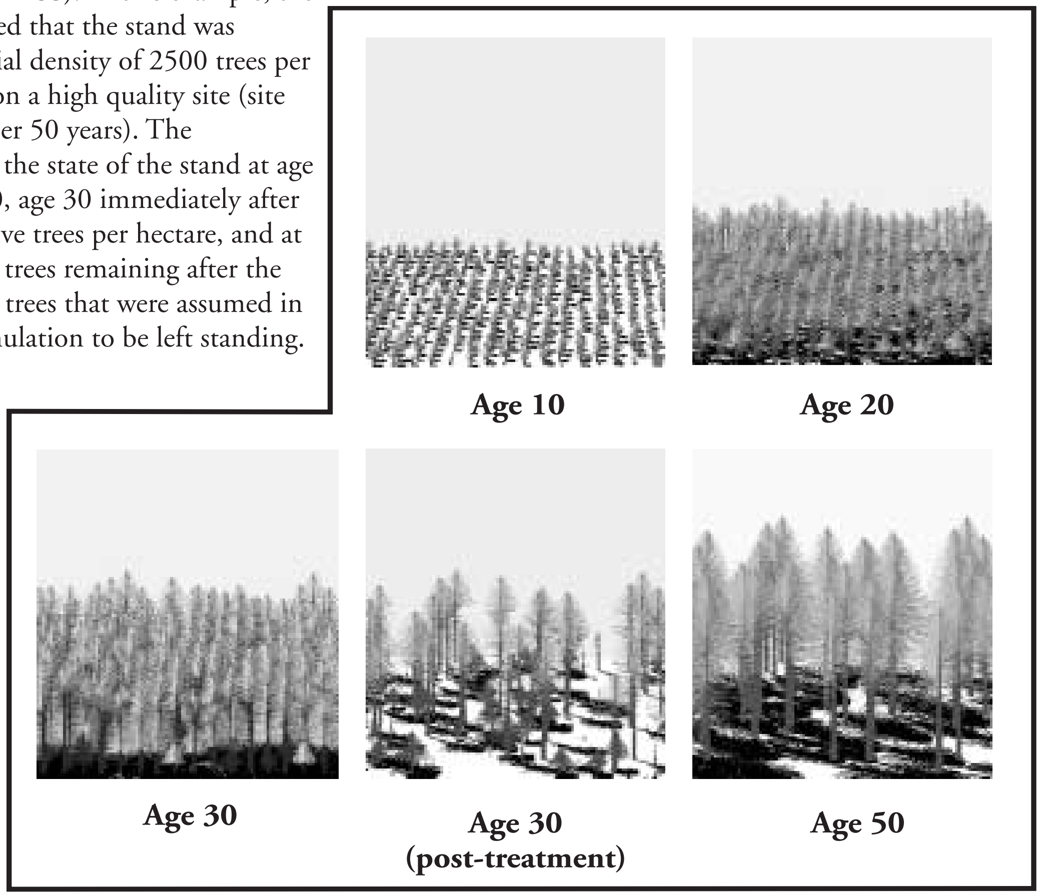
infer the environmental impacts of the different regimes is a second type of model. These models should take as their input the stand characteristics projected by TASS and then output the expected change in environmental indicators (see Figure 4).

The first step towards developing these models is to identify environmental indicators that are sensitive to changes in stand structure. The second step is to quantify the relationship between the two: how do changes in stand structure affect the value of the indicator? That quantitative relationship can then be used in combination with data on expected stand conditions to forecast changes in the indicator value. Showing how this can be done, and the results used to suggest stand tending regimes that could be used to improve habitat quality for various species, was the main goal of the current study. The indicators and indicator-relationships presented here can be refined and updated as more information becomes available.

Note that this study is not intended to be a comprehensive assessment of the environmental impacts of stand tending or of any particular stand tending regime.[2]

[2] Greenough *et al.* (1995) provide a more extensive discussion of the potential impacts that are not addressed in this study, including both other impacts that may arise from the induced changes in overstorey conditions, and impacts that are independent of overstorey changes.

Figure 3. Stand simulation models provide a means to predict the effect of proposed tending regimes throughout the course of stand development, and under varied ecological conditions. The series of illustrations here show the development of a stand of coastal Douglas-fir as simulated by the Tree and Stand Simulator (TASS). In this example, the simulation assumed that the stand was planted to an initial density of 2500 trees per hectare, and was on a high quality site (site index 36 metres per 50 years). The illustrations show the state of the stand at age 10, age 20, age 30, age 30 immediately after thinning to 200 live trees per hectare, and at age 50. The small trees remaining after the thinning are dead trees that were assumed in this particular simulation to be left standing.



Computer graphics, Ken Polsson, MoF.

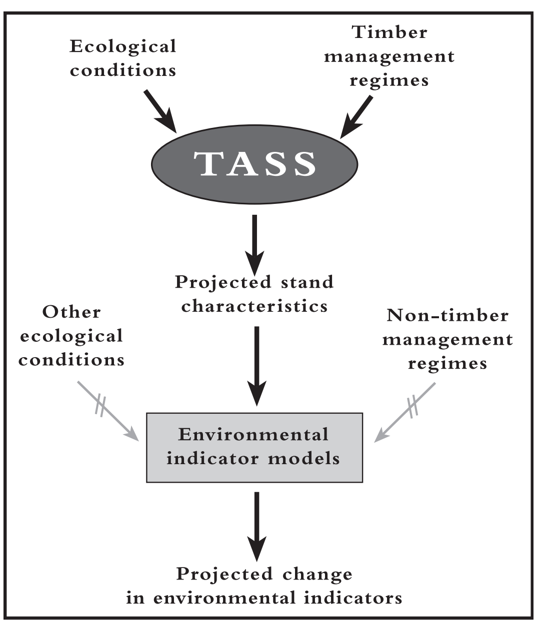


Figure 4. Conceptual design of this study. See text for explanation. Note that many potential environmental indicators depend in part on ecological conditions and management actions that could not be incorporated in the current analysis. These considerations should be incorporated in future indicator models as more information becomes available.

2 Methods

This section summarizes the procedures that were used to develop environmental indicators and analyze TASS stand data under different stand tending regimes. A more detailed description of these procedures is available in Greenough *et al.* (1995).

2.1 Selection of Environmental Indicators

To ensure that this analysis would be as well-balanced as possible—and based on the best available field data and methodology—46 resource experts in British Columbia were interviewed on the choice of environmental indicators and the relationship between those indicators and overstorey conditions. These contributors are listed in Appendix 1. They include research scientists and resource managers from the B.C. Ministry of Forests; the B.C. Ministry of Environment, Lands and Parks; the Canadian Forest Service; the Canadian Wildlife Service; the Canadian Department of Fisheries and Oceans; and the University of British Columbia; and some private resource consultants.

In the end, the study incorporated *all* of the indicators that were suggested by the interviewed contacts and for which the dependence on overstorey conditions could be quantified. In addition, two indicators were selected from the species in the *Wildlife Habitat Handbook* (Ritcey *et al.* 1988) on the basis of their complementarity—their joint ability to represent contrasting habitat requirements—and sensitivity to overstorey conditions. A total of 25 indicators are analyzed in the full report (Greenough *et al.* 1995); a subset of these is considered here.

2.2 Development of Indicator Relationships

The relationships between each environmental indicator and stand conditions were determined through consultation with the interviewed resource experts and literature reviews. The relationships that determine the value of each of the indicators discussed in this report are described in Appendix 2. Only in the case of pileated woodpeckers were conflicting stand relationships proposed (see Appendix 2). Since it was beyond the scope of the current study to resolve the debate over how best to measure woodpecker habitat quality, the study adopted all four suggested measures of habitat quality, from the least to the most conservative.

2.3 Selection of Scenarios for Analysis

The analysis was targeted towards the tree species that have the highest priority for receiving stand tending. According to the B.C. Ministry of Forests' *Silviculture Policy and Procedures Manual* (B.C. MoF 1994), these species are Douglas-fir and western hemlock on the coast, and Douglas-fir and lodgepole pine in the interior. The full study considered the effects of four stand treatments (spacing, pruning, fertilizing, and commercial thinning) and some combined treatments on the four priority species, given a variety of initial conditions and site qualities (as measured by site indices), and assuming a variety of treatment intensities and timing options. This required a total of 78 stand simulations (or TASS model runs, as they are referred to below). An additional 11 runs were added later to test the impact of some non-standard tending regimes (see section 2.5).

Appendix 3 provides a description of all 89 regimes. Note that all of the thinning treatments in all regimes involve thinning "from below." That is, they are thinnings which preferentially remove the smallest, most suppressed trees in the stand. Note also that runs 14 to 16 differ from all the other runs in that all existing snags are assumed to be felled on each stand entry in these three runs only.

2.4 Analysis of TASS Data

Each of the environmental indicators requires particular stand data for its calculation (e.g., the number of live trees greater than 37.5 cm dbh, or the average crown length of the trees removed by thinning). These information requirements determined the type and format of TASS data that were needed for the analysis. Jeff Stone (B.C. MoF) adapted an extension to TASS to provide the necessary snag data, and Ken Polsson (B.C. MoF) created a special TASS output format for all the required data.

A QuickBasic™ program was developed to read in the TASS output and calculate the value of each environmental indicator. This program fills the role of the second box in Figure 4. It creates two types of output files. One file shows average indicator values for each regime, assuming a number of different rotation lengths. The other file shows, for every tending regime, the value of each indicator in each time step of the simulation. A variety of commercial graphics programs was used to format the data for presentation in this report.

2.5 Design of Regimes for Environmental Benefit

Once environmental indicator values had been calculated for the initial seventy-eight, "standard" tending regimes, the results were examined with an eye to creating tending regimes for greater environmental benefits. Where high indicator values had not been obtained under any standard regime, more extreme regimes were suggested. Where standard regimes already produced high indicator values, consideration was given to regimes that might produce the same level of environmental benefit from a lower level of effort in tending.

The regimes created for their expected environmental benefits are described in Appendix 3 as runs 101 to 112.

3 Results and Discussion

This section presents an overview of the results of the analysis. A more detailed presentation of the results, which considers the value of all 25 environmental indicators under all 89 scenarios, is available in Greenough *et al.* (1995). The intent here is to provide examples that illustrate the effects of the different stand treatments. This is largely a story about trade-offs—most stand tending regimes improve some environmental values at the expense of others—but there are some notable exceptions.

3.1 Introduction to the Results

Figure 5 illustrates some of the output of this analysis. The figure shows the change over time in some stand conditions (canopy closure and total stand volume) that is forecast by TASS, and the resulting change in some environmental indicators (snags less than 15 cm in diameter, snags greater than 15 cm in diameter, the annual input of coarse woody debris, and the average diameter of that debris), when a lodgepole pine stand is treated with different levels of commercial thinning.

Two immediate effects of commercial thinning are evident in Figure 5. First, canopy closure is decreased, and decreased more in the case of a more intense thinning. Second, of course, stand volume is decreased by the volume of the removed trees. As dramatic as these effects is the more-or-less complete loss of small snags within five years of the thinning operation. This loss occurs because the snags that exist at the time of thinning are too small to persist for long, and no new snags are created for some time because competition between the remaining trees is reduced by the thinning. Eventually the canopy closes in

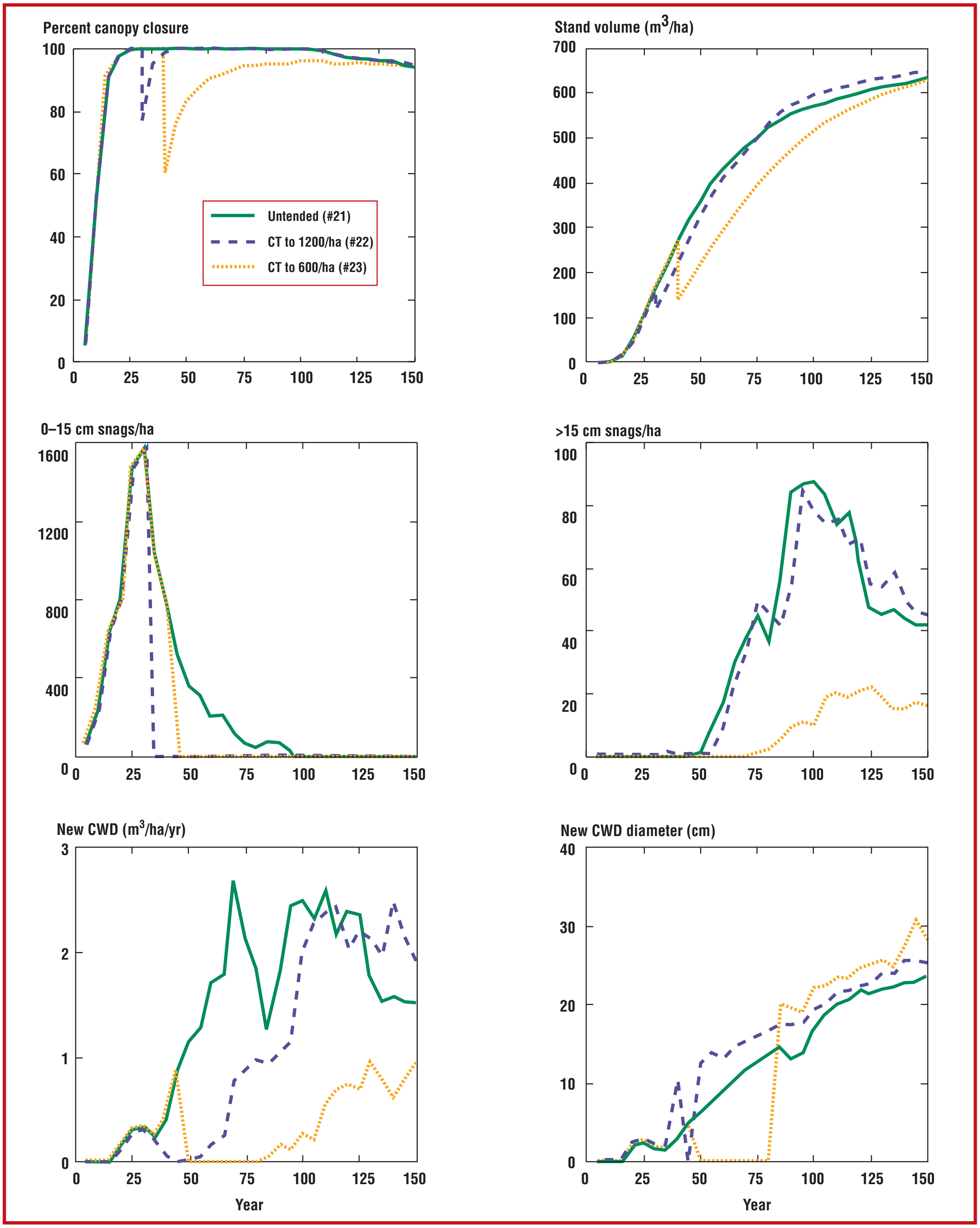


Figure 5. The response over time of some stand conditions and environmental indicators to commercial thinning. The data are for a lodgepole pine stand growing on a site with site index 22 from an initial density of 10 000 stems/ha. The different lines on each graph show the results of 3 different stand tending regimes: no tending (from run 21), commercial thinning to 1200 stems/ha at age 30 (from run 22), and commercial thinning to 600 stems/ha at age 40 (from run 23). "New CWD" is the volume of coarse woody debris that is input annually to the stand through breakage of snags. See text for further explanation.

enough that the remaining trees are again brought into competition with one another and new snags are created (in the larger size category now), but the time at which this happens is delayed significantly by the more intense thinning.

As a consequence of the decrease in snag production in more heavily thinned stands, the volume of coarse woody debris created each year from the breakage of snags is reduced. However, the bottom right graph in Figure 5 shows another consequence of the reduction in competition in more heavily thinned stands: the debris that is created is of a larger diameter than debris in less heavily thinned stands of the same age.

Although the data in Figure 5 are for a stand with a particular site index, stands with different site indices show qualitatively the same dynamics. The main influence of site index is on the pace of stand development, which is accelerated in stands with higher site indices.

3.2 Pileated Woodpecker Habitat and Size vs. Quantity of Dead Wood

The volume and size of dead wood in a stand can be important for many environmental values (Figure 6). Coarse woody debris (CWD) on the forest floor fills many roles: it is a site for nitrogen fixation and tree regeneration (i.e., nurse logs); it retains soil moisture; it provides habitat for fungi, insects, and amphibians, and is thus a foraging substrate for many birds; and it provides shelter and access beneath the snow for marten, weasels, mice, voles, snowshoe

Photo: B.C. Environment

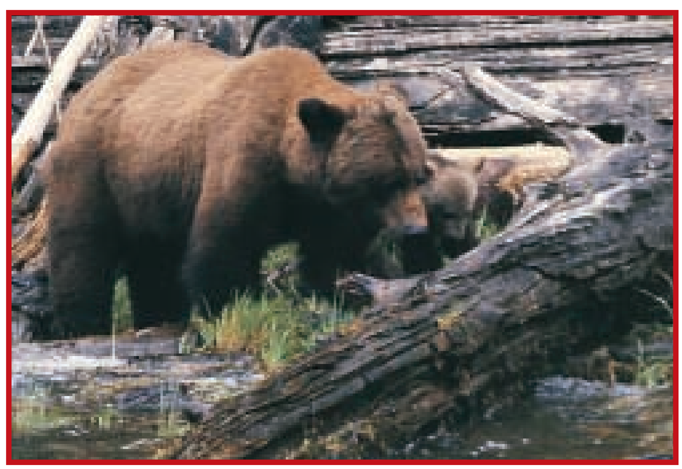


Photo: Stefan Himmer

Figure 6. Dead wood plays many roles in the forest ecosystem. Here a broken snag provides a nest site for an osprey, and a fallen log is inspected by an adult grizzly bear and her cub, probably in a search for resident insect colonies. Both the size and amount of dead wood in a stand influence other environmental values, and both variables can be affected by stand tending.

hares and squirrels (Park and McCulloch 1993). Moreover, woody debris in streams is important in maintaining ripple and pool sections for fish spawning and rearing habitat.

According to many of the resource experts that were interviewed for this study, a shortage of CWD is expected in second growth forests. In most ecosystem types, past harvesting has left much less debris in the stand than was formerly left by natural disturbances (including fire), and this debris shortage could have long-term effects on ecosystem function. The volume and size of debris expected under different stand tending regimes is therefore of considerable interest.

As suggested by Figure 7, the results of this analysis show a clear trade-off between the volume of CWD created under any given management regime and the average diameter of that debris. This trade-off is illustrated in Figure 7, which shows the results of all of the runs that were done with coastal Douglas--fir on similar site indices. The right-most circle and triangle in this figure show the untended runs on site index 36 and 35, respectively. As the figure shows, *all* stand treatments reduce the total volume of debris created over the rotation. (The total volume is proportional to the average annual debris input shown in the figure, because all points are for the same rotation length). Many stand treatments, however, appear to increase the mean debris size in direct proportion to the reduction in debris volume.

If stand tending decreases the volume of coarse woody debris present in a stand but increases the average size of that debris, what is its net effect on wildlife? Coho salmon habitat quality, for example, increases with both the

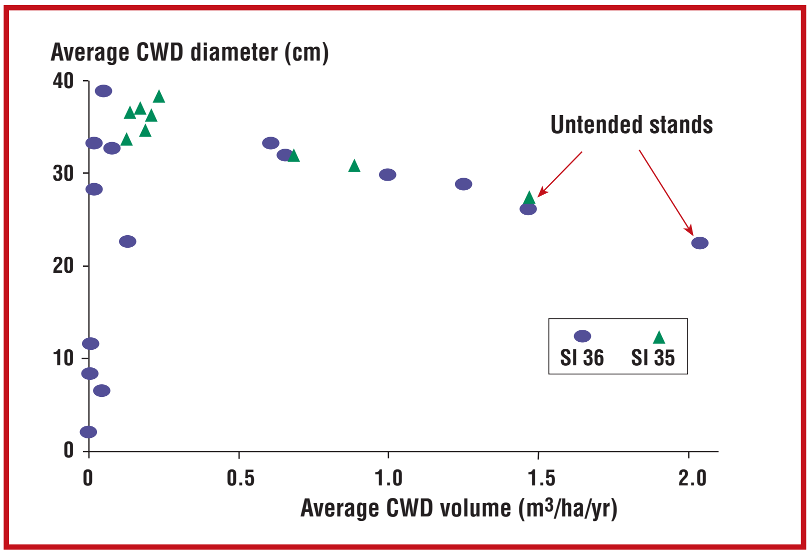


Figure 7. The trade-off between the size of debris and the volume of debris created under different management regimes. The data represent all the runs with coastal Douglas-fir on site indices 35 and 36, at the end of a 150-year rotation. The debris volumes shown do not include debris created by spacing, which was usually less than 3% of the total debris volume produced in untended stands (Greenough *et al.* 1995). The size of debris shown is a volume-weighted average for each rotation. The mean size of debris is more variable at lower average debris volumes because the results can be heavily influenced by whether or not one large snag happens to fall before the end of the rotation. Note that these runs start from different initial densities (shown in Appendix 3), but the results nevertheless conform to a single, linear relationship over a large range of debris volumes. See text for interpretation.

size of debris and the volume of debris according to the resource experts interviewed for this study. So is it better to have a lot of small debris, or a smaller amount of large debris? The habitat quality indicators for pileated woodpeckers (see Figure 8) provide one way to weigh the relative merits of debris size and debris volume. These indicators depend on both the size and number of snags present in the stand. Snag dynamics under different regimes are analogous to coarse woody debris dynamics since all snags become debris input when they fall.

Photo: Wildlife Tree Committee of B.C.

Figure 8. If both more snags and larger snags are desirable in the ecosystem, what is the net effect of producing fewer but larger snags? The habitat quality indicator developed for the pileated woodpecker, shown here, provides a means to weigh the importance of snag size versus snag abundance. The analysis suggested that high habitat values for this woodpecker were obtained earliest in stands growing at a moderate density.

Consider Figure 9. This figure shows pileated woodpecker nesting habitat quality at different points in time during the rotation. The solid lines in the figure show the results for three untended stands that differ in initial density. Compared to the dense stand (the solid squares in the figure), the stand at moderate density (solid triangles) attains higher habitat values sooner in the rotation. This is because trees grow more quickly in the more open stand, and are thus available to become large snags at an earlier age. However, the sparse stand (solid circles) takes longer than either of the other stands to provide high habitat values. This is the trade-off between the size and volume of dead wood created: trees get larger sooner in the least dense stand, but competition between trees is so low that few of them die and pileated woodpecker habitat quality remains low until later in the rotation.

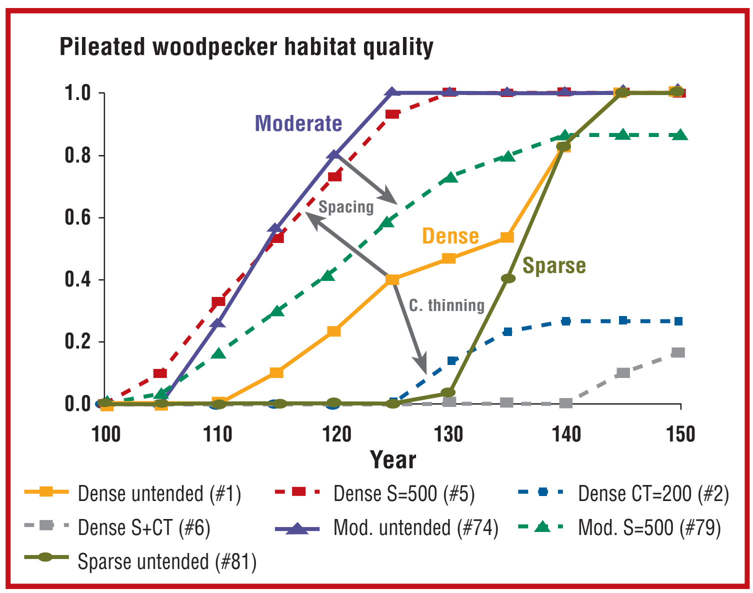


Figure 9. Pileated woodpecker nesting habitat quality as a function of stand age, for different management regimes. Solid lines have been used to show the results for untended stands; broken lines show the results for comparable tended stands. The run number represented by each line is shown in parentheses in the legend. All of the runs are for coastal Douglas-fir. Runs 1, 2, 5, and 6—the dense stands—all assume site index 36, while all the other runs use site index 35. Suitable habitat did not exist prior to 100 years in any of these runs. See text for discussion.

The effects of different stand tending regimes may be understood in light of the density effects just described. As shown in Figure 9, spacing the dense stand allows it to attain high habitat values as early as the stand with moderate initial density. However, commercial thinning the stand reduces habitat values. The remaining density is simply too low to maintain the necessary mortality rates. Commercial thinning the stand in combination with juvenile spacing gives even poorer results (even though the commercial thinning density is the same). Even spacing alone suppresses habitat values in the stand that begins at a more moderate density.

3.3 Grizzly Habitat and Understorey vs. Debris

The trade-off described in the previous section between CWD size and volume reflects the underlying relationship of both variables to canopy density: trees generally grow fastest under the open conditions where their mortality is lowest. Understorey vegetation also grows best under a more open canopy, so it should not be surprising to find a trade-off between understorey production and debris volume like the trade-off between debris size and debris volume.

The anticipated trade-off is evident in the following two figures, although some stand treatments do create exceptions. Figure 10 shows the relationship between understorey and debris production in lodgepole pine stands. As the figure shows, the higher the initial density in an untended stand, the greater the production of debris but the lower the production of understorey shrubs and herbs. Spacing greatly reduces debris production, and reduces it more when the spacing is to lower densities (points 32, 33, 34, and 35 in the figure show a range of post-thinning densities from 2300 stems/ha to 500 stems/ha, respectively). The extremely wide spacings, however, are associated with some increase in the production of shrubs and herbs. The increase is substantial shortly after spacing, although it is reflected in only a modest increase in the rotation-average production, which is shown in the figure. Among the regimes shown in the figure, the most significant gain in shrub and herb production is associated with pruning a stand following thinning (points 44 and 45). In this case, the increase in understorey growth is achieved with little or no additional reduction in debris production.

From an economic perspective, runs 31 and 35 in Figure 10 show the 'best treatment options' for lodgepole pine stands with that initial density on this site index (Massie 1995).[3] Which regime is preferred depends on which economic assumptions one wishes to make. Run 31, in which the stand was left untended, would be the preferred option if no real timber price increase were expected

[3] Massie, M.R.C. 1995. Economic component of stand tending. B.C. Min. For., Silv. Branch, Victoria, B.C.

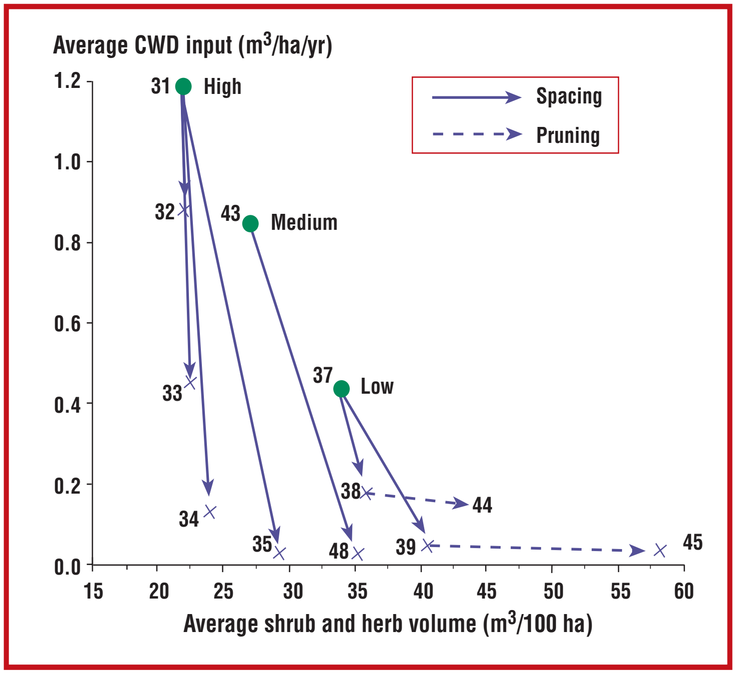


FIGURE 10. The influence of stand tending on understorey and debris production in lodgepole pine. The data are for stands growing at site index 25, and are averaged over a 75-year rotation length. The figure shows the run number associated with each data point. The closed circles labelled 31, 43, and 37 are for untended stands at different initial densities, as indicated. Solid arrows show the effect of spacing these stands to different levels, and dashed arrows show the effect of pruning.

over the course of the rotation or a 1% increase were expected over the next 20 years. Run 35 would be preferred if a 1% increase over the entire rotation were expected for large logs only. As is clear from Figure 10, run 31 provides high coarse woody debris production, run 35 provides more understorey forage production, and neither one of these potential 'best treatment options' would on its own provide both the forage and the debris that different wildlife species require. The general consequence of such environmental trade-offs is that no one treatment option should be uniformally applied across the entire landscape. For any given site quality and set of economic assumptions, however, one particular regime will be preferred from an economic perspective. Using a variety of treatments, or no treatment, will require *economic* trade-offs.

Figure 11 shows the relationship between coarse woody debris production and understorey forage production in coastal Douglas-fir stands. In this case, the indicator of understorey production is percent shrub cover. As explained in Appendix 2, these shrubs are not believed to grow back if the canopy has been closed for more than 10 years prior to thinning. Thus commercial thinning alone has no effect on shrub cover; it occurs too late to restore the lost shrubs. Commercial thinning, therefore, reduces debris production without providing any increase in shrub cover. Spacing, because it occurs before viable shrubs are lost from the stand, provides a modest increase in the average shrub production over the rotation. Following spacing with commercial thinning provides some additional shrub production, but at the expense of virtually eliminating any further debris production over the rest of the rotation. Additional runs suggested that fertilization could restore some of the lost debris production (by accelerating the onset of competition, as described in section 1). These runs are not shown here because the stand relationship used in this analysis to predict understorey growth is not suitable for predicting understorey response to fertilization (Appendix 2). From an economic perspective, run 76 in this figure is the best treatment option for stands with that initial density on that site index under all of the three alternative assumptions described above (Massie 1995).

One consequence of the trade-off between debris production and the production of understorey vegetation is shown in Figure 12. As described in Appendix 2, feeding habitat quality for grizzly bears increases with the amount of shrub cover in western hemlock stands. "Functional maturity," on the other hand, requires the presence of coarse woody debris, large snags and large trees (Steventon 1994). Figure 12 shows that the application of different spacing regimes can strongly influence both the quality of grizzly feeding habitat and the age of functional maturity in a stand (See Figure 13). However, the spacing regimes that allow the stand to reach functional maturity at the earliest age (shown in the figure as the number of years in that condition prior to age 150) provide only low grizzly feeding habitat values in the first part of the rotation. Conversely, the regimes that provide the highest grizzly feeding habitat values early in the rotation delay the onset of functional maturity beyond the 150 years considered in this analysis. This results because forage production is better in more widely spaced stands while snag recruitment is delayed in these stands. This implies that no one type of stand or stand treatment should be expected on its own to meet the needs of all wildlife species. In other words, there is not simply one best way to tend all of the stands in the landscape.

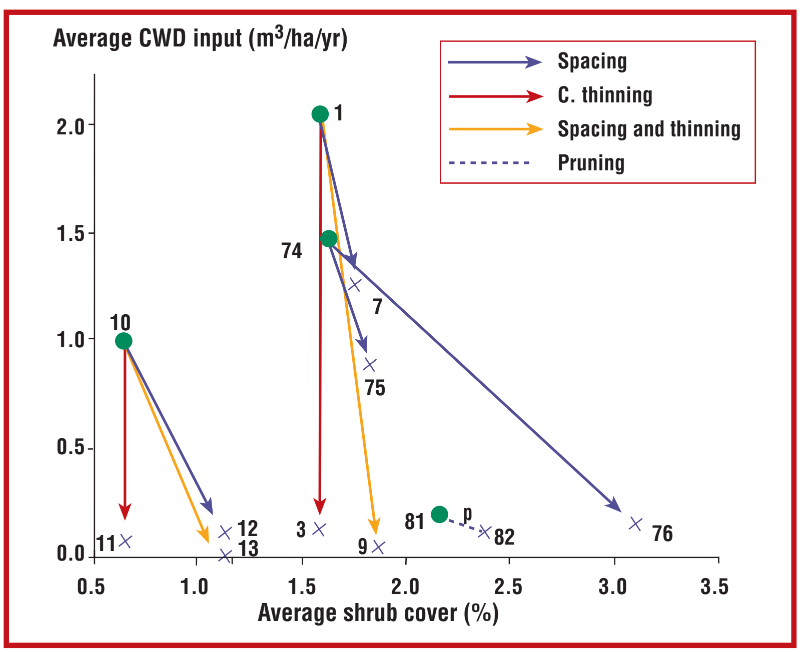


Figure 11. The influence of thinning on understorey and coarse woody debris production in coastal Douglas-fir. The data are the average values over a 150-year rotation. The run number associated with each data point is shown. The points labelled 10, 1, 74, and 81 represent untended stands at different initial densities. As in Figure 10, the numbers indicate the run number associated with each data point. Points 10 to 13 represent stands growing at site index 30, points 74 to 82 represent stands at site index 35, and all other points are for stands at site index 36. The arrows show the effect of different treatments, as labelled.

FIGURE 12. The effect of spacing on grizzly feeding habitat and "functional maturity" (the presence of old growth characteristics) in western hemlock. The figure shows the relationship between grizzly feeding habitat quality in the first part of the rotation (to age 75) and the number of years that the stand will qualify as functionally mature later in the rotation (up to age 150). The figure shows the range of effects that can be achieved through stand tending. The data are for stands growing at site index 30, and the run number associated with each data point is shown. The size of each marker square is related to the intensity of spacing applied in each stand treatment; smaller markers indicate a lower residual density of trees remaining after spacing. The single '*' indicates that the stand was both spaced and pruned, and the double '**' indicates that the stands were spaced repeatedly. See text for interpretation.

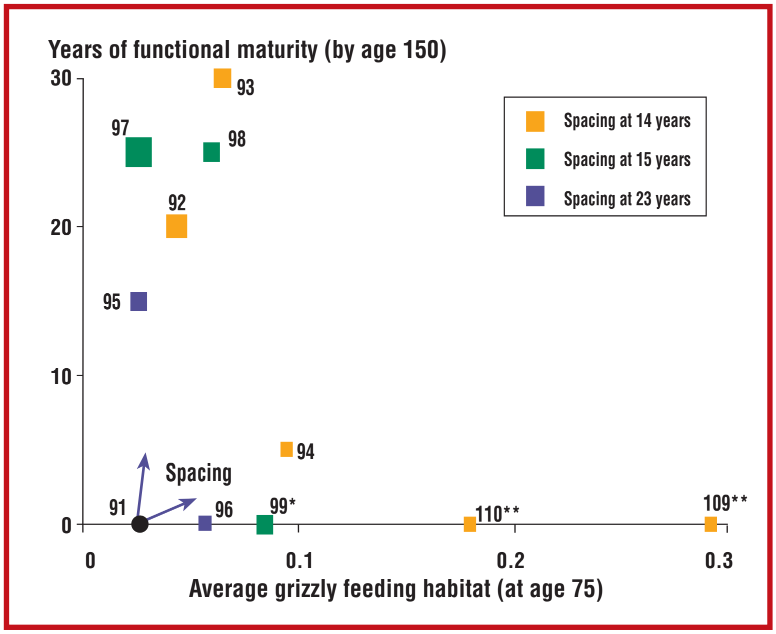


FIGURE 13. Spacing and thinning can improve the growth of understorey vegetation and provide better foraging opportunities for grizzly bears, like the two juveniles shown in this photo. However, the analysis in this report shows that the tending regimes that promote the most understorey growth tend to delay the recruitment of snags. The conclusion is that a variety of stand treatments are needed at the landscape level, including the option of no treatment.

Photo: Wayne McCrory

From an economic perspective, runs 94 and 96 in Figure 12 are considered the best treatment options for western hemlock on this site index if no real timber price increase is expected over the rotation or a 1% increase for large logs only is expected (Massie 1995). Runs 95 and 97 are close to the best economic option if a 1% increase is expected in the next 20 years (Massie 1995). Under the best economic regimes, the age of functional maturity becomes irrelevant because stands would be harvested well before this age was reached in any of the runs tested (approximately age 120 at the earliest).

3.4 Cougar and Hoary Bat Habitat Quality

The previous two sections have shown how, as a rule, stand tending involves trading-off an increase in one environmental value against a decrease in another value. One surprising exception to this rule is the impact of stand tending on cougar and hoary bat habitat quality. As described in section 2, these species were chosen for analysis because of their opposing habitat preferences: the highest cougar habitat values are in open stands, while the highest hoary bat habitat values are in closed stands. Since thinning and pruning open the canopy, it was expected that most tending regimes would improve cougar habitat quality at the expense of hoary bat habitat quality. Figure 14 shows that this is not the case. In fact, almost every regime tested improves *both* habitat values over the untended stand (although the increase is small in many cases). This can be understood in light of the fact that both species prefer stands with larger trees, even if they disagree on the optimal canopy cover in those stands. There is still a trade-off in the sense that the regime that produces the greatest habitat quality increase for one species is not the regime that produces the greatest increase for the other species. However, both species can benefit from the same regime compared to the untended condition (Figure 15).

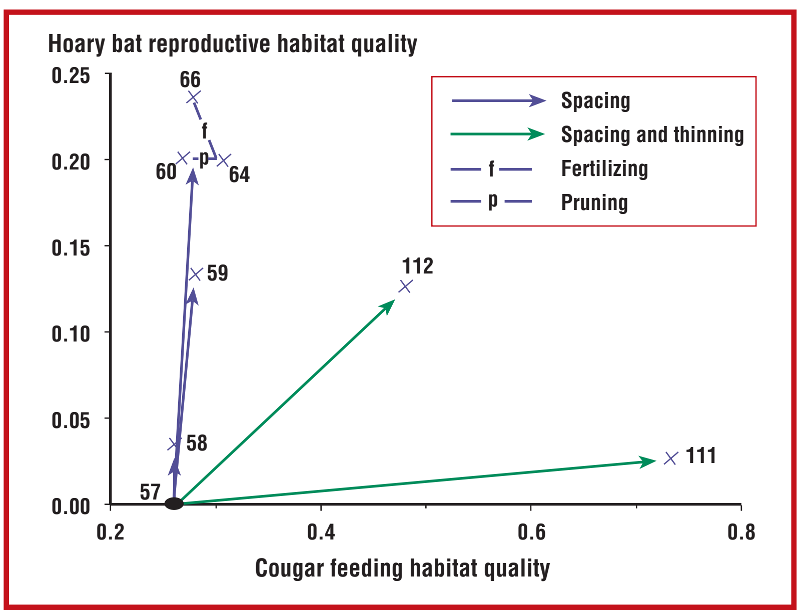


Figure 14. The influence of stand tending on cougar and hoary bat habitat quality. The data are for interior Douglas-fir stands growing at site index 25, and are the average values over a 75-year rotation. The run number associated with each data point is shown. The point labelled 57 is the untended stand. The arrows show the effects of different stand treatments, as in the previous figures.

FIGURE 15. The habitat value models used in this analysis suggest that cougars, like the one shown here, and hoary bats can both benefit from the same stand tending regimes when compared to the untended condition. Much higher cougar habitat values were predicted for novel, extreme thinning regimes than for more conventional regimes.

From an economic perspective, run 60 is the best treatment option if a 1% timber price increase is expected over the rotation for large logs only (Massie 1995). Run 57, the untreated stand, is the economically favoured option under either of the other two economic assumptions described in Section 3.3 above. Note that the only treatments that provided a substantial increase in cougar feeding habitat quality (runs 111 and 112) are two of the non-conventional runs developed in this study specifically to meet environmental goals.

3.5 The Effect of Rotation Length

A clear example of the trade-offs that do arise in managing for cougar and hoary bat habitat quality occurs in the issue of optimal rotation lengths. Figure 16 shows the rotation-average cougar and hoary bat habitat quality values that could be achieved under the tending regime used in run 111. As the figure shows, the average cougar habitat quality over a rotation initially increases with an increase in rotation length, because larger trees are associated with higher habitat values. Under still longer rotations, however, the benefit to cougar habitat quality of the continued increase in tree size is outweighed by the increase in canopy cover, which is associated

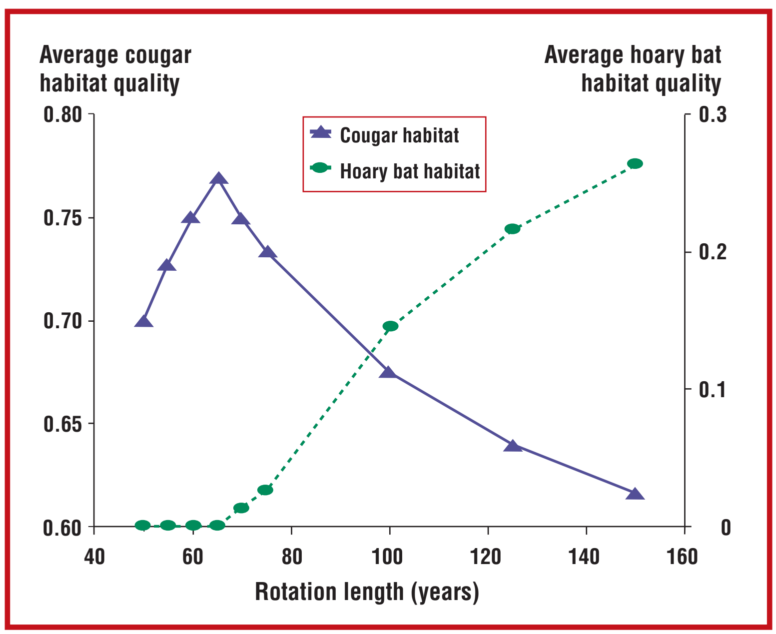


FIGURE 16. The effect of rotation length on the average cougar and hoary bat habitat quality. The figure shows the average cougar and hoary bat habitat quality over a variety of rotation lengths from 50 to 150 years. The data are from run 111 with interior Douglas-fir. See text for discussion.

Photo: Merlin D. Tuttle, Bat Conservation International.

Figure 17. Hoary bats, like this one, enjoy higher average habitat values over long harvest rotations than short ones. Under some tending regimes, however, cougars would experience higher habitat values if the rotation period was relatively short. Stand simulation models can be coupled with environmental indicator models like the ones used here to predict these trade-offs and ensure that the landscape will continue to provide some high quality habitat for each species.

with lower habitat values (Appendix 2). As a result, the average cougar habitat quality over the rotation would be maximized by harvesting these stands at the age of 65 years. However, the stands are just beginning to provide habitat of any value for hoary bats at this age. If all stands were harvested at age 65, there would be no adequate habitat for hoary bats in the landscape (Figure 17).

Figure 18 provides another example of the importance of rotation length in determining average environmental indicator values. Since shrub production is greatest very early in the rotation, the average shrub production over a rotation would be maximized by using short rotation lengths. However, if spacing is used to reduce the age at which trees reach a harvestable size, stands will just be beginning to produce significant levels of coarse woody debris around age 60, and large gains in annual debris production are made over the following decades. This is the case for the run

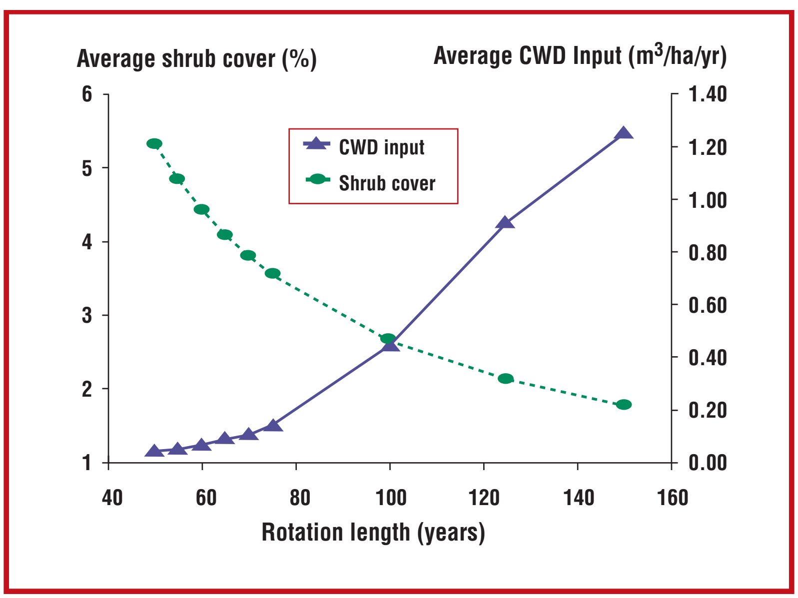


Figure 18. The effect of rotation length on average shrub cover and debris production. The figure shows the average percent shrub cover and annual debris input over a variety of rotation lengths. The data are from run 7 (coastal Douglas-fir spaced to 800 stems/ha). See text for discussion.

shown in the figure. According to these data, short rotation lengths may increase the average shrub production over a rotation, but they will virtually eliminate the production of coarse woody debris.

3.6 "Old-growth" Dependent Values

Related to the issue of rotation length discussed in the previous section is the use of stand tending to enhance "old-growth" dependent values. It should be noted that *none* of the stand tending regimes tested in this analysis were able to meet some of the indicator requirements within the maximum 150 year rotation length for which TASS data were available.

Photo: Bill Keay, Vancouver Sun

FIGURE 19. Spotted owl in a hollow tree. None of the tending regimes tested in this analysis were expected to provide high quality spotted owl habitat and other 'old-growth' dependent values under short rotation cycles—or even within the 150 years for which stand simulation data were available. However, the results of analyses like this could be used to select tending regimes that, in combination with extended rotation lengths, may provide these values sooner than would otherwise have been the case.

As shown in Table 3, neither type A nor type B spotted owl habitat were provided at any point in time in any of the runs for coastal Douglas-fir. In most runs, this failure was because there was 100% canopy cover by the time the trees were large enough to qualify for either habitat type, and the canopy remained closed until the end of the rotation; canopy cover must be between 60 and 80% to provide either type A or type B habitat.[4] Run 105 was an attempt to rectify the canopy density problem by opening the canopy, but thinning to the necessary level eliminated the production of the large snags that are also required to meet the species' habitat requirements. These results suggest that, even in 150-year rotations, spotted owl habitat requirements may only be met through artificial snag creation. Based on the indicator relationships described in Appendix 2, opening the canopy of older, unmanaged stands may also help enhance spotted owl habitat quality. Notice also in Table 3 that even the 150-year rotations with coastal Douglas-fir provide only 10 years of habitat that meets the bat habitat conditions suggested by the *Guidelines for Maintaining Biodiversity During Juvenile Spacing* (Park and McCulloch 1993; see Appendix 2), and only 5 to 20 years of habitat that meet some of the woodpecker habitat conditions.

4 This may be partly a result of the fact that TASS is designed to simulate *potential*—not actual—stand development, as is discussed in section 3.8.

TABLE 3. Old-growth indicator values at age 150. The abbreviations used in the table are as follows: 'S' stands for spacing, 'CT' for commercial thinning, 'PRU' for pruning, 'FER' for fertilizing, and 'DBH' for diameter at breast height. '+' is used to indicate that the threshold age is greater than the 150 years of the simulation (i.e., the condition was not met during the simulation). The coastal habitat condition tested for bats is that there be at least 5 snags/ha that exceed 50 cm in diameter (at breast height). The interior habitat condition tested for bats is that there be at least 5 snags/ha that exceed 40 cm in diameter. The woodpecker habitat conditions tested are: 1) at least 0.15 snags /ha of at least 60 cm diameter; 2) at least 1.6 snags/ha of at least 60 cm diameter; and 3) the quadratic mean diameter of live trees exceeds 25.8 cm. All of the environmental indicators shown here are explained in more detail in Appendix 2.

Coastal Douglas-fir: Indicator values at age 150

						Threshold stand age for:				Number of years of:		
			Total stand volume	Quad. mean DBH	Average pileated habitat	Bat coastal	Woodpecker habitat conditions			Functional maturity	Spotted owl coastal habitat type	
Run	SI	Tending regime	(m^3/ha)	(cm)	quality	habitat	1	2	3	(coastal)	A	B
1	36	untended	1658	68.5	0.152	+	+	+	50	50	0	0
2	36	CT	1637	82.8	0.039	150	135	+	30	10	0	0
3	36	CT	1589	79.8	0.021	+	130	150	40	0	0	0
4	36	CT	1660	66.3	0.196	145	+	+	40	50	0	0
5	36	S	1738	72.4	0.254	140	+	+	30	55	0	0
6	36	S + CT	1716	84.8	0.009	150	130	145	30	0	0	0
7	36	S	1696	70.0	0.262	145	145	+	35	55	0	0
8	36	S + CT	1692	84.3	0.035	150	145	150	30	0	0	0
9	36	S + CT	1693	82.6	0.000	+	130	+	30	0	0	0
10	30	untended	1251	47.6	0.000	+	+	+	60	0	0	0
11	30	CT	1011	66.1	0.000	+	+	+	50	0	0	0
12	30	S	1293	56.1	0.000	+	+	+	35	5	0	0
13	30	S + CT	1117	71.9	0.000	+	+	+	35	0	0	0
14	36	CT	1589	79.8	0.000	+	+	+	40	0	0	0
15	36	CT	1660	66.3	0.000	+	+	+	40	0	0	0
16	36	S + CT	1693	82.6	0.000	+	+	+	30	0	0	0
71	25	untended	948	38.8	0.000	+	+	+	60	0	0	0
72	30	untended	1315	51.5	0.000	+	+	+	50	5	0	0
73	30	S	1314	57.0	0.000	+	+	+	35	5	0	0
74	35	untended	1632	68.3	0.254	+	+	+	40	55	0	0
75	35	S	1654	70.3	0.260	145	+	+	35	55	0	0
76	35	S	1683	78.8	0.187	150	140	+	30	40	0	0
77	35	S + FER	1696	78.5	0.129	150	135	+	30	45	0	0
78	35	S + FER twice	1692	78.7	0.196	150	140	+	30	45	0	0
79	35	S	1694	69.8	0.189	+	+	+	35	55	0	0
80	35	S	1719	77.8	0.128	+	+	+	30	45	0	0
81	35	untended	1693	71.4	0.109	+	+	+	30	35	0	0
82	35	PRU twice	1679	73.3	0.061	+	+	+	35	35	0	0
83	30	untended	1290	48.7	0.000	+	+	+	65	0	0	0
84	30	S	1295	51.1	0.000	+	+	+	50	0	0	0
85	30	S	1303	57.2	0.000	+	+	+	40	0	0	0
101	36	S	1729	70.8	0.254	145	+	+	35	60	0	0
102	36	untended	1693	70.8	0.253	140	+	+	30	50	0	0
103	36	multiple thinnings	605	118.3	0.000	+	+	+	30	0	0	0
104	36	S + CT	1322	107.3	0.000	+	+	+	25	0	0	0
105	36	multiple thinnings	901	112.6	0.000	+	+	+	30	0	0	0
Maximum:			1738	118.3	0.262					60	0	0
Minimum:			605	38.8	0.000	140	130	145	25	0	0	0

Table 3. Old-growth indicator values at age 150 (continued)

Western hemlock: Indicator values at age 150

			Total	Quad.	Average	Threshold stand age for:				Number of years of:		
			stand	mean	pileated	Bat	Woodpecker habitat			Functional	Spotted owl	
			volume	DBH	habitat	coastal	conditions			maturity	coastal habitat type	
Run	SI	Tending regime	(m^3/ha)	(cm)	quality	habitat	1	2	3	(coastal)	A	B
91	30	untended	2033	52.0	0.000	+	+	+	60	0	0	0
92	30	S	2076	56.2	0.002	+	+	+	40	20	0	0
93	30	S	2094	59.3	0.006	+	+	+	35	30	0	0
94	30	S	1942	71.3	0.000	+	+	+	35	5	0	0
95	30	S	2101	56.8	0.000	+	+	+	40	15	0	0
96	30	S	1943	69.3	0.000	+	+	+	35	0	0	0
97	30	S	2042	54.2	0.000	+	+	+	45	25	0	0
98	30	S	2094	59.1	0.000	+	+	+	35	25	0	0
99	30	S + PRU twice	1748	63.8	0.000	+	+	+	50	0	0	0
109	30	multiple thinnings	878	96.6	0.000	+	+	+	30	0	0	0
110	30	multiple thinnings	1282	90.8	0.000	+	+	+	30	0	0	0
Maximum:			2101	96.6	0.006					30	0	0
Minimum:			878	52.0	0.000	> 150	> 150	> 150	30	0	0	0

Lodgepole pine: Indicator values at age 150

			Total	Quad.	Average	Threshold stand age for:				Number of years of:		
			stand	mean	pileated	Bat	Woodpecker habitat			Functional	Spotted owl	
			volume	DBH	habitat	coastal	conditions			maturity	coastal habitat type	
Run	SI	Tending regime	(m^3/ha)	(cm)	quality	habitat	1	2	3	(coastal)	A	B
21	22	untended	627	31.9	0.000	+	+	+	95	0	0	30
22	22	CT	641	32.8	0.000	+	+	+	85	0	0	40
23	22	CT	631	35.9	0.000	+	+	+	60	0	0	55
24	22	untended	640	33.6	0.000	+	+	+	80	5	0	50
25	22	CT	653	33.5	0.000	+	+	+	75	0	0	45
26	16	untended	507	23.1	0.000	+	+	+	+	0	0	0
27	16	CT	468	25.9	0.000	+	+	+	150	0	0	0
31	25	untended	650	36.6	0.000	+	+	+	70	0	0	65
32	25	S	664	37.3	0.000	+	+	+	70	10	0	70
33	25	S	692	38.6	0.000	+	+	+	60	30	0	80
34	25	S	719	40.5	0.001	150	+	+	45	15	0	85
35	25	S	725	45.6	0.000	+	+	+	40	15	0	85
36	15	untended	468	22.5	0.000	+	+	+	+	0	0	0
37	25	untended	676	40.1	0.000	+	+	+	55	20	0	85
38	25	S	681	41.0	0.000	+	+	+	50	25	0	85
39	25	S	680	44.6	0.000	+	+	+	40	15	0	75
40	15	S	449	29.7	0.000	+	+	+	100	0	0	0
43	25	untended	669	38.5	0.000	+	+	+	65	35	0	75
44	25	S + PRU	618	42.7	0.000	+	+	+	55	25	0	75
45	25	S + PRU	532	45.7	0.000	+	+	+	50	0	0	80
48	25	S	722	45.5	0.000	+	+	+	40	20	0	70
49	25	S + PRU	615	46.3	0.000	+	+	+	45	0	0	65
106	25	S + CT	153	59.5	0.000	+	+	+	35	0	0	0
107	25	S + CT	585	50.4	0.000	+	+	+	35	0	0	75
Maximum:			725	59.5	0.001					35	0	85
Minimum:			153	22.5	0.000	150	> 150	> 150	35	0	0	0

Table 3. Old-growth indicator values at age 150 (conclusion)

Interior Douglas-fir: Indicator values at age 150

						Threshold stand age for:				Number of years of:		
			Total stand volume	Quad. mean DBH	Average pileated habitat	Bat coastal	Woodpecker habitat conditions			Functional maturity	Spotted owl coastal habitat type	
Run	SI	Tending regime	(m³/ha)	(cm)	quality	habitat	1	2	3	(coastal)	A	B
51	25	untended	968	35.9	0.000	+	+	+	95	0	0	20
52	25	S	964	38.4	0.000	+	+	+	80	0	0	30
53	25	S	980	41.5	0.000	+	+	+	60	0	0	35
54	25	S	952	49.1	0.000	+	+	+	50	0	0	30
55	16	S	467	24.1	0.000	+	+	+	+	0	0	0
56	16	S	391	34.3	0.000	+	+	+	85	0	0	0
57	25	untended	964	37.2	0.000	+	+	+	90	0	0	40
58	25	S	950	39.5	0.000	+	+	+	75	0	0	55
59	25	S	965	41.8	0.000	+	+	+	60	0	0	40
60	25	S	933	49.1	0.000	+	+	+	50	0	0	45
61	16	S	459	24.1	0.000	+	+	+	+	0	0	0
62	16	S	384	34.3	0.000	+	+	+	85	0	0	0
63	25	S + PRU	954	45.2	0.000	+	+	+	55	0	0	35
64	25	S + PRU	912	51.9	0.000	+	+	+	50	0	0	40
65	25	S+FER+PRU	991	43.1	0.000	+	+	+	55	0	0	45
66	25	S+FER+PRU	952	50.1	0.000	+	+	+	50	0	0	50
111	25	S + CT	172	84.4	0.000	+	+	+	40	0	0	0
112	25	S + CT	495	75.5	0.000	+	+	+	40	0	0	0
Maximum:			991	84.4	0.000					0	0	55
Minimum:			172	24.1	0.000	> 150	> 150	> 150	40	0	0	0

The runs with western hemlock show the same problem (Table 3). None of the runs were able to provide either type A or type B spotted owl habitat within 150 years. This is consistent with Dunbar and Blackburn's report (1994) that, to date in British Columbia, no spotted owls have been detected using stands in the coastal western hemlock zone that are dominated by trees less than 120 years old. In addition, none of the western hemlock runs in this study provided any habitat that met the guidelines' standards for bats or that met two of the three suggested woodpecker habitat conditions (Appendix 2). The average pileated woodpecker habitat quality was zero under the majority of treatments.

The difficulty in providing for old-growth values in managed stands can also be seen in the data for lodgepole pine (Table 3). No type A spotted owl habitat was provided in any run, pileated woodpecker habitat quality was essentially zero throughout all runs, and no habitat met the guidelines' standards for bats.

The same story is seen in the data for interior Douglas-fir, with the additional consideration that, because of a lack of large snags, none of the stands tested ever met the minimum criteria for functional maturity (Table 3). The interior Douglas-fir stands did provide up to 50 years of type B spotted owl habitat during a 150-year rotation, depending on the treatment applied. This result is again consistent with Dunbar and Blackburn's finding (1994) that spotted owls will use younger stands in the interior Douglas-fir zone, provided that these stands have the right structural characteristics.

3.7 Benefits of Non-standard Regimes

One final point deserving emphasis is the potential value of non-standard stand tending regimes designed to meet environmental goals. Some of the novel regimes tested were found to produce large gains in the value of environmental indicators. For example, it was only these regimes of all the ones tested that provided peak cougar habitat quality values (run 111), that maintained a high index of small mammal diversity beyond age 40 or so (also run 111; see Greenough *et al.* 1995 for details), and that maintained substantial shrub production beyond age 30 (e.g., runs 103, 106, 109, and 111).

3.8 Cautions on the Interpretation of the Results

The following sections describe a number of cautions that are warranted in interpreting the results of this study.

3.8.1 Habitat Quality vs. Population Level

The analysis presented in this report considers the impact of stand tending regimes on some measures of wildlife habitat quality. However, an increase in habitat quality—even an average increase in habitat quality across the entire landscape—cannot be assumed to lead to an increase in survival rates, reproductive success or population size. Many other factors must be taken into account before population-level inferences may be drawn. These factors include, for example, hunting/predation rates, the seasonal requirements of the species, and the ability of the species to track shifting resource availability through space and time.

3.8.2 Simulated Canopy Closure vs. the Real Thing

TASS is designed to estimate the *potential* stand yield given a specified site quality. As such, it assumes that the simulated stand is growing on a completely uniform site (e.g., no rock outcrops), and it considers only normal, background levels of mortality (i.e., no disease or pest outbreaks, unless the model user elects to activate special pest extensions). This allows the simulated stands to quite quickly reach 100% canopy closure. A natural stand, however, would likely have a more variable canopy and might never reach more than 90% closure. Depending on the reason for the gaps and their distribution, forage production and habitat quality values in the natural stand could be either more or less than is predicted in this report for stands with that level of canopy closure.

3.8.3 Snags and Safety Regulations

All of the simulated snag data presented in this paper were generated under the assumption that existing snags are not affected by stand tending operations. However, B.C.'s Industrial Health and Safety Regulations require that all existing snags that are within reach of work areas must be felled if workers are to be active in the stand (as quoted in the *Guidelines for Maintaining Biodiversity During Juvenile Spacing*, Park and McCulloch 1993).

As part of the original study on which this paper is based (Greenough *et al.* 1995), three stand tending regimes were simulated in a coastal Douglas-fir stand under both the assumption that all existing snags are felled on each stand entry and the assumption that no existing snags are felled. Surprisingly, the results of these simulations suggested that, in the longer term, it made very little difference whether or not snags were felled during conventional stand tending. This was because only small snags were affected—no snags larger than 15 cm diameter (at breast height) were present at the time of commercial thinning (40 years, in this case). Because the existing snags are so small at the time of stand entry, they were not expected to remain standing for long anyway. In the simulation where they were allowed to remain standing, all existing snags had fallen within 10 years after thinning.

These results suggest that, as regards the average density of snags over a rotation, the effect of removing existing snags at the time of stand entries *early in the rotation* is of much less concern than is the effect of thinning on future snag recruitment (as discussed earlier).

3.8.4 Reliability of the Indicator Relationships

The descriptions of each indicator (Appendix 2) include notes on the reliability of each indicator and the ecological units in which it is most valid. In addition to the limitations mentioned in those descriptions, one general caution should be emphasized. The indicator relationships in this study aim only to predict the average condition—they do not consider site-specific ecological conditions. For example, the understorey shrub and herb production estimates attempt to predict the *average* production in particular biogeoclimatic zones, given the specified dominant tree species and canopy density. These estimates are not influenced by site quality; the volume of debris or slash in the stand; or the amount of coniferous litterfall (which can stifle understorey development).

3.8.5 Reliability of the Overstorey Predictions

Although TASS has been well calibrated (see the sidebar on page 4), and its growth and mortality rates are accurate on average, it is still subject to error under particular conditions. Moreover, model users can err by extrapolating the model results to situations that TASS was not designed to simulate.

Readers should note, therefore, that the current version of TASS is designed to simulate single-species stands with no regeneration occuring after stand initiation. The habitat values that TASS predicts for single-species stands may be either higher or lower than those which would occur in real, mixed-species stands. For example, high pileated woodpecker habitat values may be obtained sooner in mixed conifer-hardwood stands than was predicted here for pure conifer stands. On the other hand, the absence of ongoing regeneration in TASS means that simulated canopy gaps may persist for longer than is realistic (especially if the gaps are too large to be closed by expansion of adjacent tree crowns). Some of the very low thinning densities tested here (especially in runs 101 to 112) may have produced such gaps, and the simulation results may thus give an overly optimistic prediction of the amount of understorey forage that would persist under these gaps.

A number of particular conditions in the field can also reduce the accuracy of the overstorey projections generated by TASS. For example, thinning may increase the spread of root disease in stands, which will reduce volume growth, increase tree mortality, and result in a more open stand. Similarly, unthinned lodgepole pine stands in the interior may be more susceptible to pine beetle attacks than thinned stands. There are extensions to TASS that consider some of these secondary impacts, but the extensions were not used in the current analysis.

Another factor that is not captured by TASS is the influence of wildlife on stand structure. The strength of this influence may be either increased or decreased by stand tending. For example, one study found that spacing reduced the densities of red squirrels, and hence the amount of damage that they inflicted on the overstorey in interior stands (Sullivan *et al.* 1995, Sullivan 1995[5]). Similarly, another study found that damage to lodgepole pine was reduced in the winter following thinning because snowshoe hares fed instead on the fallen stems and foliage (Sullivan and Sullivan 1988). On the other hand, after a stand of western redcedar on Vancouver Island was spaced, every remaining redcedar was killed by increased black bear feeding on the more vigorously growing trees (Sullivan 1993).

Finally, mortality from windthrow may be increased by stand tending, and TASS does not simulate this effect. However, this may be only a minor problem. According to references in Neitro *et al.* (1985), suppression, not windthrow, is the major cause of tree death in unmanaged, even-aged stands. In one study on Douglas-fir in western Oregon, "windthrow or uprooting accounted for less than one percent of annual mortality in stands less than 120 years old."

[5] Sullivan, T.P. 1995. Influence of lodgepole pine stand density on red squirrel populations, feeding damage, and wildlife habitat diversity. Silv. Branch, B.C. Min. For., Victoria, B.C. Contract report.

3.8.6 Importance of Stand Age

This study did not consider the impact of stand age on possible indicator values. Part of the justification for this is that stand age is not affected by tending (although it is obviously affected by the choice of rotation length), and the study needed to focus on variables that could reveal the impact of different tending regimes. Moreover, vertebrates that typically use old-growth stands will also use younger mature forest if the necessary structural attributes exist (Steventon 1994). That is, the occurrence of vertebrate species is thought to depend on stand structure and vegetation species composition, but not on stand age *per se*.

This may not, however, be the case for plants and other animals. As reviewed by Steventon (1994), there is "good evidence that some plants (especially epiphytes such as lichens) and invertebrates are dependent on very old trees and the interior microclimate of old-growth stands." Kremsater and Bunnell (1993) suggest that this is because lichens are slow to colonize and develop, possibly because they require deeply fissured and slowly shedding bark, both of which may be products of age. This deeply fissured bark may also be required by birds such as nuthatches, chickadees and woodpeckers which overwinter on insects that they find under bark scales. Age *per se*—and the associated rot—may also be important in producing moribund trees susceptible to disease and insect attack which serve as important sites for cavity excavation and foraging. Finally, the passage of time may be required for stands to achieve their full habitat value because "wildlife species may not respond immediately to the creation of appropriate habitat in younger stands" (Kremsater and Bunnell 1993).

4 Towards a Landscape-level Analysis

This section discusses the need for landscape-level analyses and describes by example how stand-level models may be extrapolated to the landscape-level to help meet this need.

4.1 The Need for Landscape-level Analyses

Section 3 identified a number of ways in which stand tending involves trading-off an increase in one environmental value for a decrease in another. The lesson to be drawn from this is that planning for many environmental indicators must occur at the landscape level, and not just the stand level. The landscape level may be the lowest level at which it is possible to plan for total biodiversity.

For example, a guideline that promoted a density of 1600 stems/hectare in lodgepole pine stands might ensure that enough trees are left to provide some future snag recruitment for wildlife. However, if this standard were applied to the entire landscape, the production of understorey forage could be reduced. Maximizing biodiversity at the landscape level requires maintaining a wide range of stand types.

This is true even if it means that each individual stand does not have the highest possible local diversity (Klenner and Kremsater 1993,[6] see their Figure 20). For example, the seral stage in the Interior Douglas-fir Biogeoclimatic Zone that supports the largest number of breeding bird species is the old-growth stage, with 98 species of birds (Kremsater and Bunnell 1993). However, an additional 49 species of birds in that biogeoclimatic zone do not breed in the old-growth seral stage. These species require younger stands. Since the goal of many silvicultural treatments is to reduce the period of time between the clearcut and pole-sapling stages of stand development (which naturally is already a relatively brief phase), some biologists are worried about its impact on early-successional species. Concern about the need for a diversity of stand conditions can only be addressed by landscape-level planning.

Landscape-level planning is also needed to optimize the distribution of different stand conditions and assess the *significance* of stand-level impacts. For example:

- creating additional winter range may be of no real benefit if the population in the area is limited by a lack of summer range;

6 Klenner, W. and L. Kremsater. 1993. Forest management and biodiversity. B.C. Min. For., Kamloops Region, Dept. For. Sciences, Univ. B.C., Vancouver, B.C. [Unpubl. workshop notes.]

- the use of sheep or herbicides for brush control reduces berry production, but its significance for the landscape as a whole may be minor if only a few blocks are treated in each watershed;
- grizzly forage is of the most value to the population when it is well-dispersed in order to support bears on different home ranges; and
- spring range is of greatest value to black-tailed deer if it is within one kilometre of winter range; winter range is best if it is located on south-facing slopes.

It was for reasons like these that a 1994 survey of 45 resource experts in B.C. concluded that the development of landscape-level analyses must be a high priority (Greenough and Kurz 1994).[7] If species populations are to be maintained, it must be ensured that the landscape as a whole can meet the seasonal requirements of the species for feeding, reproduction, and dispersal; and it must continue to do so as individual stands pass through their developmental stages.

4.2 The Transition from Stand to Landscape

Making the transition between stand-level environmental indicators and a landscape-level impact analysis requires four basic steps. The first step is just to sum together the data for all the individual stands. At this stage, one goes from knowing that stand A will be in seral stage 5 at a certain time in the future, stand B will be in seral stage 3, etc. to knowing how many hectares of the landscape will be in each seral stage.

The second step towards a full landscape-level impact analysis is to add knowledge of the spatial relationships between the stand-level indicators. For example, where are the stands in different seral stages located with respect to one another or with respect to elevation gradients in the landscape?

These first two steps are relatively straightforward. Stand-level overstorey and habitat-quality models like the ones described in this analysis can be used to predict the distribution of habitat types at the landscape-level by simply linking them to a Geographic Information System (or 'GIS'). Daust and Hafer (1992),[8] for example, started with a GIS-linked simulation of overstorey conditions and added a model that predicted understorey development from overstorey

[7] Greenough, J.A. and W.A. Kurz. 1994. An assessment of the need for non-timber resource modelling in British Columbia. Can. For. Serv., Victoria, B.C. Contract report.

[8] Daust, D. and M. Hafer. 1992. Predicting understorey development in the Khutzymateen watershed. B.C. Min. For., Silv. Branch, Victoria, B.C. Contract report.

conditions (like the indicator relationships used in this analysis). The resulting combined model allowed them to predict the supply of grizzly bear foraging habitat under different landscape-level harvest schedules.

The third step towards a landscape-level impact analysis is to develop indicators of the properties that, by their nature, can not be measured at the level of individual stands. These so-called "emergent properties" (i.e., properties that only emerge at larger spatial scales than that of a single stand) can only be assessed once the stand data have been put in a spatial context. They include properties like the amount of edge habitat between discontinuous stand types, and the issue of corridors or connectivity between habitats.

The fourth and most difficult step is to assess the implications of the different habitat distributions and indicator values once they have been predicted. How, for example, can one compare the relative merits of having more spring range but less winter range under particular regimes? (Let alone the merits of spring range on particular aspects or at particular distances from winter range.) There are two main ways in which this can be done: by comparing the different distributions to the natural or historic distribution, and by inferring the implications of each distribution for the population levels of key species. Examples of each of these approaches for indicators presented in this report are described in the next section.

4.3 Examples of the Extrapolation of Stand-level Models

The first sub-section here describes how population-level impacts can be inferred from stand-level habitat quality information. The second sub-section shows how the distribution of stand-level indicators across the landscape can be compared to an 'optimal' distribution.

4.3.1 Potential Cougar Population Levels

The analysis of cougar feeding habitat quality presented in the previous section was based on the fact that stands differ in their suitability as feeding habitat for cougars, and these differences have been related to differences in stand structure and species composition. The *Habitat Handbook for the Southern Interior Ecoprovince* (Vol. 5 by Ritcey *et al.* 1988) provides a means to infer population-level implications from the stand-level differences in feeding habitat quality. The habitat values that the handbook assigns to different stands (and which were used in the above analysis; see Appendix 2) are directly related to the potential contribution of those stands towards maintaining a species population. The following example is presented purely to illustrate how this information can assist landscape-level analyses.

According to data presented in Ritcey *et al.* (1988), each individual cougar requires 13 000 hectares of summer feeding habitat.[9] However, all stand area does not contribute equally to meeting this requirement. Each hectare in a stand with a feeding habitat value of "1" counts as one hectare towards meeting the feeding area requirement, but hectares in stands with lower habitat values count proportionately less towards meeting the requirement. That is, hectares with a habitat value of "0.5" count as one half hectare, and hectares with a value of "0.2" count as only one-fifth of a hectare.

In theory, this information makes it possible to weight the significance of evolving stand conditions across an entire landscape. To sum up the cumulative effect of stand changes across an entire landscape, one need only count the number of value-weighted hectares present in the landscape at any point in time (for example, 1000 hectares with a value of "1" plus 1000 hectares with a value of "0.2" would count as 1200 hectares towards meeting an individual cougar's requirements). Dividing the resulting total by the 13 000 hectares required by each individual yields an index of the potential population size that could be maintained in the landscape at that point in time (e.g., 1200/13000 = 0.09 cougars indicating that each cougar needs a lot of feeding habitat).

In this way, once future stand conditions have been projected, an index of potential population size can be forecast over time, and the results used to compare the implications of different management regimes. A more complete numeric example is developed in Greenough *et al.* (1995).

While this approach is conceptually sound, note that the resulting index of potential population size is exactly that—only an *index* of *potential* population size. Actual population size would depend on many factors besides the quality and abundance of feeding habitat. These factors would have to be addressed before any model should be used to predict cougar population changes. Nonetheless, the approach described here is potentially valuable because it offers a means to quantify the relative worth of different types of habitat, and thus to sum up the significance of stand structure changes across the landscape as a whole. This, in turn, makes it possible to weigh in advance the implications of alternative treatment schedules and management regimes.

4.3.2 The Distribution of Habitat Classes

Rather than doing a full population analysis, the landscape-level implications of different tending regimes may be assessed by comparing the expected distribution of habitat types under each regime to a desired distribution. This section uses a hypothetical target distribution to illustrate the approach.

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9 This figure may be conservative. Other sources have estimated that cougar home ranges extend up to 9000 hectares (Stevens and Lofts 1988).

If a model like TASS is available to predict stand development, then the future distribution of habitat classes at the landscape-level may be predicted from harvest and treatment schedule information. Consider, for example, the distribution of canopy cover classes in a landscape made up of interior Douglas-fir stands like the one simulated in run 57 (Appendix 3). For simplicity, imagine that the landscape is treated like 700 separate but identical stands, with all stands harvested in turn at a rate of 10 stands per year. After the first 70-year cycle of such treatment, the watershed will reach a steady state where there are always ten 1-year-old stands, ten 2-year-old stands, etc. In this situation, the distribution of cover classes across the landscape will be exactly the same as the distribution of cover classes over time within any one stand. In other words, the percent of the rotation that each stand spends in a given cover class is exactly the percent of the landscape that will be in that cover class at any point in time.

Figure 20 shows the landscape-level distribution of canopy cover classes that some of the tending regimes in this report would create under the steady-state scenario just described. Now consider a target canopy cover distribution. The rationale for such a distribution could be that a species of management concern requires both dense stands to provide thermal cover and open stands to provide understorey forage, or that a focal species prefers one stand type but a certain proportion of other stand types is required to meet other management goals. Maintaining biodiversity, afterall, may require maintaining a diversity of stand types at all points in time. Deviations from the target distribution could indicate either a habitat supply shortfall or a missed opportunity.

Figure 20 shows a hypothetical target distribution. In this example, if all the stands in the landscape are untended, then the amount of the landscape in the highest cover class will be greater than the target distribution, and there will not be enough area under more open canopies. On the other hand, if all the stands are heavily thinned, the landscape will have too little dense cover. The “mixed stands” distribution in Figure 20 comes closest to matching the target values, but some intermediate thinning regime would be required to provide more area in the “moderate” cover class. If the expected distribution under this intermediate regime were available, a simple spreadsheet analysis could be used to devise a mixture of tending regimes such that the landscape was expected to meet the target values for each cover class.

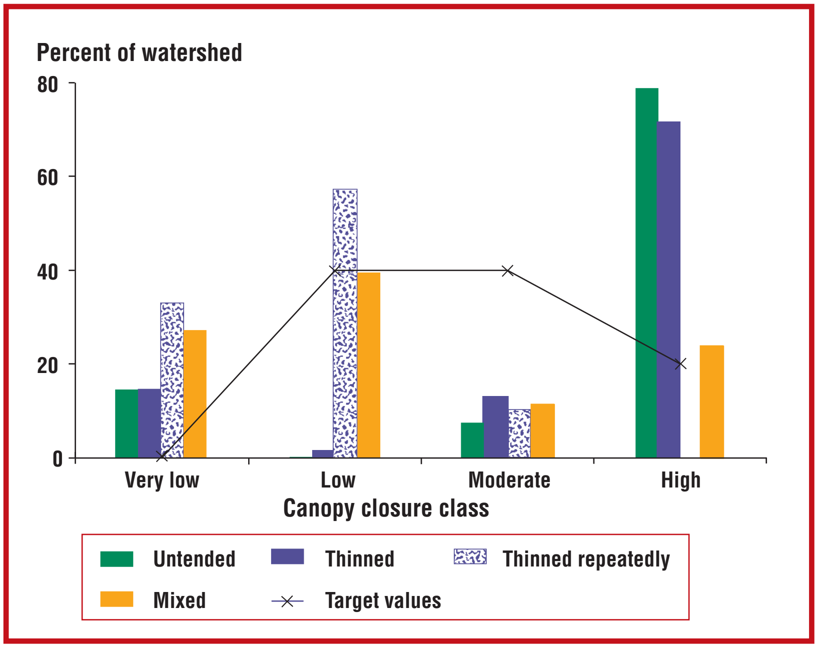

Figure 20. The distribution of canopy cover classes at the landscape level. The figure shows the distribution of canopy cover classes that would result under a steady-state scenario (i.e., one-seventieth of the watershed is harvested each year in strict rotation). The bars labelled "untended" show the distribution that would result if none of the stands in the landscape were tended (based on run 57). The thinned distribution is the expected result if all of the stands are thinned as in run 60. The heavily thinned distribution is expected if all stands are thinned as in run 111. The mixed stands distribution is that which results if one-third of the stands are thinned as in run 60 and the remaining two-thirds are thinned as in run 111. The target distribution was chosen arbitrarily for the purposes of illustration. The canopy cover classes are as follows: very low = less than 16%; low = 16–35%; moderate = 36–65%, high = more than 65%.

5 Conclusions and Recommendations

The following sections consider the environmental role of stand tending, and the relative strengths of the assessment approach used in this study. The final section contains some recommendations for the refinement of this approach and the development of decision support tools.

5.1 Role of Stand Tending

As Steventon (1994) discusses, "we cannot manage for every species individually." Given the current state of knowledge, the surest way to maintain the full range of biological diversity in the long-term is to ensure the maintenance of the full-range of seral stages across the landscape (as is required in the *Biodiversity Guidebook* that accompanies B.C.'s Forest Practices Code; Government of British Columbia 1995b).

However, stand tending may provide an important supplement to this approach in the medium term. This report has shown that different stand tending regimes can be used to achieve desired habitat conditions. Regimes designed for particular environmental benefits could be used to help cover habitat supply gaps as we move towards a steady-state distribution of seral stages in the working forest. Analysis of the old-growth dependent indicators considered in this report suggests that no amount of stand tending can provide for all values under short rotation lengths, but stand tending can still be used to provide these values sooner than would otherwise have been the case.

5.2 Benefits of this Approach to Assessment

This study used a novel approach to assess the impacts of different silvicultural regimes. As illustrated in Figure 1 a stand simulation model (TASS) was used to project the expected stand conditions under different silvicultural regimes. Numerous indicator models were developed to translate changes in stand structure into changes in the affected environmental indicators. These models were then applied to the stand simulation data to determine how environmental values are expected to change over time under a variety of stand tending regimes (Figure 21).

The strengths of this approach are as follows:

- It produces numerical data, which may be used to weigh the impacts of different treatments and to assess trade-offs;
- It is objective and impartial (once indicator relationships have been developed; diverse input was sought on this first phase of the analysis);

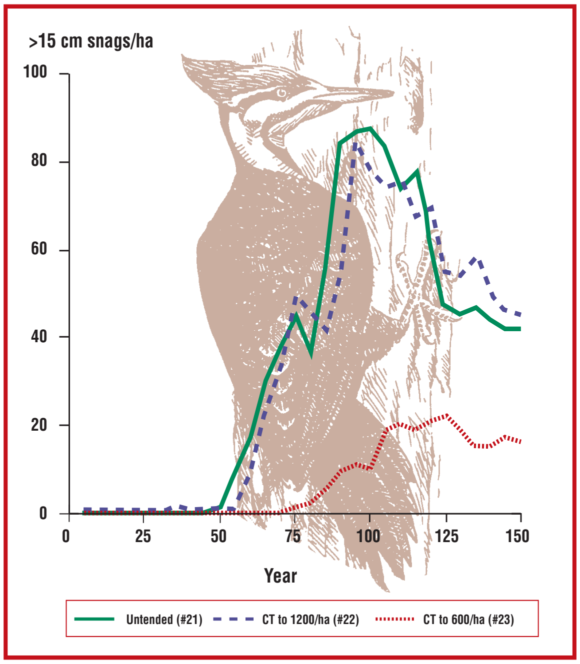

Figure 21. In this report, quantitative indicator models were used to translate predicted changes in stand structure throughout the rotation into expected changes in the affected environmental values. This approach provided reproducible, numerical data on the environmental impacts of alternative management regimes.

- It is reproducible;
- It can be applied to the assessment of any management actions that primarily affect the stand variables from which indicator values are derived;
- It is transparent—it is a numerical process in which all of the assumptions are documented and accessible to review;
- It is independent of the stand simulation model used to provide overstorey data. It can be used in conjunction with TASS, PROGNOSIS (the B.C. Ministry of Forests is now using PROGNOSIS to study the dynamics of uneven-aged, multi-species stands in the interior), or any other model that projects stand conditions;
- It is modular—each of the indicator models is a separate unit that can be replaced with more refined models as these become available, and new indicators can be added at will;
- It provides information about the dynamic changes over time in the environmental indicators; and
- It provides an important component of the information that will be required for landscape-level analyses.

The analysis that was presented here is an example of how this assessment approach can be used.

5.3 Modelling Recommendations

Environmental indicators like the ones in this report, coupled with stand simulation models, could form the basis of a new decision support tool that would help managers assess the environmental and economic trade-offs inherent in integrated resource management. The following sections consider some of the steps required for such a decision support tool to achieve its full value in operational planning.

5.3.1 Improve Knowledge of Indicator Relationships

As noted in section 3.8 and Appendix 2, the impact analyses in this report have a number of limitations. Many of these limitations could be overcome if more were known about the relationships between stand conditions and the indicators, and between the indicators and the wildlife species (and other environmental values) whose needs they are meant to represent.

To some extent, the problem is one of access to existing data. Many of the interviewed resource experts described ideal data sets that had just never been analyzed. Existing data on stand-indicator relationships, especially data from experimental stand manipulations, should be resurrected and applied to the task of developing more refined indicator models.

At the same time, many experimental studies specifically on the effect of different silvicultural treatments are now underway (see the listing by the B.C. Forest Service and B.C. Environment 1994). Ultimately, these studies should yield controlled data that can be used to refine the indicator relationships. Additional information will be produced by 'adaptive management' programs that are now being implemented in the absence of definitive information. More complete habitat inventories would facilitate the learning process.

One of the biggest weaknesses in environmental impact modelling in British Columbia is currently the lack of accurate models to predict understorey vegetation in response to ecological conditions and silvicultural treatments (see also Kurz *et al.* 1994). Habitat quality for many wildlife species depends on understorey vegetation conditions. In this report, indicators for these species were based on "average" relationships between canopy cover and understorey production. The resulting indicators are insensitive to many different ecological conditions. Calibrating the relationships by more precise ecological units, such as biogeoclimatic variants and site series, could significantly increase the accuracy of the predictions. Such a refinement must be a priority in non-timber resource modelling if the results are to achieve their full value in operational planning. The COVER extension (Moeur 1985, 1986) to the Forest Vegetation Simulator is an approach to modelling understorey vegetation that could be adapted to B.C.

Another significant area of weakness is in our ability to predict the dynamics of snags and coarse woody debris. The nature, size, and volume of dead wood in a stand is as important for many species as are the characteristics of understorey vegetation. Unfortunately, good data on dynamics of dead wood are scarce because large snags and logs can be so long-lived.

5.3.2 Develop Landscape-level Analyses

As Steventon (1994) stated, "we cannot provide for all species on every hectare of forest." This conclusion is endorsed by the *Biodiversity Guidebook* (Government of British Columbia 1995b), which states that "not all elements of biodiversity can be—or need to be—maintained on every hectare." The conclusion is also supported by the analysis presented here. If producing more shrubs and herbs means producing fewer snags, how can managers decide which option is better?

Fortunately, it is possible to choose both options at the landscape level. However, in order to determine whether the amounts and distribution of different habitat features will be adequate under proposed management regimes, managers will need better decision support tools. These tools should incorporate a set of indicators that are complementary to each other—indicators which, in combination, represent much of the habitat variation required by different species. For example, a comprehensive management tool would need to include both indicators that consider the size and volume of dead wood present (like the pileated woodpecker indicator in section 3.2), and indicators that consider the amount and quality of understorey vegetation.

As a first step, a prototype decision support tool could simply apply a stand simulation model to each stand in the landscape, and aggregate data on the indicator values in each stand. For example, the support tool could produce information on how many hectares of high quality woodpecker habitat or high value forage can be expected at different times in the future. The next steps would involve taking into account the spatial arrangement of the different habitat classes. As outlined in section 4.2, this could mean calculating indices of habitat fragmentation, or discounting the value of spring range that is too distant from winter range. Ultimately, the landscape-level decision support tool could be coupled to economic models to allow managers to simultaneously explore both the environmental and economic implications of different management regimes.

5.4 Operational Recommendations

The same stand tending regime can do either more harm or more good to environmental values depending on how the activities are implemented. The resource experts that were interviewed during the course of this study had many suggestions to help mitigate the negative impacts of tending operations and enhance the positive impacts. For example:

- Ensure that all tree species found naturally on the site are still present after spacing or thinning;
- Leave part of the area in unthinned patches, and thin other parts below normal stocking standards;
- Retain uncut patches of wildlife trees (large, well-branched, and often partially rotten trees of high value to wildlife) during commercial harvesting, to ensure future snag recruitment independently of the tending regime applied to the rest of the stand;
- Retain non-merchantable defect trees during commercial thinning (so that they may be a source of snags in the future);
- Time activity for winter to minimize the degree of soil compaction, and to make canopy foliage available to wildlife at a time when forage may be most limiting;
- Leave a visual barrier of unpruned trees along main roadways to minimize traffic disturbance to wildlife; and
- Space stands earlier so that the smaller trees removed will create less slash, and understorey shrubs will still be present to grow back.

Many of these suggestions are contained in the *Biodiversity Guidebook* (Government of British Columbia 1995b), the *Guidelines to Maintain Biological Diversity During Juvenile Spacing* (Park and McCulloch 1993), and the *Guidelines to Maintain Biological Diversity in Coastal Forests* (B.C. MoF and B.C. MELP 1992). Such suggestions should be incorporated in stand tending activities wherever feasible.

References Cited

Armleder, H.M., R.J. Dawson, and R.N. Thompson. 1986. Handbook for timber and mule deer management co-ordination on winter ranges in the Cariboo Forest Region. Land Manage. Hdbk. No. 13. B.C. Min. For., Victoria, B.C.

B.C. Forest Service and B.C. Environment. 1994. Managing forest habitats: an integrated approach. Compendium of projects funded under the Habitat Silviculture Protection Account 1987–1993. B.C. Min. For. and B.C. Min. Environ., Lands and Parks, Victoria, B.C.

B.C. Ministry of Forests. 1994. Silviculture planning and procedures manual. Section 2: Stand tending. B.C. Min. For., Victoria, B.C. Rev. date: 94-02-01.

B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks. 1992. Guidelines to maintain biological diversity in coastal forests. B.C. Min. For. and B.C. Min. Environ., Lands and Parks, Victoria, B.C.

Cline, S.P., A.B. Berg, and H.M. Wight. 1980. Snag characteristics and dynamics in Douglas-fir forests, western Oregon. J. Wildlife Manage. 44(4):773–786.

Government of British Columbia. 1994a. British Columbia's Forest Renewal Plan: Working in partnership. Government of British Columbia, Victoria, B.C.

Government of British Columbia. 1994b. Bill 40: Forest Practices Code of British Columbia Act. Government of British Columbia, Victoria, B.C.

Government of British Columbia. 1995a. Forest Practices Code of British Columbia: Regulations. Government of British Columbia, Victoria, B.C.

Government of British Columbia. 1995b. Forest Practices Code of British Columbia: Biodiversity Guidebook. Government of British Columbia, Victoria, B.C.

Government of British Columbia. 1995c. Forest Practices Code of British Columbia: Forest Development Plan Guidebook. Government of British Columbia. Victoria, B.C.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack, Jr., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advan. Ecol. Res. 15:133–302.

Kellogg, R.M., ed. 1989. Second growth Douglas-fir: Its management and conversion for value. A report of the Doulas-fir task force. Forintek Canada Corp. Vancouver, B.C. Special Publ. No. SP-32.

Kremsater, L.L. and F.L. Bunnell. 1993. Volume 10: Silviculture options for wildlife. *In* A.P. Harcombe (tech. ed.). Wildlife Habitat Handbooks for the Southern Interior Ecoprovince. A cooperative effort of the Centre for Applied Conservation Biology, U.B.C.; B.C. Min. Environ., Lands and Parks; B.C. Min. For.; and Wildlife Habitat Canada. B.C. Min. Environ., Lands and Parks. Victoria, B.C.

Kurz, W.A, C.H.R. Wedeles, P.D.S. Morrison, I. Parnell, and J.K. Pawley. 1994. A status assessment of Non-timber Resource Modelling. Canada-British Columbia Partnership Agreement on Forest Resource Development: FRDA II. Working Paper WP-1.5-001, Victoria, B.C., 83 pp.

Mitchell, K.J. and I.R. Cameron. 1985. Managed stand yield tables for coastal Douglas-fir: initial density and precommercial thinning. B.C. Min. For., Victoria, B.C.

Mitchell, K.J. 1975. Dynamics and simulated yield for Douglas-fir. Forest Science Monograph 17.

Moeur, M. 1985. COVER: A user's guide to the CANOPY and SHRUBS extension of the stand prognosis model. U.S. Dep. Agric., For. Serv., Ogden, UT. Gen. Tech. Rep. INT–190.

__________. 1986. Predicting canopy cover and shrub cover with the Prognosis-COVER model. *In* J. Verner, M.L. Morrison, and C.J. Ralph (eds.). Wildlife 2000: Modeling habitat relationships of terrestrial vertebrates. Univ. Wisconsin Press, Madison, WI. pp. 339–345.

Neitro, W.A., R.W. Mannan, D. Taylor, V.W. Binkley, B.G. Marcot, F.F. Wagner, and S.P. Cline. 1985. Snags (wildlife trees). *In* E.R. Brown (ed.). Management of Wildlife and Fish Habitats of Western Oregon and Washington. U.S. Dep. Agric. For. Serv., Pacific Northwest Region, Portland OR. No. 7. pp. 129–169.

Park, A. and L. McCulloch (comps. and prods.). 1993. Guidelines for maintaining biodiversity during juvenile spacing. Habitat Silviculture Protection Committee, Canada-British Columbia Partnership Agreement on Forest Resource Development (FRDA II). B.C. Environ., For. Can. and B.C. Min. For., Victoria, B.C.

Ritcey, R., D. Low, A. Harestad, R.W. Campbell, and A.P. Harcombe. 1988. Species-habitat relationship models for mammals. *In* A.P. Harcombe (tech. ed.) Wildlife Habitat Handbooks for the Southern Interior Ecoprovince. B.C. Min. Environ., B.C. Min. For., Victoria, B.C. Vol. 5.

Stevens, V. and S. Lofts. 1988. Species notes for mammals. Volume 1. *In* A.P. Harcombe (tech. ed.). Wildlife handbooks for the Southern Interior Ecoprovince. B.C. Min. Environ. and B.C. Min. For., Victoria, B.C.

Steventon, J.D. 1994. Biodiversity and forest management in the Prince Rupert Forest Region: a discussion paper. B.C. Min. For., Victoria, B.C. Land Mgmt. Rep. No. 82.

Sullivan, T.P., W. Klenner, and P.K. Diggle. 1995. Response of red squirrel populations and feeding damage to variable stand density in young lodgepole pine. Ecol. Applica. (in press).

Sullivan, T.P. 1993. Feeding damage by bears in managed forests of western hemlock-western redcedar in midcoastal British Columbia. Can. J. For. Res. 23: 49–54.

Sullivan, T.P. and D.S. Sullivan. 1988. Influence of stand thinning on snowshoe hare population dynamics and feeding damage in young lodgepole pine forest. J. Appl. Ecol. 25: 791–805.

Unpublished Citations

The following citations have been footnoted throughout this report.

Daust, D. and M. Hafer. 1992. Predicting understorey development in the Khutzymateen watershed. B.C. Min. For., Silv. Branch, Victoria, B.C. Contract report.

Dunbar, D. and I. Blackburn. 1994. Management options for the northern spotted owl in British Columbia. Canadian Spotted Owl Recovery Team. Government of B.C. [Unpubl. report.]

Greenough, J.A., W.A. Kurz, and C.L. Murray. 1995. The environmental impacts of incremental silviculture. B.C. Min. For., Silv. Branch, Victoria, B.C. Contract report. 56 pp. and appendices.

Greenough, J.A. and W.A. Kurz. 1994. An assessment of the need for non-timber resource modelling in British Columbia. Can. For. Serv., Victoria, B.C. Contract report.

Klenner, W. and L. Kremsater. 1993. Forest management and biodiversity. B.C. Min. For., Kamloops Region, Dept. For. Sciences, Univ. B.C., Vancouver, B.C. [Unpubl. workshop notes.]

Massie, M.R.C. 1995. Economic component of stand tending. B.C. Min. For., Silv. Branch, Victoria, B.C.

Sullivan, T.P. 1995. Influence of lodgepole pine stand density on red squirrel populations, feeding damage, and wildlife habitat diversity. Silv. Branch, B.C. Min. For., Victoria, B.C. Contract report.

Appendix 1 – List of Contributors

The following people were interviewed on the development of environmental indicators, reviewed earlier versions of the report, and/or provided other information to the study:

Dianne Allen, Habitat Protection Branch, Ministry of Environment, Lands and Parks

Harold Armleder, Forest Sciences, Cariboo Forest Region, Ministry of Forests

Laura Darling, Wildlife Branch, Ministry of Environment, Lands and Parks

Dave Daust, Centre for Applied Conservation Biology, University of British Columbia

Nelly de Geus, Integrated Resource Section, Policy and Planning Div., Ministry of Forests

Dennis Demarchi, Wildlife Branch, Ministry of Environment, Lands and Parks

Nancy Densmore, Silviculture Practices Branch, Ministry of Forests

Andrew Derocher, Forest Sciences, Vancouver Forest Region, Ministry of Forests

Scott Dunn, Campbell River Forest District, Ministry of Forests

Dave Dunbar, Wildlife, Ministry of Environment, Lands and Parks

Robert Elner, Ecosystem Research, Canadian Wildlife Service

Katherine Enns, Larkspur Biological Consultants Ltd.

Matt Fairbarns, Range Branch, Ministry of Forests

Gerry Fox, Fish and Wildlife Branch, Kootenay Region, Ministry of Environment, Lands and Parks

Brian Fuhr, Habitat Branch, Skeena Region, Ministry of Environment, Lands and Parks

Grant Furness, Habitat Protection, Ministry of Environment, Lands and Parks

Ron Gray, Kamloops Forest Region, Ministry of Forests

Tony Hamilton, Wildlife Branch, Ministry of Environment, Lands and Parks

Andrew Harcombe, Conservation Data Centre, Ministry of Environment, Lands and Parks

Anne Harfenist, Marine Bird Biologist, Canadian Wildlife Service

Gordon Hartman (retired from the Department of Fisheries and Oceans)

Chris Hitchcock, Systems Ecologist, Canadian Wildlife Service

Walt Klenner, Kamloops Forest Region, Ministry of Forests

Eric Lofroth, Wildlife Branch, Ministry of Environment, Lands and Parks

Andy MacKinnon, Research Branch, Ministry of Forests

Todd Manning, Branta Consulting

David Marmorek, ESSA Technologies Ltd.

Rhonda Millikin, Upland Bird Biologist, Canadian Wildlife Service

Dean Mills, Canadian Forest Service

Melonie Milum, Guidelines Forester, Ministry of Forests

Ken Mitchell, Research Branch, Ministry of Forests

Ken Morgan, Ecosystem Biologist, Canadian Wildlife Service

Don Morgan, Integrated Resource Management Section, Ministry of Forests

Reinhard Muller, Duncan Forest District, Ministry of Forests

Rick Page, Research Branch, Ministry of Forests

John Parminter, Research Branch, Ministry of Forests

John Payne, Habitat Protection, Ministry of Environment, Lands and Parks

Les Peterson, Research Branch, Ministry of Forests

Ken Polsson, Research Branch, Ministry of Forests

Harry Quesnel, Nelson Forest Region, Ministry of Forests

Cole Shirvell, Pacific Biological Stn., Department of Fisheries and Oceans

John Smith, Research Biometrician, Canadian Wildlife Service

Susan Stevenson, Silvifauna Research

Jeff Stone, Research Branch, Ministry of Forests

Tom Sullivan, Dept. of Forest Science, University of British Columbia

Oliver Thomae, District Land Information Manager, Cranbrook Forest District, Ministry of Forests

Rob Thomson, Integrated Resource Section, Ministry of Forests

Brian Turner, Habitat Protection Branch, Ministry of Environment, Lands and Parks

Sylvia von Schuckmann, Habitat Protection Branch, Ministry of Environment, Lands and Parks

Michaela Waterhouse, Research Section, Cariboo Forest Region, Ministry of Forests

Nancy Wilkin, Habitat Protection Branch, Ministry of Environment, Lands and Parks

Ralph Winter, Silviculture Practices Branch, Ministry of Forests

Dave Woodgate, Integrated Resource Management, Duncan Forest District, Ministry of Forests

Guy Woods, Fish and Wildlife Branch, Kootenay Region, Ministry of Environment, Lands and Parks

Karen Yearsley, Research Branch, Ministry of Forests

Appendix 2 – Description of Environmental Indicators

This appendix describes the environmental indicators that were considered in this analysis, and the relationships used to derive changes in each indicator from the stand data that are produced by TASS.

Indicator: Percent shrub cover

- *Relationship to stand data:* Shrub cover in this analysis depends on canopy closure as shown in Figure A-1. The upper line in this graph shows the growth and subsequent loss of group 1, shade-intolerant shrubs during stand development. The lower line shows the progression of group 2, shade-tolerant shrubs. Prior to canopy closure, total shrub cover can be predicted by summing the group 1 and group 2 cover values expected at the current canopy cover. Total shrub cover can be predicted in the same way following stand treatments that reduce canopy cover, provided that neither shrub group has been at 0% cover for more than 10 years at the time of treatment. If either group has been at 0% cover for more than 10 years, it will not be restored by stand tending because the bud bank will be dead.[10] It may happen that only group 1 shrubs are in this condition, in which case total shrub cover should be predicted from the group 2 line alone. If both groups have been lost for more than 10 years, shrub cover should be expected to remain at zero throughout the rest of the rotation.

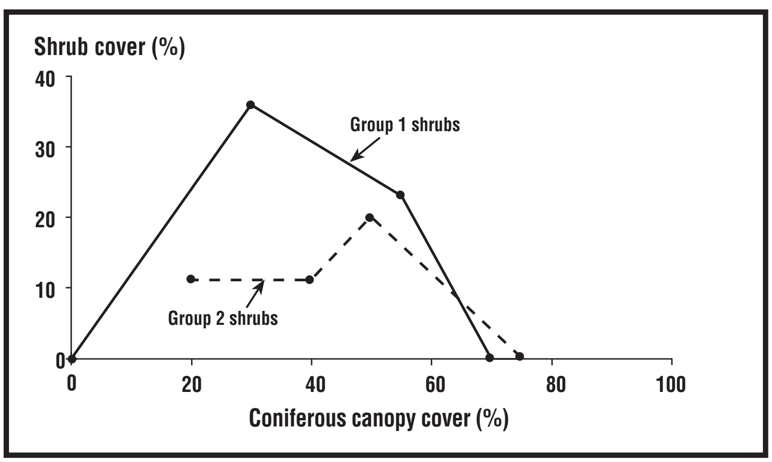

Figure A-1. Percent shrub cover as a function of canopy closure. See text for explanation.

- *Ecological units where valid:* CWH, the wet subzones of ICH, and possibly SBS. High site indices only.
- *Reliability:* The relationship is based on experimental field data and expert opinion. However, debris loading following stand tending may inhibit understorey recovery. Also, since it considers only light availability to the understorey, this relationship is not suitable for predicting the understorey response to fertilization. Fertilization will

[10] Thinning after canopy closure results primarily in increased growth of swordfern (which neither deer, elk, nor bear like), with little increase in berry-producing shrubs.

exert an influence on understorey development through its effect on nutrient availability, in addition to its effect on canopy closure.

- *Sources:* Interview with Tony Hamilton; Daust and Hafer, 1992.

Indicator: Grizzly bear feeding habitat quality

- Relationship to stand data: Feeding habitat quality for grizzly bear depends in part on shrub cover which, as calculated above, is influenced by canopy cover. Higher forage value is associated with higher shrub cover, as shown in Figure A-2.

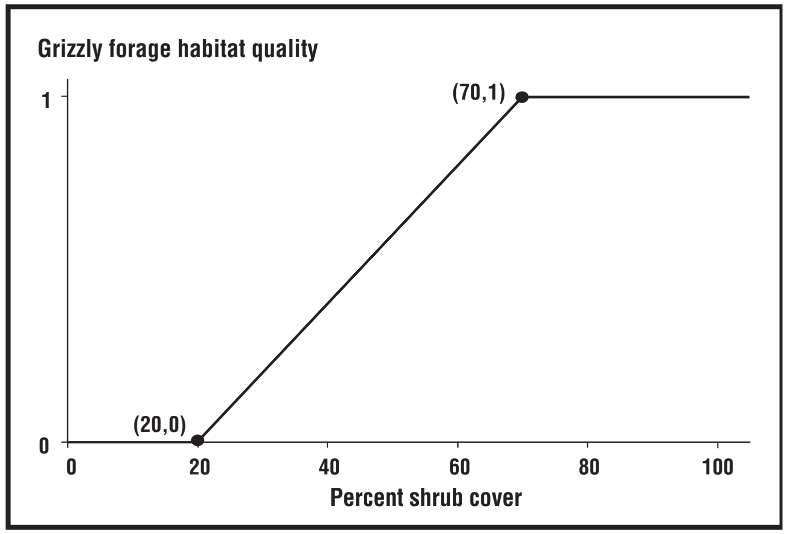

FIGURE A-2. Forage habitat quality for grizzly bear as a function of percent shrub cover.

- Ecological units where valid: CWH (wet hemlock stands, not Douglas-fir); wet sub-zones of ICH; possibly SBS.
- *Reliability:* Shrub cover is used as a surrogate for fruit production, because the latter is impractical to measure directly. Actual fruit production would depend not just on percent shrub cover, but on the species composition of that shrub cover. Bears avoid human activity, so effective habitat values will be lower during tending operations.
- *Sources:* Interview with Tony Hamilton.

Indicator: Volume of shrubs and herbs

- *Relationship to stand data:* The equilibrium volume of shrubs and herbs can be estimated from canopy closure and time since thinning, as indicated in Figures A-3 and A-4. The actual volume at any point in time can be estimated by assuming that a stand will be below the equilibrium line following any sudden decrease in canopy closure but will move back towards equilibrium in subsequent years. The volume of shrubs can be assumed to increase toward equilibrium at a rate of 10 m^3 /100 hectares each year. Herb volume can be assumed to reach the equilibrium line by the following year. Change in canopy closure during this time will be forecast by TASS. The resulting stand trajectory can be plotted as shown in the following figures.

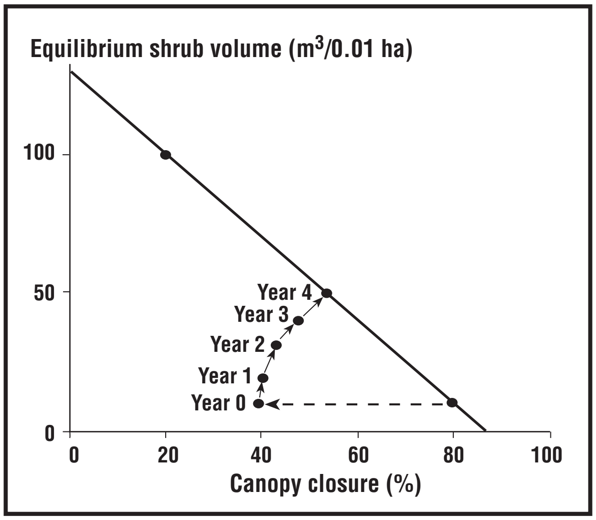

FIGURE A-3. Equilibrium shrub volume as a function of canopy closure. See text for explanation.

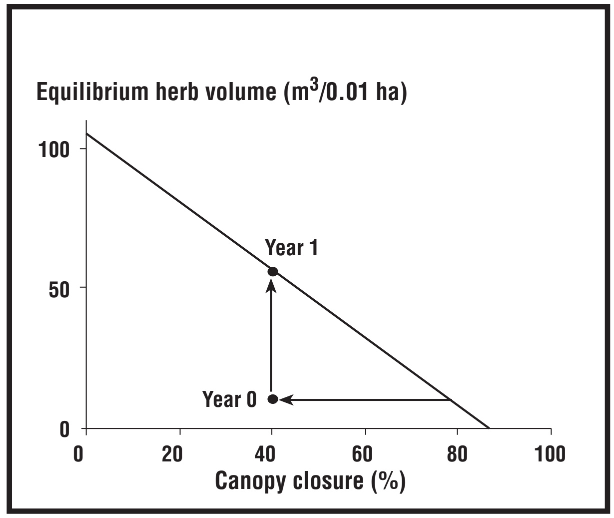

FIGURE A-4. Equilibrium herb volume as a function of canopy closure. See text for explanation.

- *Ecological units where valid:* Southern interior lodgepole pine stands.
- *Reliability:* The relationship is based on average data for three interior sites over a five-year study (unpublished); it is "projective" rather than merely speculative, and should be fairly reliable. However, it does ignore the interaction between herb and shrub production. Shrub grow-back could facilitate herb growth by providing shade in summer and helping retain soil moisture. Also, since it considers only the availability of light to the understorey, this relationship is not suitable for predicting the understorey response to fertilization. Fertilization will exert an additional influence on understorey development through its effect on nutrient availability.
- *Sources:* Interview with Tom Sullivan.

Indicator: Number and size of snags

- *Relationship to stand data:* TASS simulates (random) juvenile mortality and the (non-random) mortality of suppressed trees due to over-topping. Jeff Stone has developed an extension to TASS to track the rate of fall, decay and breakage of dead trees, and provide data on the number of snags still standing at any point in time during the simulation. In doing this, the extension considers the influence of snag size, species, and age.
- *Ecological units where valid:* The snag extension is calibrated separately for Douglas-fir, western hemlock and lodgepole pine, based on available data for temperate forests (Cline *et al.* 1980, and Harmon *et al.* 1986).

- *Reliability:* The snag extension used here does not distinguish coastal and interior Douglas-fir, and has had to assume that the rate of snag fall is independent of the cause of death, the biogeoclimatic zone, and the site index. This extension is currently under revision. However, it seems to perform quite well for aggregated data like the size classes considered in this study, and for the rotation length considered in this study.
- *Sources:* Interview with Jeff Stone.

Indicator: Volume and size of coarse woody debris

- *Relationship to stand data:* For the purpose of comparing different stand tending regimes, the average volume of debris added to the stand each year may be assumed to be roughly proportional to the average volume of debris present at any one time during the rotation. The former quantity—debris inputs—can be estimated from the volume of bole wood from live and dead trees that falls in each step (obtained from Jeff Stone's snag extension to TASS). Debris volumes were calculated from bole diameter and height using standard taper equations.
- *Ecological units where valid:* Roughly valid for the purpose of comparing different regimes wherever the snag extension is valid.
- *Reliability:* The average annual debris input over a rotation is sufficient to allow an unbiased comparison of the volume of debris present under different regimes as long as the rate of log decay is independent of the stand tending regime employed in a stand (i.e., if decay rates depend on species, site index and piece size, but not on stand density or canopy closure *per se*). Strictly speaking, decay rates probably do depend on canopy closure.[11] However, since decay rates are expected to be slowest under the same conditions in which snag production is greatest (i.e., under dense canopies), taking this dependence into account should only increase the debris differences reported here, not reduce or reverse them.

  The calculation of debris volume used here does not account for the reduction in snag diameter as the outer bark is lost, but this is only a small portion of total diameter and further diameter reductions are very slow while snags remain standing. In reality, large branches could also contribute to coarse woody debris volumes. It was not technically feasible to consider the volume of these branches in this analysis, but they should be a relatively minor component of total debris. Branches removed by pruning would be too small to contribute to coarse woody debris. Stems cut during spacing were also not included in the debris values reported

[11] No data are available with which to quantify the dependence.

here. The original analysis indicated that they usually amounted to less than 3% of the total amount of debris that would be produced over the rotation in untended stands, but they constitute a larger proportion of the debris produced in thinned stands and are sometimes the bulk of all debris ever produced in those stands (Greenough *et al.* 1995).

- *Sources:* Based in part on an interview with Brian Fuhr.

Indicator: Pileated woodpecker habitat quality

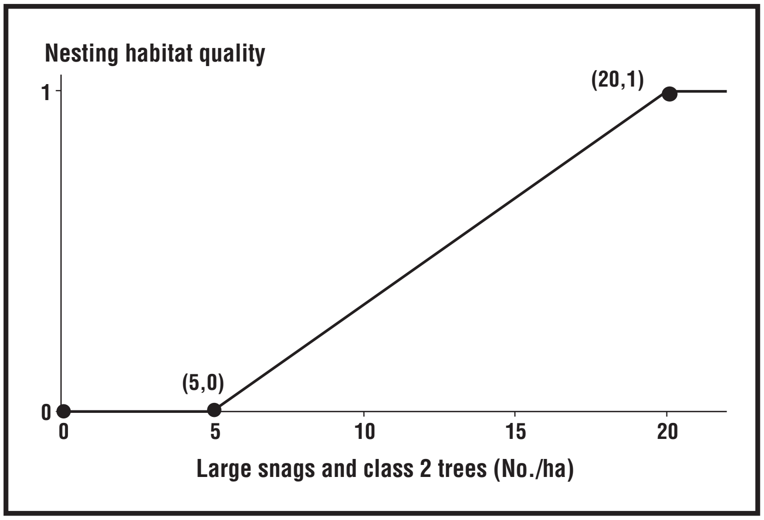

Figure A-5. Nesting habitat quality for pileated woodpeckers as a function of the density of large (> 40 cm) snags and class 2 trees.

- *Relationship to stand data:* Pileated woodpeckers require large snags and damaged trees for nesting, feeding, and winter roosting. The relationship between nesting habitat quality and the density of snags and class 2 live trees,[12] both > 40 cm dbh, is shown in Figure A-5.
- *Ecological units where valid:* The relationship is relevant in all biogeoclimatic zones in which the species occur: CDF, CWH, MH, BG, PP, IDF, MS, ICH, SBPS, SBS, ESSF, BWBS.
- *Reliability:* Actual habitat suitability depends on not only the quantity of large dead or damaged trees but also their quality (species and state of decay), location (proximity to riparian areas and hardwoods), and distribution (clumped vs. uniform).
- *Sources:* Interview with Todd Manning.
- *Additional indicators of habitat quality:* The following snag size and density conditions were also adopted as measures of pileated woodpecker habitat quality:

[12] Because TASS does not distinguish class 2 trees, this analysis assumed that half of the new large snags (> 40 cm) created in each time step must have been class 2 live trees (i.e., dying trees) in the previous time step. This is probably a conservative estimate. However, the estimate should not introduce any bias into the comparison of different tending regimes because the number of class 2 trees produced over a rotation must be highly correlated with the number of snags. Omitting class 2 trees from the analysis will simply underestimate woodpecker habitat quality in all TASS runs.

– **Condition 1** (from Klenner and Kremsater (1993), and Kremsater and Bunnell (1993)): At least 0.15 snags of 60 cm dbh or greater are required per hectare to provide nesting habitat for pileated woodpeckers in the Kamloops Forest Region.

– **Condition 2** (from Neitro *et al.* (1985)): 1.60 snags of 25 inches (roughly 60 cm) would be required per hectare to support the maximum density of nesting pairs observed in published studies from western Oregon and Washington.[13]

– **Condition 3** (from Guy *et al.* (1994)[14]): This study in the Kamloops area found that pileated woodpeckers will nest in live trees and may even prefer nesting in live trees. The minimum size of tree that was observed to be used for nesting was 25.8 cm dbh (although, on average, the trees used for nesting were 40.5 cm dbh). A small number of large-enough trees per hectare may or may not be sufficient for nesting, as it may be that only a fraction of all such trees have suitable characteristics. In either case, the complete size distribution of live trees was not recorded during the TASS runs in this analysis. Therefore, condition 3, the minimum requirement, was implemented as a requirement the quadratic mean diameter of live trees exceed 25.8 cm.

Indicator: Spotted owl habitat quality

- *Relationship to stand data:* Type A habitat—habitat that is suitable for nesting and all other activities—requires the following characteristics in the Coastal Western Hemlock (CWH) biogeoclimatic zone:
  – Canopy closure between 60 and 80%;
  – Overstorey dominated by trees ≥ 76 cm dbh;[15] and
  – Presence of snags ≥ 76 cm dbh, typically more than five per hectare.[16]

13 This value has been corrected from that shown in table 6 of the reference which is erroneously based on the *minimum* reported nesting density.

14 Guy, S., T. Manning, J. Cooper, M. Fenger, and P. Bradford. 1996. Wildlife trees: a field guide to the tree dependent animal species of British Columbia. Lone Pine Publishing, Edmonton, Alta. In press.

15 In the current analysis, the criteria for size of live trees were implemented as tests on 'quadratic mean diameter' at the specified threshold.

16 In the current analysis, this criterion was implemented as 'presence of snags ≥ 60 cm dbh.'

- Type B habitat—habitat that is suitable for roosting, foraging and dispersal—requires the following characteristics in the CWH:
  - Canopy closure between 60 and 80%;
  - Overstorey dominated by trees ≥ 51 cm dbh; and
  - Presence of snags ≥ 51 cm dbh.[17]
- In the Interior Douglas-fir (IDF) biogeoclimatic zone, type A habitat requires the following characteristics:
  - Canopy closure between 60 and 80%;
  - Overstorey dominated by trees ≥ 51 cm dbh; and
  - Presence of snags ≥ 51 cm dbh, typically more than seven per hectare.[17]
- In the IDF, type B habitat—which may be used for nesting in this zone—requires the following characteristics:
  - Canopy closure ≥ 50%;
  - Overstorey dominated by trees ≥ 30 cm dbh; and
  - Presence of snags and down logs, some of which are of similar size to the dominant live trees.[18]
- *Ecological units where valid:* The CWH and IDF biogeoclimatic zones, as noted. The CWH criteria were applied to both western hemlock and coastal Douglas-fir stands in this analysis, and the IDF criteria were applied to both interior Douglas-fir and lodgepole pine stands.
- *Reliability:* These criteria give only minimum conditions for a stand to be suitable for spotted owls. Other criteria must also be met (e.g., multi-species canopy, presence of deformed trees). The criteria are based on observations in Washington state, but have been extrapolated to the most similar biogeoclimatic zones in B.C.
- *Sources:* Dunbar and Blackburn (1994).

Indicator: Bat habitat condition

- *Relationship to stand data:* The *Guidelines for Maintaining Biodiversity During Juvenile Spacing* suggest retention of an average per hectare of 5 to 10 snags (or hollow live trees) that exceed 50 cm dbh in coastal areas, or 40 cm dbh in the interior.
- *Ecological units where valid:* The coast (50 cm dbh snags) and interior (40 cm dbh snags).

[17] In the current analysis, this criterion was implemented as 'presence of snags ≥ 50 cm dbh.'

[18] In the current analysis, this criterion was implemented as 'presence of snags ≥ 25 cm dbh.'

- *Reliability:* Suggested guideline only.
- *Sources: Guidelines for Maintaining Biodiversity During Juvenile Spacing* (Park and McCulloch 1993).

Indicator: Hoary bat reproductive habitat quality

- *Relationship to stand data:* Size of live trees and canopy closure.
  - The following table shows the reproductive habitat suitability indices that Ritcey et al. (1988) assign for hoary bats in Douglas-fir—ponderosa pine stands with different tree sizes and levels of canopy closure. According to this ranking scale, a 'high' suitability ranking is numerically equivalent to a '1,' and lower rankings receive lower numerical values.

Reproductive Habitat Suitability Indices

	Usual diameter at breast height of trees in the stand[19]		
Canopy cover	< 25 cm	25–60 cm	> 60 cm
0–25 %	0	0	0.2
26–65%	0	0.2	0.5
66–100%	0	0.5	1.0

- *Ecological units where valid:* Douglas-fir–ponderosa pine stands in the Southern Interior Ecoprovince.
- *Reliability:* The habitat suitability rankings presented in Ritcey *et al.* (1988) were developed by species experts at modelling workshops. Thus these rankings may be taken to represent a consensus of expert opinion.
- *Sources:* Ritcey *et al.* (1988) and interview with Andrew Harcombe.

Indicator: Cougar feeding habitat quality

- *Relationship to stand data:* The following table shows the feeding habitat suitability indices that Ritcey *et al.* (1988) assign for cougars in Douglas-fir–ponderosa pine stands with different tree sizes and levels of canopy closure. According to this ranking scale, a high suitability ranking is numerically equivalent to a '1,' and lower rankings receive lower numerical values.

19 In the current analysis, this criterion was implemented as a test on the quadratic mean diameter (breast height) of the trees in the stand.

Feeding Habitat Suitability Indices

Canopy cover	Usual diameter at breast height of trees in the stand[20]		
	< 25 cm	25–60 cm	> 60 cm
0–25 %	0.5	1	1
26–65%	0.5	0.5	0.5
66–100%	0.2	0.2	0.2

- *Ecological units where valid:* Douglas-fir–ponderosa pine stands in the Southern Interior Ecoprovince.
- *Reliability:* The habitat suitability rankings presented in Ritcey *et al.* (1988) were developed by species experts at modelling workshops. Thus these rankings may be taken to represent a consensus of expert opinion.
- *Sources:* Ritcey *et al. (*1988) and interview with Andrew Harcombe.

Indicator: "Functional maturity"

- *Relationship to stand data:* The following table shows the *minimum* structural objectives that have been established for functionally "mature" stands in the Prince Rupert Forest Region. These objectives are based on a percentage (as low as 10%) of the values found naturally in late seral stands.

Minimum structural objectives	ICH	CWH
Snags/ha > 17.5 cm dbh	10	10
Snags/ha > 27.5 cm dbh	5	5
Snags/ha > 37.5 cm dbh	3	3
Debris > 10 cm (m^3/ha)[21]	50	50
Live trees/ha > 17.5 cm dbh[22]	400	300
Live trees/ha > 37.5 cm dbh[23]	20	30

[20] In the current analysis, this criterion was implemented as a test on the quadratic mean diameter (breast height) of the trees in the stand.

[21] In the current analysis, this criterion was implemented as a requirement that some debris greater than 10 cm was created in the preceding time step (a period of five years, except when interrupted by a tending operation).

[22] In the current analysis, this criterion was implemented as a requirement that the total *basal area* of trees larger than 17.5 cm be at least as great as the basal area of the given number of 17.5 cm trees. This resulted in a minimum basal area of 9.62 m^2/ha in the ICH, and 7.22 m^2/ha in the CWH. The criterion was adapted in this way after it was observed in test runs that undisturbed 'mature' stands would lose their mature status after year 130 or so, because natural mortality reduced the total tree density even though the remaining trees were much larger than 17.5 cm.

[23] This criterion was adapted for the current analysis as explained in the previous footnote. That is, the basal area of trees larger than 37.5 cm was required to exceed 2.21 m^2/ha in the ICH and 3.31 m^2/ha in the CWH.

- *Ecological units where valid:* ICH and CWH, as specified. In the current study, these criteria were also used to calculate an index of functional maturity for coastal Douglas-fir (using the CWH criteria), and both interior Douglas-fir and ponderosa pine (using the ICH criteria).
- *Reliability:* The relationship is meant to serve as a guideline only; there is no guarantee that maintaining structural attributes at 10% of their natural values is sufficient to maintain all other environmental values.
- *Sources:* Steventon (1994).

Appendix 3 – Description of TASS Runs in this Analysis

The table below shows the parameter values that were used in each TASS run. The abbreviations used in the table are as follows: "Fdc" stands for coastal Douglas-fir, "Fdi" is interior Douglas-fir, "Pli" is interior lodgepole pine, "Hw" is western hemlock, "CT" is commercial thinning, "m" stands for metres, "y" is for years, "n" stands for naturally regenerated trees, "p" represents planted trees, "CC" stands for canopy closure, "qDBH" is the quadratic mean diameter at breast height, and "ASAP" indicates that a target is to be achieved as soon as possible. "*" is a reminder that all existing snags were felled on each stand entry for runs 14, 15, and 16 only. "Pruning Height" is the height to which branches were pruned on each stand entry. All densities are given as the number of stems per hectare.

Parameter Values for Each TASS Run

Run #	Species	Site index	Method of regeneration	Initial density	Spacing timing	Spacing density	Fertilization timing	Pruning timing	Pruning height	CT timing	CT density
1	Fdc	36	planted	2500	–	–	–	–	–	–	–
2	Fdc	36	planted	2500	–	–	–	–	–	30y	200
3	Fdc	36	planted	2500	–	–	–	–	–	40y	200
4	Fdc	36	planted	2500	–	–	–	–	–	40y	800
5	Fdc	36	planted	2500	14y	500	–	–	–	–	–
6	Fdc	36	planted	2500	14y	500	–	–	–	30y	200
7	Fdc	36	planted	2500	14y	800	–	–	–	–	–
8	Fdc	36	planted	2500	14y	800	–	–	–	30y	200
9	Fdc	36	planted	2500	14y	800	–	–	–	40y	200
10	Fdc	30	planted	2500	–	–	–	–	–	–	–
11	Fdc	30	planted	2500	–	–	–	–	–	50y	200
12	Fdc	30	planted	2500	19y	500	–	–	–	–	–
13	Fdc	30	planted	2500	19y	500	–	–	–	40y	200
14*	Fdc	36	planted	2500	–	–	–	–	–	40y	200
15*	Fdc	36	planted	2500	–	–	–	–	–	40y	800
16*	Fdc	36	planted	2500	14y	800	–	–	–	40y	200
21	Pli	22	natural	10000	–	–	–	–	–	–	–
22	Pli	22	natural	10000	–	–	–	–	–	30y	1200
23	Pli	22	natural	10000	–	–	–	–	–	40y	600
24	Pli	22	natural	2500	–	–	–	–	–	–	–
25	Pli	22	natural	2500	–	–	–	–	–	50y	1200
26	Pli	16	natural	10000	–	–	–	–	–	–	–
27	Pli	16	natural	10000	–	–	–	–	–	70y	900
31	Pli	25	natural	10000 (at 4m)	–	–	–	–	–	–	–
32	Pli	25	natural	10000 (at 4m)	4m	2300	–	–	–	–	–
33	Pli	25	natural	10000 (at 4m)	4m	1500	–	–	–	–	–
34	Pli	25	natural	10000 (at 4m)	4m	900	–	–	–	–	–
35	Pli	25	natural	10000 (at 4m)	4m	500	–	–	–	–	–
36	Pli	15	natural	10000 (at 4m)	–	–	–	–	–	–	–
37	Pli	25	natural	1600 (at 4m)	–	–	–	–	–	–	–

(continued)

Parameter Values for Each TASS Run (continued)

Run #	Species	Site index	Method of regeneration	Initial density	Spacing timing	Spacing density	Fertilization timing	Pruning timing	Pruning height	CT timing	CT density
38	Pli	25	natural	1600 (at 4m)	4m	900	–	–	–	–	–
39	Pli	25	natural	1600 (at 4m)	4m	500	–	–	–	–	–
40	Pli	15	natural	10000 (at 4m)	4m	900	–	–	–	–	–
43	Pli	25	natural	4000 (at 4m)	–	–	–	–	–	–	–
44	Pli	25	natural	1600 (at 4m)	4m	900	–	6m	3m	–	–
45	Pli	25	natural	1600 (at 4m)	4m	500	–	6m	3m	–	–
48	Pli	25	natural	4000 (at 4m)	4m	500	–	–	–	–	–
49	Pli	25	natural	4000 (at 4m)	4m	500	–	6m	3m	–	–
51	Fdi	25	natural	10000 (at 4m)	–	–	–	–	–	–	–
52	Fdi	25	natural	10000 (at 4m)	4m	1500	–	–	–	–	–
53	Fdi	25	natural	10000 (at 4m)	4m	900	–	–	–	–	–
54	Fdi	25	natural	10000 (at 4m)	4m	500	–	–	–	–	–
55	Fdi	16	natural	10000 (at 4m)	4m	1500	–	–	–	–	–
56	Fdi	16	natural	10000 (at 4m)	4m	500	–	–	–	–	–
57	Fdi	25	natural	4000 (at 4m)	–	–	–	–	–	–	–
58	Fdi	25	natural	4000 (at 4m)	4m	1500	–	–	–	–	–
59	Fdi	25	natural	4000 (at 4m)	4m	900	–	–	–	–	–
60	Fdi	25	natural	4000 (at 4m)	4m	500	–	–	–	–	–
61	Fdi	16	natural	4000 (at 4m)	4m	1500	–	–	–	–	–
62	Fdi	16	natural	4000 (at 4m)	4m	500	–	–	–	–	–
63	Fdi	25	natural	4000 (at 4m)	4m	900	–	6m	3m	–	–
64	Fdi	25	natural	4000 (at 4m)	4m	500	–	6m	3m	–	–
65	Fdi	25	natural	4000 (at 4m)	4m	900	4m	6m	3m	–	–
66	Fdi	25	natural	4000 (at 4m)	4m	500	4m	6m	3m	–	–
71	Fdc	25	900p + 300n	1200 (BH–age 7)	–	–	–	–	–	–	–
72	Fdc	30	900p + 300n	1200 (BH–age 7)	–	–	–	–	–	–	–
73	Fdc	30	900p + 300n	1200 (BH–age 7)	6m	500	–	–	–	–	–
74	Fdc	35	900p + 300n	1200 (BH–age 7)	–	–	–	–	–	–	–
75	Fdc	35	900p + 300n	1200 (BH–age 7)	6m	600	–	–	–	–	–
76	Fdc	35	900p + 300n	1200 (BH–age 7)	6m	300	–	–	–	–	–
77	Fdc	35	900p + 300n	1200 (BH–age 7)	6m	300	6m	–	–	–	–
78	Fdc	35	900p + 300n	1200 (BH–age 7)	6m	300	6m + 30y	–	–	–	–
79	Fdc	35	900p + 300n	1200 (BH–age 7)	12m	500	–	–	–	–	–
80	Fdc	35	900p + 300n	1200 (BH–age 7)	12m	300	–	–	–	–	–
81	Fdc	35	planted	400 (BH–age 10)	–	–	–	–	–	–	–
82	Fdc	35	planted	400 (BH–age 10)	–	–	–	10y +13y	2.5m + 5.5m	–	–
83	Fdc	30	natural	4000 (pre–PCT)	–	–	–	–	–	–	–
84	Fdc	30	natural	4000 (pre–PCT)	6m	1000	–	–	–	–	–
85	Fdc	30	natural	4000 (pre–PCT)	6m	500	–	–	–	–	–
91	Hw	30	natural	4000 (BH–age 7)	–	–	–	–	–	–	–
92	Hw	30	natural	4000 (BH–age 7)	6m	800	–	–	–	–	–
93	Hw	30	natural	4000 (BH–age 7)	6m	600	–	–	–	–	–
94	Hw	30	natural	4000 (BH–age 7)	6m	300	–	–	–	–	–
95	Hw	30	natural	4000 (BH–age 7)	12m	600	–	–	–	–	–
96	Hw	30	natural	4000 (BH–age 7)	12m	300	–	–	–	–	–
97	Hw	30	natural	4000 (BH–age 7)	15y	1000	–	–	–	–	–
98	Hw	30	natural	4000 (BH–age 7)	15y	600	–	–	–	–	–
99	Hw	30	natural	4000 (BH–age 7)	15y	600	–	10y +13y	2.5m + 5.5m	–	–

(continued)

Parameter Values for Each TASS Run (concluded)

Run #	Species	Site index	Method of regeneration	Initial density		Environmental goal and tending regime
Runs designed to meet environmental goals:						
101	Fdc	36	planted	2500	Goal:	attempt to optimize production of large snags & pileated habitat
					Regime:	space at 14y to 650 stems/ha.
102	Fdc	36	planted	538	Goal:	to achieve high snag values of Run 5 without intensive treatment
					Regime:	untended.
103	Fdc	36	planted	2500	Goal:	to improve production of salal, huckleberries, herbs & lichen [treat to maintain CC between 40% and 60%]
					Regime:	space or CT at 12y to 1012, 14y to 575, 17y to 308, 21y to 170, 27y to 102, 36y to 64, and 58y to 40 stems/ha.
104	Fdc	36	planted	2500	Goal:	attempt to improve forage production with fewer treatments
					Regime:	space at 14y to 200 stems/ha, then CT at 25y to 100 stems/ha.
105	Fdc	36	planted	2500	Goal:	to improve spotted owl habitat quality values [treat to maintain CC 40–60% until qDBH=76cm, then CC 60–80%]
					Regime:	as in run 103, but omitting the last CT.
106	Pli	25	natural	10000 (at 4m)	Goal:	to increase herb & shrub biomass, & small mammal diversity [treat to maintain CC below 25%]
					Regime:	space at 12y to 290, and CT at 30y to 53 stems/ha.
107	Pli	25	natural	10000 (at 4m)	Goal:	to improve spotted owl habitat quality values [treat to achieve qDBH=30cm with CC above 66% ASAP]
					Regime:	space at 16y to 1022, and CT at 30y to 264 stems/ha.
109	Hw	30	natural	4000 (BH–age 7)	Goal:	to increase forage production & grizzly habitat values [treat to maintain CC between 40% and 60%]
					Regime:	space or CT at 16y to 1060, 19y to 550, 23y to 299, 29y to 173, 39y to 104, and 58y to 64 stems/ha.
110	Hw	30	natural	4000 (BH–age 7)	Goal:	to improve spotted owl habitat quality values [treat to maintain CC 40–60% until qDBH=76cm, then CC 60–80%]
					Regime:	as in run 109, but omitting the last CT.
111	Fdi	25	natural	4000 (pre-space)	Goal:	to improve cougar habitat quality values [treat to maintain CC below 25%]
					Regime:	space at 14y to 198, and CT at 28y to 28 stems/ha.
112	Fdi	25	natural	4000 (pre-space)	Goal:	to improve hoary bat & cougar habitat quality values [treat to achieve qDBH=51cm ASAP, then maintain CC 66–80%]
					Regime:	space at 14y to 254, and CT at 25y to 97 stems/ha.