CRANBROOK LANDSCAPE MODEL

DRAFT

Prepared by
Don Morgan, R.P.Bio
Ministry of Forests Research Branch, Smithers

S. Andrew Fall, PhD.
Gowland Technologies, Victoria
and
Rob McCann, MSc.
Consultant

Executive Summary

The Cranbrook Landscape Model (CLM) uses spatially-explicit simulation modelling to capture knowledge about the Cranbrook timber supply area, including the Flathead SRMP area, to simulate landscape change over time, to perform retrospective scenarios, and to project implications of land-use policies on timber supply, natural disturbance, coarse filter biodiversity and habitat for species of interest in the Cranbrook timber supply area. Associated spatial analysis models are used to examine patterns of historical logging, fires and mountain pine beetle, and to back-cast forest conditions.

The CLM is intended to examine future trends if current forest practices continue unchanged (Base Case Analysis), estimate landscape patterns that would result from natural disturbances in the absence of industrial forestry (Natural Case Analysis), experimentally examine consequences of alternative forest practices (Scenario Analysis), and project future trends likely to result from the final management direction recommended in the SRMP (Final Scenario Analysis).

The CLM consists of an interacting suite of SELES[1] (Fall and Fall, 2001) models. The base landscape module combines spatial timber supply projection with road building, species succession and natural disturbance. It can project specific locations where roads are built and logging undertaken, and simulate forest succession and growth. In the Natural Case simulation, the model applies forest-replacing disturbances (including fire and insect outbreaks) in each Biogeoclimatic Variant based on disturbance history information, creating disturbances patches across the landscape. The CLM projects conditions on each individual one-hectare piece of the landscape, so both temporal and spatial consequences of management policies and decisions can be explored and contrasted with natural disturbance.

Implications for timber supply are explored within the core CLM module. For any given set of management constraints, the CLM is run iteratively to test different annual cut rates and converge on the maximum rate (expressed as a proportion of the current harvest level) that satisfies long range yield criteria.

The CLM does not in itself evaluate biodiversity or rate wildlife habitat suitability. Instead, the CLM exports descriptive landscape data, which is then either interpreted directly by domain experts, or used to drive separate computer models which rate habitat suitability for species of interest.

Biodiversity data exported by the CLM include forest age, patch size, patch connectivity, and other related landscape metrics. Interpretation of biodiversity data is intended to be undertaken by the project leaders and participants with the assistance of domain experts.

The CLM exports other landscape data such as forest age, canopy closure, and tree height to species models that use the data to evaluate habitat suitability. Species models for grizzly bear, woodland caribou, and American marten are programmed in NETICA, and a model

---

[1] Spatially Explicit Landscape Event Simulator

for northern goshawk is implemented in SELES as an independent module of the CLM. Since the CLM provides landscape data both over time and for each hectare in the SRMP area, the combination of the CLM and species models can estimate how the spatial distribution of habitat changes over time.

The CLM also exports data regarding species of interest for which no species models are available. These data are intended, rather than for use in species models, for direct interpretation by a domain expert. For example, seral state data is used to assess general implications of landscape change for moose, and distance to roads is used to assess implications of access patterns for mountain goat.

The CLM is intended to assist the Cranbrook Timber Supply Area MPB stakeholders (CBMPB) by exploring implications of alternative management policies and decisions. Results from Base Case and Natural Case simulations are incorporated into the Draft Environmental Risk Assessment (Edie, 2003). Results from scenario simulations now underway are intended to facilitate discussion of the CBMPB of alternate management policies and decisions that they may wish to recommend. Once the CBMPB chooses a recommended management direction, the CLM will help identify the long-term consequences of recommended management.

Effective interpretation of CLM projections is best accomplished with the assistance of relevant domain experts. The CLM cannot examine all potential management decisions, nor is it designed to directly undertake necessary social choices among competing land use alternatives. Ultimately, human judgement on the parts of both CBMPB and expert advisors will be critical supplements to the information provided by the CLM.

Table of Contents

Acknowledgements

Development of the Cranbrook Landscape Model was a collaborative effort by many people. The process required input from experts in a wide variety of fields, including among others, data management, spatial analysis, environmental risk assessment, decision support systems, timber supply, timber inventory, operational forestry, species biology and land use planning. It would be difficult to list all those who have contributed in one way or another. However, the authors wish to acknowledge the particular efforts of Fred Hovey and Bruce McLellan of the Ministry of Forests, Tony Hamilton of the Ministry of Water, Air and Land Protection, Gord Stenhouse, Alberta Fish and Wildlife, Rob McCann and Michael Proctor, independent consultants, Greg Utzig, Kutenai Nature Investigations Ltd, Dave Quinn East Kootenay Environmental Society, Ken Streloff Tembec Industries, John Bergenske East Kootenay Environmental Society and Rick Ellis Ellis & Associates. Without the considerable effort provided by these persons, development and interpretation of the CLM would not have been accomplished.

.

1.0 Introduction

The purpose of this document is to describe the Cranbrook Landscape Model, and clarify its role in the FIA projects “A Strategic Analysis Framework for Managing Forests under the Mountain Pine Beetle Outbreak “ and “Development of analytic and decision models for assessing grizzly bear needs from forest management objectives” (Grizzly Bear Decision Support). Intended audiences are the Flathead landscape stakeholders including; government agencies, MoE, MoF and ILMB, Tembec and Canfor Licensees, Nature Trust, Nature Conservancy, and the East Kootenay Environmental Society.

The Cranbrook Landscape Model (CLM) is a set of spatial simulation models implemented using the Spatially Explicit Landscape Event Simulator spatio-temporal modelling tool (SELES; Fall and Fall, 2001). These models track conditions on the landscape, and provide data used by domain experts and other computer models to examine timber supply impacts, coarse filter biodiversity and habitat suitability for selected wildlife species, specifically Grizzly Bear (*Ursus Horribilis*). Further detail on the structure of the CLM and the linkage of its components is provided later in this document.

The CLM was constructed under direction from the Grizzly Bear Decision Support project (GBDS) and the Cranbrook study area MPB stakeholders (CBMPB). The models purpose is to help the CBMPB and GBDS project leaders and stakeholders examine future consequences of management directions on landscape condition and grizzly bear habitat supply. Specifically, the CLM will be used to:

- project future trends in coarse filter biodiversity, and indicators of grizzly bear habitat under current forest management continues,.
- project patterns of forest structure that would exist on the landscape as a result of natural disturbance in the absence of industrial forestry, and
- experimentally examine future trends in timber, biodiversity and indicators of wildlife habitat supply if alternate forest management decisions are made.

Construction of the CLM is a collaborative effort by a team of experts from both inside and outside government. The team includes experts in data management, spatial analysis, environmental risk assessment, decision support systems, timber supply, timber inventory, operational forestry, species biology, conservation biology and land use planning. Construction and interpretation of the CLM will benefit from experience in other planning processes, particularly the Morice Land and Resource Management Plan (LRMP), North Coast LRMP, planning undertaken regarding mountain pine beetle attack in the Kamloops, Morice and Lakes TSAs (Fall et al. 2002, Fall et al. 2003), and collaboration with Timber Supply Branch (Fall 2002). Rather than starting from scratch, implementation of the CLM started with SELES programs originally prepared during mountain pine beetle evaluation, Morice LRMP (Fall et al. 2004) and the North Coast LRMP (Morgan et al. 2002) process.

Results from the CLM are intended to be considered by the GBDS and the CBMPB project leaders in the context of understanding landscape dynamics and interactions. Results should be interpreted with the advice from, and discussion with, appropriate technical experts. There are many reasons why expert advice may be helpful, but three major ones, with respect to the CBMPB, deserve mention here:

- Output from the model must be evaluated with the underlying assumptions and data limitations in mind. Since it is unlikely that all CBMPB members will be able to become sufficiently familiar with the CLM to fully understand its characteristics and limitations, expert assistance can help ensure that model output is kept in appropriate perspective.
- It is not feasible, both due to time limitations and to technical constraints, for the CLM to test all management decisions of potential interest to the CBMPB. At best, the CLM can clarify the implications of only some management options, not all of them. This means that expert assistance can help combine and compare results of formal modelling with other means of analysis. There is insufficient time to perform complete analysis of the timber supply implications. The timber supply implications are meant to capture a coarse assessment of the relative degree of impact of different scenarios.
- Finally, the CLM describes the technical ecological dimension of a socio-ecological system. The CBMPB may have an interest in considering social choices, not just technical projections. The CLM can provide information relevant to these social choices, but it is not set up to, or intended to, directly assist with the necessary and important social choices that will inevitably be part of a full discussion of socio-ecological system condition. Human judgement on the part of CBMPB and technical advisors will be very important regardless of model projections.

Remaining sections of this report describe the structure and functioning of the CLM. Linkages with grizzly bear models and other analysis will be described in Section 3, but detailed descriptions of the species models themselves have been undertaken elsewhere, and will not be repeated here.

2.0 Cranbrook Landscape Model Description

This part of the document briefly describes the concepts (main assumptions) used in the Cranbrook Landscape Model developed for the Cranbrook study area. It describes the planning indicators calculated and the ecological and management processes modelled. Appendices describe more details regarding calibration with the timber supply review analysis, and specific model outputs.

2.1 Overview of the SELES Model for the Cranbrook TSA

The Cranbrook Landscape Model (CLM) was developed with SELES (Spatially Explicit Landscape Event Simulator; Fall and Fall 2001), a tool for building landscape models that supports a collaborative framework (Fall et. al 2001). The CLM combines and adapts models built in SELES for other study areas and projects. In particular, it integrates the Spatial Timber Supply Model (STSM) built in collaboration with Forest Analysis and Inventory Branch (Fall 2002b). It includes agents of natural disturbance, such as were built in the Robson Valley, Columbia Mountains and Invermere landscape models (Morgan and Fall 1999). The CLM also adds some newly developed elements, in particular to support retrospective analysis.

The SELES model constructed for the Cranbrook TSA consists of a linked set of sub-models. There are two classes of sub-models. First, there are models of landscape change that simulate forest growth, natural disturbance (fire and mountain pine beetle), forest harvesting, and road development. Second, there are models that calculate and export indicators for forestry, coarse filter biodiversity, caribou, grizzly bear, patch pattern and timber. The resulting integrated model is called the Cranbrook Landscape Model (CLM).

The first step in the development of the CLM is to calibrate harvesting and forest growth with the timber supply analysis done aspatially using FSSIM for TSR 3 (Forsite Consultants 2004). This step ensures that the CLM accurately models timber supply assumptions (Fall 2002) in the Cranbrook TSA. The next step is to incorporate components specific to the Flathead needs. This includes making the harvesting sub-model spatial and to include road development, to include species succession dynamics, to include stand-replacing natural disturbance, to track canopy closure class, and to output a suite of indicators of interest for the GBDS project leaders and the CBMPB. The harvesting and disturbance modules were also enhanced to support retrospective analyses based on historic disturbance history for the area.

The CLM can be viewed most simply as an "input-process-output" system (Figure 1). The inputs consist of digital, raster maps describing the land base and parameter files and variables that control model behaviour. The outputs include text files that record various aspects of the condition of the land base (e.g. growing stock, age class distribution) and raster maps of habitat patch types (e.g. young, mid-age and old forest patches) during the simulation. Output is used both to verify correct model behaviour and as indicators for values of interest. Via the user interface of SELES, the model landscape can also be viewed during model runs. The "process" portion of the Flathead Landscape Model consists of dynamic sub-models that simulate ecological and management-induced change (e.g., stand ageing, harvesting) as a complex interacting system. The model projects initial landscape conditions (described by input maps) forward through time, using processes represented in the sub-models (and controlled partially by input parameters) to create a model of landscape dynamics and to estimate future landscape conditions (summarised in output files and spatial maps).

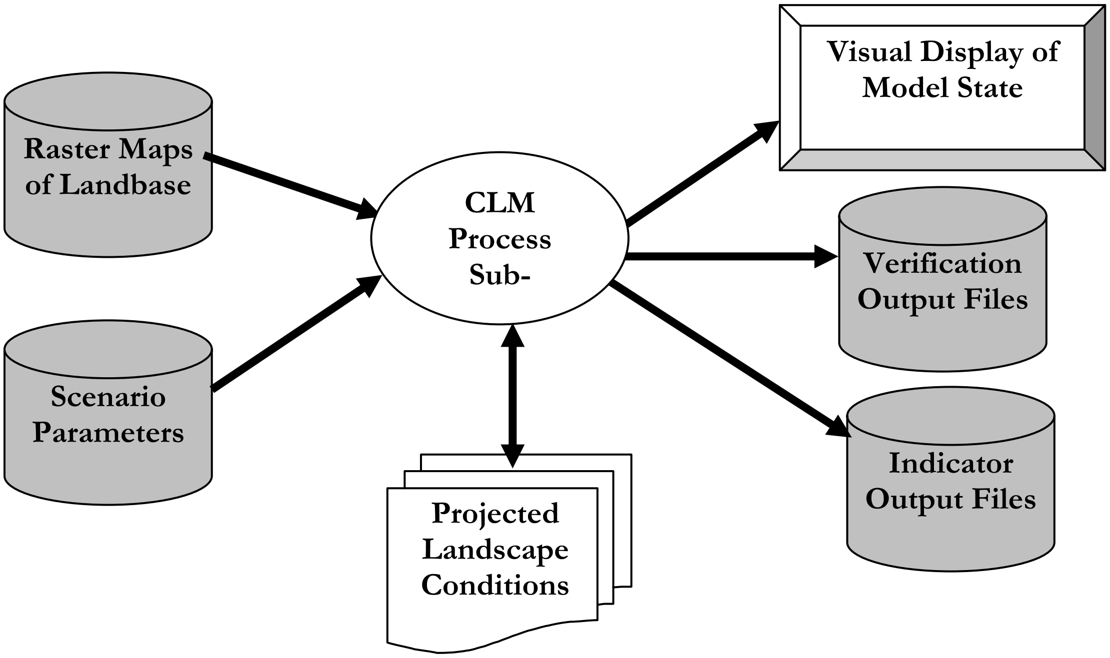

Figure 1. General structure of the Cranbrook Landscape Model. Spatial and tabular information specify the starting conditions, while scenarios set up a desired set of parameters to run. The process models project landscape conditions through time, and output is available visually and in output indicator files.

The CLM simulates specific processes; it does not determine optimal solutions. The model is stochastic, generating disturbance events in space and time using probability distributions. Thus, each model run may produce different results and hence when appropriate, the model must be run several times to determine averages and ranges for each scenario modelled.

The CLM is more accurately portrayed as a meta-model that consists of several distinct SELES models, which communicate via files known a loose-coupling via pipelining (Figure 2). The "processing" module represents a suite of modules used to derive information for input to the main model, such as road network processing, disturbance and harvesting patch pattern analysis. The "landscape projection" module processes the principal agents of change being modelled, specifically ageing, tree species succession, inventory assessment, stand-replacing natural disturbance (mostly fire), partial natural disturbance (mostly mountain pine beetle), harvesting, and road building. Note that these event types are semi-independent, and some can be disabled when appropriate (e.g. some management scenarios do not include explicit natural disturbance, while the natural base case does not include harvesting and road building). The output from the primary landscape dynamics component is used as input to the indicator summary modules. The patch pattern analysis module only requires projected stand age conditions. The grizzly bear habitat suitability model requires fairly detailed spatial analysis, and so is processed in a separate module from the other indicators (timber), which essentially summarize landscape conditions under a variety of strata.

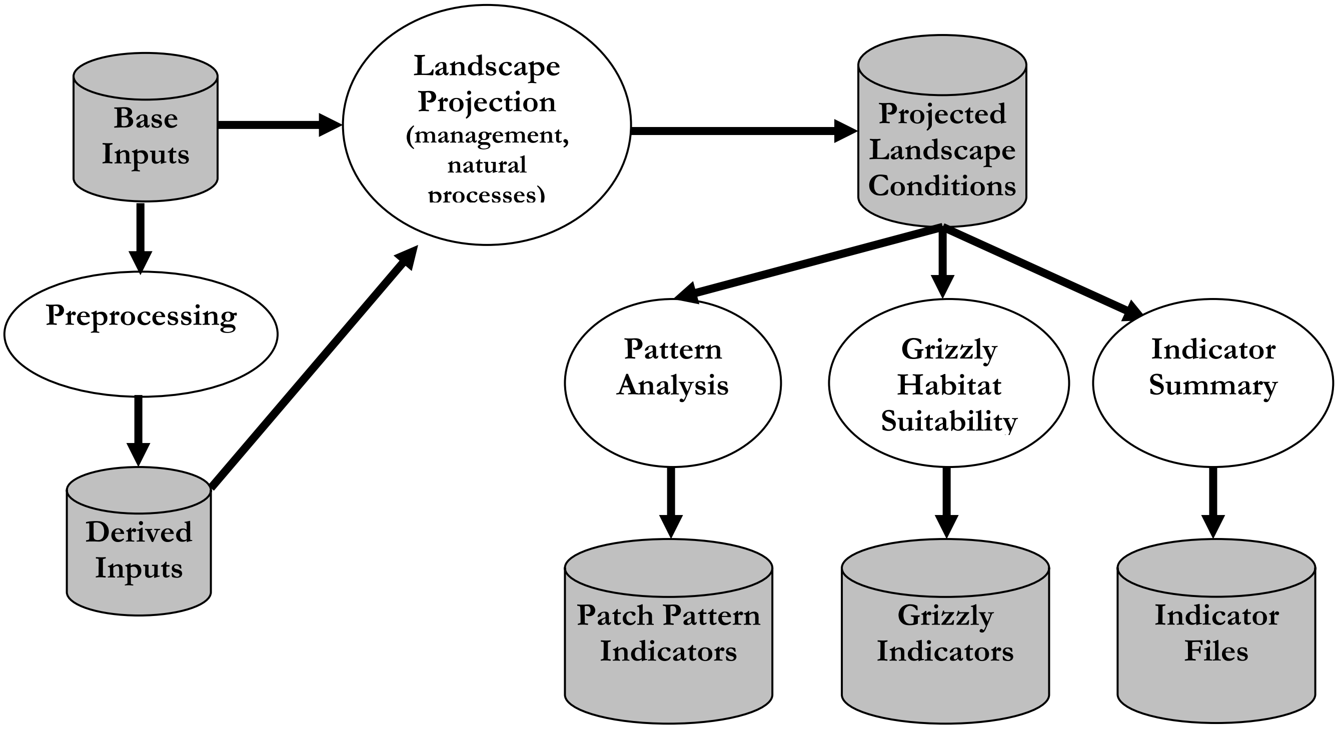

Figure 2. Linkages among the CLM modules, showing how the landscape dynamics outputs are used as inputs to post-processing modules to compute the desired indicator files.

2.2 Spatial and Temporal Resolution

The CLM uses 1ha cell resolution, where each cell is 100m x 100m square. Spatial entities below this resolution, such as stream buffers and roads, are modelled as a percent of a cell. The CLM generally models time in 10-year steps, it exports indicator attributes each decade (although analysis focuses on specific periods). The time horizon for each run of the model is generally 400 years, but can be varied depending on the simulation objective.

2.3 Input Data

Digital maps describe land units that are used by a modelled process or that are used to create indicators. All maps came directly from or were derived from information from MoF inventory. Digital maps describe physiography, ecology, timber values, land-use units and roads (See Appendix 1 for a complete inventory list). See Timber Supply Review Report (Forsite Consultants, 2004) for a description of analysis units, and other base inventories.

2.3.1 Roads

The CLM uses maps of existing roads to identify initial conditions. New roads in the THLB are built within the CLM by connecting short segments to the mapped road network as development progresses.

2.3.2 Parameter Files

In addition to spatial information, a variety of parameters are required. Influential parameters include stand growth and yield curves, minimum harvest ages, annual allowable cut, forest cover constraints and species succession probabilities (See Fall, 2002b for a full list of parameter files).

Along with zoning, forest cover rules provide a means of emphasising different values in different model scenarios. Within zones, harvesting is restricted by specifying forest cover rules that require a minimum amount of old forest or of mature and old forest combined, a minimum amount of forest between two age ranges, or a maximum amount of young forest. The proportions of each forest age class required and the definitions of each age class vary among zone types.

Forest cover rules do not necessarily apply to a single zone, rather they are usually applied to all areas in the same zone within a landscape unit[2]. To the extent they are ecologically distinct, landscape units provide a logical scale for applying forest cover rules. They are typically used as a proxy for managing for coarse filter biodiversity within TSR. The size of management zones, as influenced by the applicable landscape unit and land base influences the effect of forest cover rules. Large zones potentially allow a concentrated disturbance; several smaller zones (of the same type) distribute the disturbance.

2.3 Pre-processing Models

Several previously constructed spatial models are used to prepare inputs for the CLM. Road access is a key issue in the study area. A "network processing" model takes the provided road layer and breaks it into small road segments (e.g. dividing at bifurcations). This can then be used to capture road access constraints during harvesting and used to estimate road activity levels for the grizzly habitat model.

A patch pattern analysis tool, similar to Fragstats but implemented in SELES, was used to examine historic patterns of harvest, fires and mountain pine beetle. These assessments were used to derive parameters for empirically-based natural disturbance models (patch size distribution, number of patches distribution).

2.4 Landscape Projection Model

The overall design of the primary landscape dynamics component consists of a set of linked process models for inventory assessment, harvesting, natural disturbance, stand ageing and succession, and road development (Figure 3).

---

[2] Landscape units describe geographic regions approximately analogous to large watersheds.

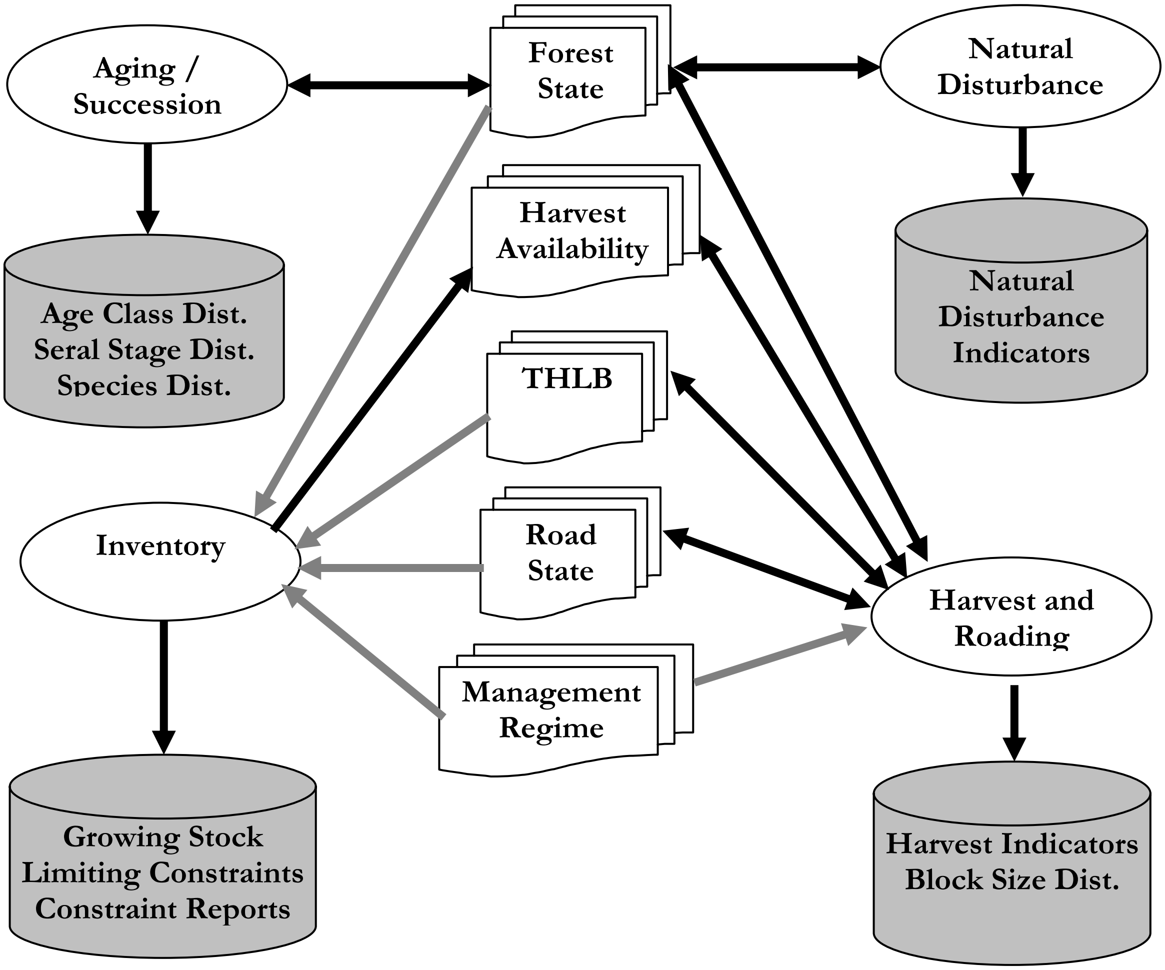

Figure 3. Overall conceptual design of the Cranbrook Landscape Model landscape dynamics component. Each main modeled process is shown as an oval, while the main parts of the landscape state (represented as spatial data layers and tables) are shown in the centre, and output files are shown as grey drums. Arrows indicate whether a process depends on and/or modifies the connected landscape state, or produces output.

The forest is represented using species (dominant, sub-dominant) and age. It also includes volume (standing green, salvageable) and stand height estimates. Harvest availability indicates which cells are available for harvesting according to harvest policy and rules as specified in the timber supply analysis or according to spatial rules (e.g. road access limits). The timber harvesting landbase (THLB) is modeled spatially as a percentage of each cell in the THLB, derived using the same information as in TSR 3. We compute analysis units (AUs) using the same set of rules as used in the timber supply review (TSR 3) and track the volume of growing stock in each cell based on input yield curves, analysis unit and stand age. The road state tracks current and developed roads.

Models of landscape change include forest growth, natural disturbance, forest harvesting and access development. Within-stand disturbances, caused by disease, insects and windthrow, are not explicitly modelled, however, their timber-related impacts are accounted for in estimates of volume harvested (non-recovered losses).

Forest management strategies used in the model control the amount and distribution of logging disturbance within zones, as well as amount and location of roads developed.

Priorities and partitions can be used to control harvest focus. One set of priorities were defined to capture the rules applied in TSR 3. Other sets were designed to focus on (i) salvage; (ii) minimizing road construction; (iii) stands susceptible to mountain pine beetle; or (iv) historic logging locations (for matching past harvest sequence in some retrospective analyses).

2.4.1 Forest Growth and Succession

The forest growth sub-model was designed to age forested cells annually, to maintain analysis units, to update global tracking variables and to enable post-harvest planting and forest growth to be modelled. Stand ageing simply increments the age in each forested unit by the timestep (10-years) up to a maximum age (450 years).

Initial analysis units were provided from inventory, and are updated post-harvesting using the same rules as in the TSR. Resource Emphasis Area (REA) zones include visual quality (VQO), caribou, grizzly, and integrated resource management (IRM) zones. Target amounts are computed over the productive forest for VQO and landscape-scale biodiversity (B.C. Min. for Forests and B.C. Min. of Environment, Lands and Parks. 1999) as applied in the TSR, and over the THLB forest for the IRM, caribou and grizzly zones.

Stand volume at a given age on a given analysis unit is estimated by a yield table look-up. Planting is assumed to occur in all stands after harvest. Following their first harvest, stands move to a “managed stand” analysis unit, having a different associated growth curve. Managed stands grow faster than natural stands.

Succession was modelled using vegetation pathway diagrams developed as part of the Invermere Landscape Model (Morgan and Fall 1999). These pathways were developed through workshops, and capture the trends generally agreed to by experts regarding species shifts through time on different sites following different events.

2.4.2 Inventory and Harvest Availability

At the start of each 10-year period, the volume estimates are updated and growing stock in various categories are computed (e.g. overall, in timber harvesting landbase, merchantable, available). This sub-model also assesses harvest availability by applying the various constraints on harvesting (min. harvest age, access, forest cover constraints). When constraints are not met (e.g. min. old-growth requirements), stands may be reserved as recruitment. In addition to growing stock information, this sub-model outputs the area of

THLB that is unavailable for harvest (*locked-up* or *limited*) due to maturity, access or management objectives (e.g. adjacency if it is enabled or BEOs) (See Fall 2002 for further discussion).

2.4.3 Harvesting Model

The harvesting sub-model is implemented using a variant of the SELES Spatial Timber Supply Model (Fall 2002b) and captures the management regime, assumptions and uses the same data as the base Cranbrook Timber Supply analysis done using FSSIM (Forsite Consultants 2004). Instead of harvesting portions of analysis units, as FSSIM does, the CLM implementation harvests the THLB portion of 1 hectare cells within the eligible analysis units that meet the "relative oldest first" harvest rule to achieve the harvest rate (m^3/yr) using volume yield information (curves that describe volume for different types and ages of forest). Priorities define areas of the land base (static or dynamic) into which to focus harvest or to apply additional preferences. They can be in scenarios to focus harvest on salvage, stand with high susceptibility to MPB, etc. A description of the logic is given in Table 1. In a spatial context this is analogous to harvesting in a given polygon without a target block size. Height is assigned to each stand based on height curves generated from the Cranbrook Timber Supply Analysis.

Table 1. Steps used to choose cells in the logging sub-model.

1. Limit harvesting disturbance to eligible land:
    - the timber harvesting landbase;
    - eligible zones (age class structure allows harvesting; status updated with each disturbance);
    - areas within 2 km of an existing road;
    - stands older than minimum harvest age;
    - stands without adjacency constraints (i.e., stands not next to recently harvested stands);
    - Stands within the current priority or partition definition.
2. Assign priority of <u>new</u> harvesting to each map cell based on

- stand age;
- priority or partition focus;
- select <u>new</u> cell location (first map cell to harvest) based on eligibility and priority:
    - build a road from the cell to the nearest road cell (see section 2.4.4)
- harvest the cell and set stand age to zero;
- update tracking variables (e.g. annual volume harvested and seral distribution for applicable zones);
- reduce the area of THLB in the cell to account for new access roads and for within-block development.

2.4.4 Road Access

With cutblock (1 hectare cells in this case) spread, the sub-model assumes that roads, skid trails and landings develop. Within-cutblock (cell) development (roads, skid trails and landings) reduces the net forested area and hence future volumes harvestable. In addition, a pre-defined average aerial impact of main road access is applied to each block, further reducing net forested area. Within-block development and average road impacts apply only when a natural stand is harvested the first time.

The logging sub-model explicitly connects cutblocks to the main road network. It connects "landings" (first cell harvested in block) by straight-line "spur" road segment to the nearest existing or future road location. Spur roads may connect to an existing mapped road, a previously created spur road or a future mapped road. In the latter case, the future segment is then activated along with any "downstream" future roads to the nearest existing road. This method of modelling road development allows an approximation of the amount of road required to meet a harvest request, allows access restrictions to influence harvesting while harvesting reduced access constraints over time, and allows roads to be used in the computation of output indicators.

2.4.5 Natural Disturbance

Several difference approaches to modelling natural disturbance have been developed for the CLM.

The first approach is empirical disturbance projection. Stand-replacing natural disturbance is modelled with disturbance rates and patch sizes applied separately by BEC zone based on an analysis of historic disturbance levels for the Cranbrook TSA, estimated from previous work done in the Invermere TSA (Morgan and Fall 1999). This sub-model captures all stand-replacing natural disturbance events, primarily fire, mountain pine beetle, spruce beetle and balsam fir beetle. The disturbance parameters specify the overall disturbance cycle (e.g. 350 years) to apply within a BEC zone, as well as the number of disturbance patches and patch size distribution. In each 10-year period, a number of ignitions are chosen for each BEC zone, and for each ignition a target size is selected. The disturbance patch spreads from the start point, setting stand age to zero as it proceeds. The BEC zone boundaries do not preclude spread, and so areas near a boundary will be influenced by the neighbouring BEC zone (as would be expected).

The second approach is to apply historic disturbances for retrospective analysis. These models simply disturb a specified area each period. Spatial time series maps are input in a scheduled manner (e.g. every year) to control where disturbance occurs each period. The effect of disturbance is the same as the empirical approach.

The third approach is to apply MPB projections from the provincial scale BCMPB model. This allows the CLM to use a detailed spatial time series of MPB attach severity (partial disturbance) to capture MPB disturbance over the course of the current outbreak.

For all cases, the harvesting model is capable of salvaging standing dead wood, based on preferences, and the succession model captures merchantable decay of standing dead wood (shelf life).

2.5 Outputs

During processing, the core dynamics can be set to output a time series of projected landscape states (stand age, stand height, volume per hectare, etc.) required for indicator processing. The indicator post-processing modules (patch pattern analysis, grizzly bear, general indicators) take as input a series of landscape state snapshots for analysis. Other output indicators directly from the core dynamics include growing stock, constraint information, harvest information and natural disturbance information. Many of the timber indicators are used to verify model behaviour.

2.5.1 Timber Supply Indicators

The timber model follows the STSM (Fall 2002b). Growing stock, defined as the volume in cubic metres for certain strata in the landscape, is the primary indicator used in timber supply analysis to determine sustainable harvest projections. Secondary indicators include harvesting summaries, age class distribution and limiting constraints.

The growing stock sub-model assesses and outputs the growing stock and forest age class structure as well as updating a layer with volume/ha in each cell of the landscape based on the TSR volume tables, analysis unit, stand age and THLB. The indicators tracked include growing stock (m^3) and area (ha) for various components of the forest, including forest in and out of the THLB, resource emphasis areas, BEC zones, and areas under various constraints.

Harvest Statistics: A range of output values track key aspects of the harvesting process as means across each period, and include annual volume harvested, volume salvaged, area harvested, volume per hectare harvested, mean age harvested, estimated kilometres of roads constructed, harvest profile in terms of the proportion of harvested stands by leading species.

Limiting Constraints: Track the area of forest unavailable for harvest due to the various objectives. This is output as net and gross values, where the net value is the incremental area constrained after preceding constraints have been accounted for, and the gross value is the total amount the would be constrained independent of the other constraints. The primary order of constraints applied is minimum harvest age, road access (if enabled), adjacency, forest cover constraints (applied in order specified in input file).

3.0 Model Linkages

3.1 Linkages with Species Habitat Models

The CLM exports data to grizzly bear habitat supply models (HSMs) which rate seasonal habitat suitability on the basis of the data received from the CLM. The grizzly bear HSMs were originally developed for the Mackenzie TSA but are undergoing further development for application on the Cranbrook TSA. The seasonal models are programmed in NETICA, a Bayesian Belief Network (BBN) modelling shell. The BBNs determine the probability that habitat is suitable given the state of input variables (forest age and canopy closure, for example) provided by the CLM. Because the relationships between input variables and habitat suitability are probabilistic the BBNs express habitat suitability as a probabilistic outcome. For example, the BBNs would allow specification that, given a certain forest structure, there is an 80% chance that food value would be high, and a 20% chance that it would be medium.

The grizzly bear models receive data from the CLM in the form of database text files that describe the characteristics of each 1 ha piece of the Cranbrook TSA area. Before exporting data to the species programs, the CLM first groups individual 1ha cells into sets of multiple cells with identical characteristics. This reduces the processing time required to run the grizzly bear HSMs.

Processing of CLM data in the NETICA models for grizzly bear requires manual manipulation of files. Consequently, for these species, it is not possible to evaluate habitats in Natural Case "landscapes". Doing so would require manual work with 100 sets of output data files, which would take a great deal of time.

3.2 Linkages with other analysis

In addition to exporting data specifically designed to drive the grizzly bear HSM models, the CLM exports data that can be directly evaluated by domain experts. All biodiversity indicators, including forest age structure and patch characteristics are intended to be interpreted directly by domain experts before results are presented to the CBMPB. Similarly, seral state data allow domain experts to examine implications for wildlife species (e.g. moose) without the aid of species models, and simulated road locations allow examination of the implications of access patterns for mountain goat.

4.0 Benchmark Scenarios

4.1 TSR 3 Base Case

The TSR 3 base case is a non-spatial assessment using the same assumptions as applied using FSSIM for the timber supply review analysis. Some key assumptions are described in Appendix 2. We used the information in the TSR 3 report first to calibrate the CLM to ensure we captured the same assumptions. We call this step "TSR alignment". Then we generate the base case harvest flow from scratch as a verification step.

The THLB we obtained was 422,373 ha, while the TSR 3 analysis reported 416,196 ha.

We applied the partitions as in TSR 3. One partition was created to treat salvage from 2003 mapped fires. Volumes were reduced by 30%. Fire salvage was assigned a high harvest priority. Areas salvaged were given a 2-year regeneration delay and placed on managed stand AUs. Stands not salvaged within 3 years were assumed to regenerate naturally on unmanaged stand AUs with a 4 year regeneration delay. Productive area was reduced by 10%, and forest cover constraints were not applied in salvaged areas.

A second and third priority was placed to control harvest within open forest and open range, with caps of 30% and 14% of the harvest, respectively. A fourth priority was created for young pine leading stands (< 110 years old), with an aim to reduce landscape susceptibility to MPB. The main priority (for all remaining stands) applied an oldest-first rule.

Indicators for growing stock, mean age harvested, mean volume/ha harvested, etc. were quite close to the TSR 3 results, indicating a reasonable match of assumptions. The resulting harvest flow is compared with the TSR 3 base case harvest level in

Table 2. Comparison of TSR 3 base case harvest level with harvest level from CLM when applying same assumptions, but generating a harvest flow.

Year	TSR 3	CLM TSR3
3	908,000	908,000
10	838,000	796,600
20	838,000	796,600
30	838,000	796,600
40	800,000	796,600
50	767,000	796,600
60	767,000	796,600
70	767,000	796,600
80	767,000	796,600
90	767,000	796,600
100	800,000	796,600
110	841,000	796,600
120	841,000	796,600
130+	841,000	806,200

4.2 Projection scenarios: alternative futures

4.2.1 Spatial Base Case

The Spatial Base Case (SBC) is intended to demonstrate the long-term effects of current forest management policies in the Cranbrook TSR on coarse filter biodiversity and habitat for grizzly bear. Accordingly, the spatial base case simply applies the current policy used in the Cranbrook TSR except that the CLM locates cutblocks spatially and applies access constraints. Block size ranges were estimated from recent harvest history, and applied as a uniform distribution from 10-100ha. No effect of access is applied up to 200m from an existing road, then the likelihood of selecting a cell to initiate a block declines linearly until 2km from a road. Areas at greater distances from roads are unavailable for harvest until additional road development occurs. Since there is little variance among runs, only a single replicate was required.

In addition, this scenario includes natural disturbance using the empirical fire model and the MPB disturbance stream from BCMPB (first 20 years), and salvage.

4.2.2 Natural Base Case

The Natural Base Case is intended to act as a benchmark against which the structure of managed forests can be compared. This intended function is similar to the use of Natural Disturbance Types in the Biodiversity Guidebook. However, in the Natural Base Case, natural disturbances are modelled explicitly in both time and space, and rates of natural disturbance are applied individually to each different Biogeoclimatic Variants within the SRMP area. The disturbance rates applied were based on disturbance history analysis for the Invermere TSA (Morgan and Fall 1999). Since disturbance rates as well as the locations of disturbances were controlled by probability functions, no single simulation could be assumed to represent the natural landscape. Consequently, multiple sample "landscapes" were required. To avoid spatio-temporal autocorrelation among samples, 10 simulation runs were made, each with 10 landscape snapshots taken at a 300 years spacing between snapshots. We determined that 300 years between samples was adequate to remove any effect of the preceding sample.

5.0 Conclusion and next steps

This document describes the current status of the Cranbrook landscape model, and some of the scenarios designed to date. Most of the application has so far focused on retrospective analysis prior to 2004. In the upcoming year, we will continue to refine the model, and use it to project future conditions under a range of scenarios. We will also continue to explore the retrospective scenarios, to examine seral stage distributions and patterns.

References

B.C. Min. for Forests and B.C. Min. of Environment, Lands and Parks. 1999. Biodiversity Guidebook.

Eng, M., A. Fall and G. Sutherland. 2001. Simulating Natural Disturbance Dynamics and Evaluating Management Scenarios with the Robson Valley Landscape Model Year 1 Report to the Robson Valley Forest District Enhanced Forest Management Pilot Project.

Fall, A. D. Morgan, L. Bolster and A. Edie. 2004. Morice Landscape Model. Unpublished Report to the Morice LRMP Technical Committee.

Fall, A., Eng, M., Shore, T, Safranyik, L., Riel, B., Sachs, D. 2001. Mountain Pine Beetle Audit Project: Kamloops Forest District Landscape Model. Final Report.

Fall, A., D. Sachs, T. Short, L. Safranyik and B. Riel. 2002. Application of the MPB/SELES Landscape-Scale Mountain Pine Beetle Model in the Lakes Timber Supply Area. Final Report, March 2002.

Fall, A., D. Sachs, T. Short, L. Safranyik and B. Riel. 2003. Application of the MPB/SELES Landscape-Scale Mountain Pine Beetle Model in the Flathead Timber Supply Area. Final Report, March 2002.

Fall, A. 2002. SELES Spatial Timber Supply Model. Unpublished report to Ministry of Forests, Timber Supply Branch.

Fall, A., Daust, D. and Morgan, D. 2001. A Framework and Software Tool to Support Collaborative Landscape Analysis: Fitting Square Pegs into Square Holes. *Transactions in GIS*. 5(1):67-86

Fall, A., and Fall. J. 2001. A Domain-Specific Language for Models of Landscape Dynamics. *Ecological Modelling* 141(1-3): 1-18.

Forsite Consultants. 2004. Cranbrook Timber Supply Area Timber Supply Review #3 Analysis Report.

Morgan, D. and A. Fall. 1999. The Invermere Landscape Model. Unpublished Report. Research Branch. BC Ministry of Forests, Smithers, BC

Morgan, D., D. Daust and A. Fall. 2002. North Coast Landscape Model: Benchmark Scenario. Unpublished Report to North Coast LRMP Technical Team.

Appendix 1. Data inputs to CLM

Most data was obtained from LRDW, while some was provided by Min. of Environment and ForSite.

Base inventory	Attribute	Comment
Forest Cover		
	Inventory Type Group, Species, Species Percent	
	Projected Age, height	
	Site Index	
	Inventory volume	
	Non-forest code	
	Non-productive code	
	Type Id	
	Logging history	Year of logging
	ESA1, 2	Environmentally sensitive areas
TRIM		
	Roads	
	Elevation	In metres
	Slope	In percent
Management Zones		
	Landscape units	
	Operability	
	Inclusion factor	
	VQO/IRM	Used VQO information from a provincial-scale dataset
	UWR / PEM-UWR	Ungulate winter range
	Caribou zones	
	SRMMP	Southern Rocky Mountains Management Plan
	Watersheds	As in Ministerial Order
Other		
	BEC	
	Ownership	
	Management Unit	
Non-spatial inputs		
FSSIM files	Volume/height	Volume yields from TSR 3 (by analysis unit)

Appendix 2: Timber Supply Review Alignment: Forest Management Assumptions

The following were taken or adapted from the TSR 3 analysis report.

(i) *Growth and yield data and analysis unit definitions:* as in TSR3 report (including genetic gain assumptions).

(ii) *Unsalvaged losses (USLs):* Specified as an annual volume loss and are added to the annual harvest request. The USL applied was 77,241 m^3/year, as in TSR. The largest factors were mountain pine beetle (43,561 m^3/year), blowdown (25,228 m^3/year) and fire 7,384 m^3/year).

(iii) *Disturbance outside THLB:* as in TSR3 report.

(iv) *Silvicultural systems:* As in TSR3, clearcut with reserves (WTPs) or short-term shelterwood harvest systems were assumed, except in in open forest and open range, where partial harvest was assumed.

(v) *Basic silviculture and regeneration assumptions:* After harvesting, an analysis unit-specific regeneration delay of 1-3 years is applied, depending on the AU, and a regenerated analysis unit is assigned to the cell.

(vi) *Immature plantation history:* As in TSR 3, all stands up to 20 years were placed on existing managed yield curves in the initial conditions, as were any previously harvested stands with planting records.

(vii) *Not satisfactorily restocked areas:* As in TSR 3. Some backlog NSR was removed from the THLB, while some was assumed to grow with lower yield expectations.

(viii) *Wildlife tree patches (WTPs):* As in TSR 3: a 2.7% volume reduction in Aus other than open range/forest.

(ix) *Forest cover requirements – resource emphasis areas and landscape level biodiversity:* Forest cover constraints were applied as in the TSR, and shown in the following tables.

Table 3. Forest cover constraints by landscape unit (except for landscape level biodiversity and UWR).

Resource emphasis	**Maximum disturbance (%)**	**Green-up height (m) or years**	**Land base to which constraints apply**
VQO – preservation	**0 – 5%**[3]	**3 - 8.5 m**[4]	**Productive forest**
VQO – retention	**3 – 15%**	**3 - 8.5 m**	**Productive forest**
VQO – partial retention	**10 –25%**	**3 - 8.5 m**	**Productive forest**
VQO – modification	**15-33%**	**3 - 8.5 m**	**Productive forest**
Enhanced resource development zone (ERDZ)	**33%**	**2 years**	**THLB**
Integrated resource management (IRM), outside ERDZ and open forest/range	**33 %**	**12 years**	**TLHB**
Community watersheds	**30%**	**22 years**	**Productive forest**
Domestic watersheds class 1	**30%**	**22 years**	**Productive forest**
Domestic watersheds class 2	**30%**	**22 years**	**Productive forest**
Domestic watersheds class 3	**30%**	**22 years**	**Productive forest**
Domestic watersheds class 3s	**30%**	**22 years**	**Productive forest**
Mark Creek	**30%**	**22 years**	**Productive forest**
Mark Creek	**14.1%**	**10 years**	
Wigwam Creek	**30%**	**22 years**	**Productive forest**
Lakeshore mgmt zone	**15%**	**17 years**	**Productive forest**

---

[3] Depending on viewing distance and visual absorption class (Table 60 in TSR 3 report).

[4] Depending on slope class. These were converted in TSR 3 to ages for modelling purposes using Site Tools.

Table 4. Forest cover constraints for UWR applied by landscape unit outside Southern Rocky Mountains Management area.

Resource emphasis	**Minimum retention (%)**	**Threshold years**	**Land base to which constraints apply**
Moose UWR – deep snowpack	**50%**	**120 years**	**Productive forest**
Moose UWR – shallow snowpack	**40%**	**81 years**	**Productive forest**
Whitetail UWR – deep snowpack	**40%**	**100 years**	**Productive forest**
Whitetail UWR – shallow snowpack	**30%**	**100 years**	**Productive forest**
Mule Deer UWR – deep snowpack	**35%**	**100 years**	**Productive forest**
Mule Deer UWR – shallow snowpack	**25%**	**100 years**	**Productive forest**
Elk UWR – deep snowpack	**30%**	**100 years**	**Productive forest**
Elk UWR – shallow snowpack	**25%**	**100 years**	**Productive forest**

Table 5. Forest cover constraints for UWR applied by landscape unit within Southern Rocky Mountains Management area.

Habitat type	**Minimum retention (%)**	**Maximum disturbance (%)**	**Threshold years**	**Land base to which constraints apply**
Managed forest – dry	**10%**		**≥ 100 years**	**Productive forest**
Managed forest – transitional	**10%**		**≥ 100 years**	**Productive forest**
Managed forest – transitional	**20%**		**≥ 60 years**	**Productive forest**
Managed forest – transitional		10%	**< 31 years**	**Productive forest**
Managed forest – mesic	**20%**		**≥ 100 years**	**Productive forest**
Managed forest – mesic	**30%**		**≥ 60 years**	**Productive forest**
Managed forest – mesic		10%	**< 31 years**	**Productive forest**
Managed forest – moist	**20%**		**≥ 60 years**	**Productive forest**
Managed forest – moist		10%	**< 31 years**	**Productive forest**
Managed forest – wet	**30%**		**≥ 60 years**	**Productive forest**
Managed forest – wet		10%	**< 31 years**	**Productive forest**

Table 6. Forest cover constraints for caribou applied by landscape unit.

BEC / caribou zone	**Minimum retention (%)**	**Threshold years**	**Land base to which constraints apply**
Subalpine parkland	**No harvest**	**-**	**Productive forest**
ESSF above caribou line	**70%**	**140 years**	**Productive forest**
ESSF below caribou line	**40%**	**140 years**	**Productive forest**
ESSF below caribou line	**10%**	**250 years**	**Productive forest**
ICH above caribou line	**70%**	**140 years**	**Productive forest**
ICH below caribou line	**40%**	**140 years**	**Productive forest**

ICH below caribou line	**10%**	**250 years**	**Productive forest**
MS	**40%**	**100 years**	**Productive forest**

Table 7. Forest cover constraints for landscape level biodiversity (applied to productive forest by landscape unit). See table 44 of the TSR 3 report. Note that the old seral requirements for low BEO units were reduced by 2/3 in the first rotation, and 1/3 in the second rotation.

Biogeoclimatic unit	**NDT Type**	**Age (years)**	**Low BEO**	**Intermediate BEO**	**High BEO**
Atp	5	N/A	N/A	N/A	N/A
ESSF wm/wmu	2	> 120	14%	28%	42%
ESSF wm/wmu	2	> 250	9%	9%	13%
ESSF dk/dku	3	> 120	14%	23%	34%
ESSF dk/dku	3	> 140	14%	14%	21%
ESSF dm/dmu	3	> 120	14%	23%	34%
ESSF dm/dmu	3	> 140	14%	14%	21%
ICH dm/mk1	3	> 100	14%	23%	34%
ICH dm/mk1	3	> 140	14%	14%	21%
IDF dm2	4	> 100	17%	34%	51%
IDF dm2	4	> 250	13%	13%	19%
MS dk	3	> 100	14%	26%	39%
MS dk	3	> 140	14%	14%	21%
PP dh2	4	>100	17%	34%	51%
PP dh2	4	> 250	13%	13%	19%