# Morice LRMP: Government Technical Team

*Morice Land and Resource Management Plan*

# Morice Landscape Model

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# Executive Summary

The Morice Landscape Model (MLM) uses spatially-explicit simulation modelling to capture knowledge about the Morice LRMP area, simulate landscape change over time, and project implications of land-use policies on timber supply, coarse filter biodiversity and habitat for species of interest in the Morice LRMP area. The MLM 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 LRMP (Final Scenario Analysis).

The MLM 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 disturbance patches across the landscape. The MLM 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 MLM module. For any given set of management constraints, the MLM 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 MLM does not in itself evaluate biodiversity or rate wildlife habitat suitability. Instead, the MLM 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 MLM include forest age, patch size, patch connectivity, and other related landscape metrics. Interpretation of biodiversity data is intended to be undertaken by the LRMP Table with the assistance of a domain expert.

The MLM exports other landscape data such as forest age, canopy closure, tree height and so on to species models which use the data to evaluate habitat suitability. Species models for grizzly bear, woodland caribou, and American marten are programmed in NETICA, and a model for northern goshawk is implemented in SELES as an independent module of the MLM. Since the MLM provides landscape data both over time and for each hectare in the LRMP area, the combination of the MLM and species models can estimate how the spatial distribution of habitat changes over time.

[1] Spatially Explicit Landscape Event Simulator

The MLM 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 MLM is intended to assist the Morice LRMP Table 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 at the Table of alternate management policies and decisions that the Table may wish to recommend in the LRMP. Once the LRMP table chooses a recommended management direction, the MLM will help identify the long-term consequences of recommended management.

Effective interpretation of MLM projections is best accomplished with the assistance of relevant domain experts. The MLM 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 Table members and expert advisors will be critical supplements to the information provided by the MLM.

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## Acknowledgements

Development of the Morice 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 William Elliot, Geoff Recknell and Laura Bolster of the Ministry of Sustainable Resource Management; and Todd Mahon, Ann Marie Roberts, and Laurence Turney, independent consultants. Without the considerable effort provided by these persons, development and interpretation of the MLM would not have been accomplished.

# 1.0 Introduction

The purpose of this document is to describe the Morice Landscape Model, and clarify its role in the Morice LRMP process. Intended audiences are the Morice LRMP Table, the Government Technical Team, and other technical advisors who assist the Table.

The Morice Landscape Model (MLM) 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 programs 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. Further detail on the structure of the MLM, its background and the linkage of its components is provided later in this document.

## *1.1 Model Objectives*

The current version of the MLM was constructed under direction of the Government Technical Team (GTT) in order to help the Morice LRMP Table examine future consequences of management directions the Table may wish to consider during the LRMP process. Specifically, the MLM is used to examine:

- Base Case: project future trends in coarse filter biodiversity, and habitat for selected species undercurrent forest management (Draft Base Case Analysis, Edie, 2003 ).
- Natural Case: project patterns of forest structure on the LRMP landscape as a result of natural disturbance in the absence of industrial forestry (Draft Natural Case Analysis, Edie 2003) The Natural Case is used to establish the Range of Natural Variation against which management results, both current and alternate, can be compared in the Environmental Risk Assessment,
- Scenario Analysis: experimentally examine future trends in timber, biodiversity and habitat supply under alternate forest management Scenario Analysis is currently being conducted, and
- Final Plan Analysis: project future trends in timber, habitat and biodiversity values in response to the management direction recommended by the Table in the final LRMP. The final Scenario analysis will be undertaken when final management direction has been established..

## *1.2 Model Context*

The Morice Landscape Model was initially constructed to address mountain pine beetle attack in the Morice TSA, involving Morice TSA licensee forestry experts, and government forestry and entomology experts (Fall et al. 2003). Construction and modification of the MLM is a collaborative effort by a team of government and non-government experts. The team includes experts in data management, spatial analysis, environmental risk assessment, decision support systems, timber supply, timber inventory, operational forestry, species biology and land use planning. The construction and the interpretation of the Morice Landscape Model has benefited from the experience gained in other landscape modelling projects, particularly the North Coast Landscape Model (Morgan et al. 2002), Lakes TSA Mountain Pine Beetle analysis (Fall et al. 2002) and collaboration with Timber Supply Branch (Fall 2002b).

The Morice LRMP is being done in conjunction with the Wet'suwet'en Stewardship Plan (WSP) and the Morice-Lakes IFPA Sustainable Forest Management (SFM) Plan. All three efforts seek to capture landscape information and processes to inform their respective decision processes. These planning processes share common data, for example, updated forest cover information for the Morice TSA was contributed by the IFPA. Although based on similar land and resource data the three processes interpret the data at different resolutions and for different values. The WSP interprets resource inventories for plant communities important to the Wet'suwet'en people and distribution of these plant communities across the landscape in space and time in relation to the various Wet'suwet'en House Territories. Also, other landscape features, such as historic trails, are interpreted with respect to Wet'suwet'en values and resource management. The Morice-Lakes IFPA SFM captures public information and forest management at a finer scale than the LRMP and gives operational guidance to resource management activities. In addition, it provides the framework for forest licensees to report on resource indicators developed by stakeholders and resource professionals for meeting the needs of certification, forest stewardship monitoring and operational forest planning.

### *1.3 Modelling Support for the Morice LRMP*

There are two methods for interpreting the output from the MLM. The first is to provide, directly to the table, detailed model output in the form of indicator data files (see Appendix 3, MLM indicator File description). The second approach is to have domain experts conduct analysis based on the model output indicator files and provide an interpretation of the model to the planning table. Domain experts include timber and habitat modellers, timber supply analysts, experts in visuals, biodiversity and species.

The MLM, itself, does not do any domain interpretations, for example, it does not predict the forest management impacts to biodiversity. Impact assessments are done by the relevant domain experts. Model output are evaluated with the underlying assumptions and data limitations in mind. Table members are encouraged to become familiar with the MLM, however, expert assistance with respect to the MLMs characteristics and limitations is provided to ensure that model output is clearly interpreted. The MLM is used to help bound the impacts of various scenarios and compare the relative impact of different management options. Given the time limitations and technical constraints it is challenging to apply the MLM to test all management decisions of potential interest to the Table. However, the MLM can be used to clarify the implications of key management options. Domain experts can help combine and compare results of formal modelling with other types of analysis. The LRMP must consider social choices, not just technical projections. The MLM can be used to help provide technical information based on resource inventories and assumptions of landscape processes and resource management. However, regardless of model projections, it is the table members and their technical advisers that interpret the relevance of model outputs to the important social choices that must be made.

This report describes the structure, assumptions and functioning of the MLM. The linkages with species models and other analysis are presented in Section 3, detailed descriptions of the species models can be found in Edie, 2003. Also presented, in this document, are the data used (appendix 1), the report on alignment of the MLM with the Morice Timber Supply Area timber supply review 2 analysis (appendix 2) and the model output indicator file descriptions for timber, habitat and biodiversity (appendix 3).

# 2.0 Morice Landscape Model Description

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

## 2.1 Overview of the SELES Model for the Morice LRMP

The Morice Landscape Model 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). It combines a simulation engine with a spatial database and a relatively simple landscape modelling language to allow rapid development of landscape simulations custom-designed for given objectives.

The SELES model constructed for the Morice LRMP consists of a linked set of submodels. There are two classes of submodels. First, there are models of landscape change that simulate forest growth, natural disturbance, forest harvesting and roading. Second, there are models that calculate and export indicators for forestry, coarse filter biodiversity, woodland caribou, grizzly bear, American marten, mountain goat, northern goshawk, patch pattern and timber. The resulting integrated model is called the Morice LRMP Landscape Model (MLM).

The first step in the development of the MLM is to calibrate harvesting and forest growth with the timber supply analysis done aspatially using FSSIM. This step ensures that the MLM accurately models timber supply assumptions (Fall 2002) in the Morice LRMP area. The next step is to incorporate components specific to the LRMP 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 LRMP.

The MLM 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 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 Morice Landscape Model consists of a set of sub-models that simulate ecological and management-induced change (e.g., stand ageing, harvesting). 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). Users create new scenarios mainly by modifying maps of management zones and parameters affecting management and natural disturbance processes.

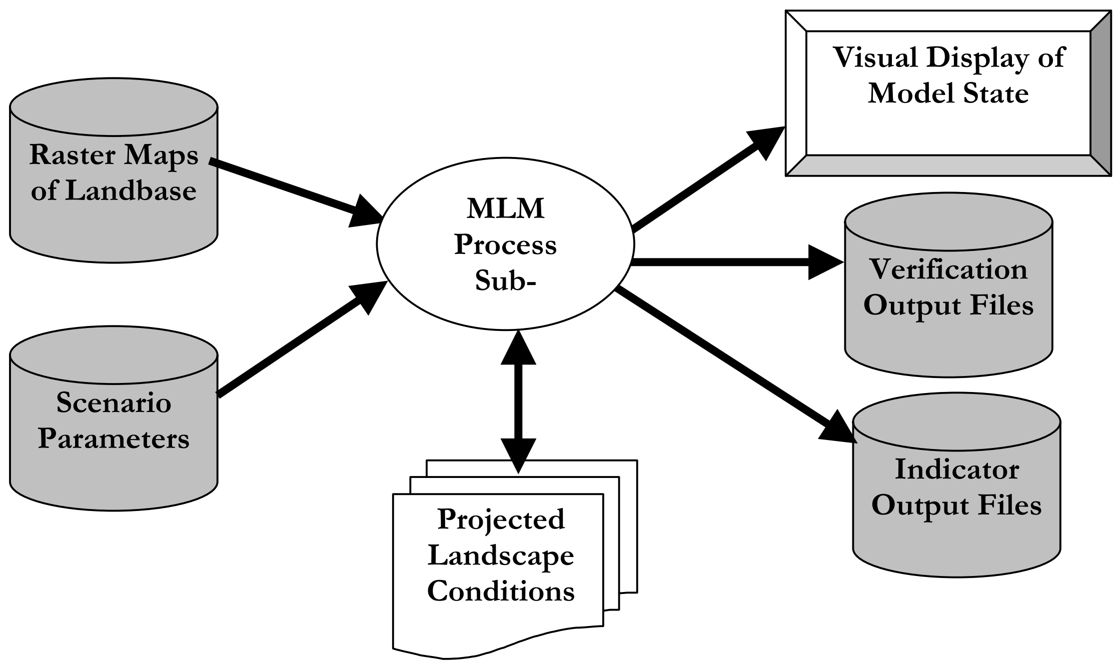


Figure 1. General structure of the Morice Landscape Model. Spatial and tabular information specify the starting conditions, while scenarios set up a desired set of parameters to run. The process models project landscape conditions through time, and output is available visually and in output indicator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

The MLM 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.

Internally, the MLM consists of several distinct SELES modules, which communicate via files (Figure 2). The "primary dynamics" module processes the principal agents of change being modelled, specifically aging, tree species succession, inventory assessment, stand-replacing natural disturbance, harvesting, and road building. Note that these event types are semi-independent, and some can be disabled when appropriate (e.g. most 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 other indicator summaries require an estimate of canopy closure to first be generated from the projected conditions, using a function developed using regression analysis on inventory data. The northern goshawk habitat suitability model requires fairly detailed spatial analysis, and so is processed in a separate module from the other indicators (caribou, grizzly, marten, mountain goat, timber), which essentially summarize landscape conditions under a variety of strata (see Appendix 3).

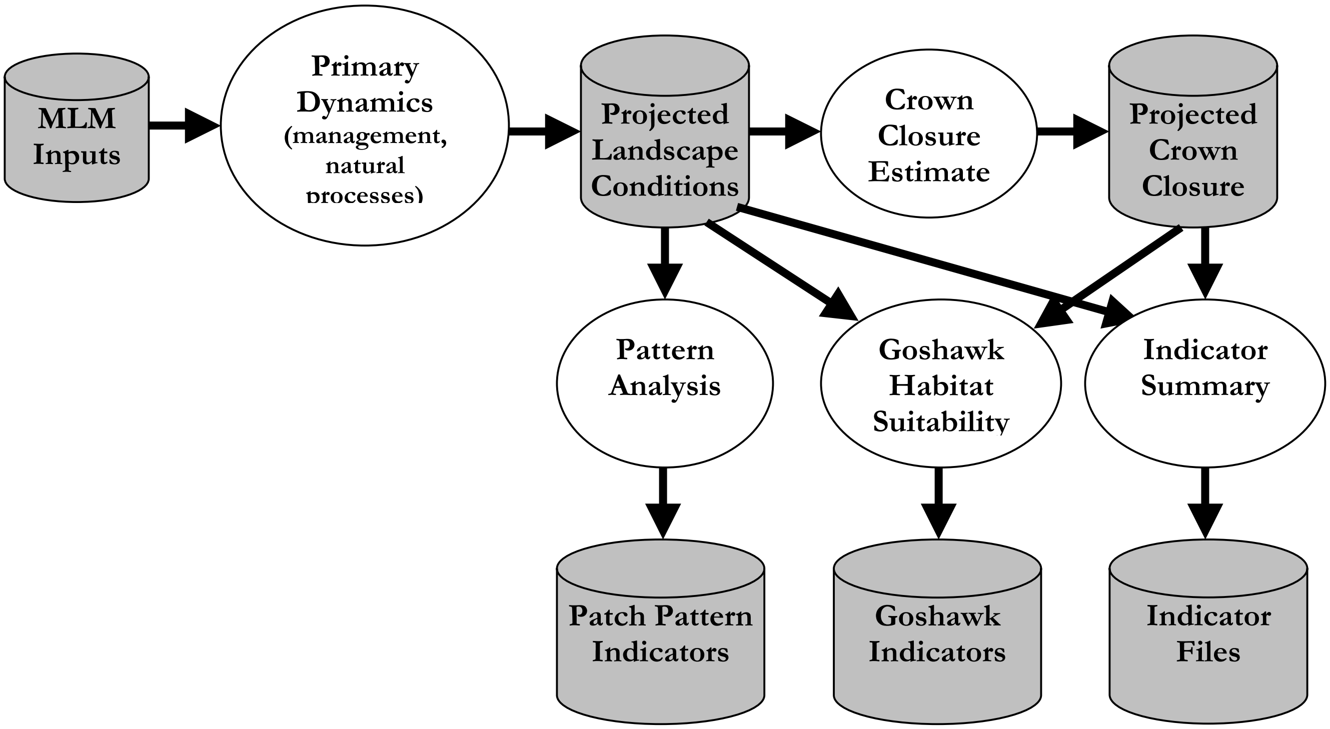


Figure 2 Linkages among the MLM modules, showing how the landscape dynamics outputs are used as inputs to post-processing modules to compute the desired indicator files.

The overall design of the primary landscape dynamics component is shown in Figure 3. All data layers were derived from information from inventory information (See Appendix 1).

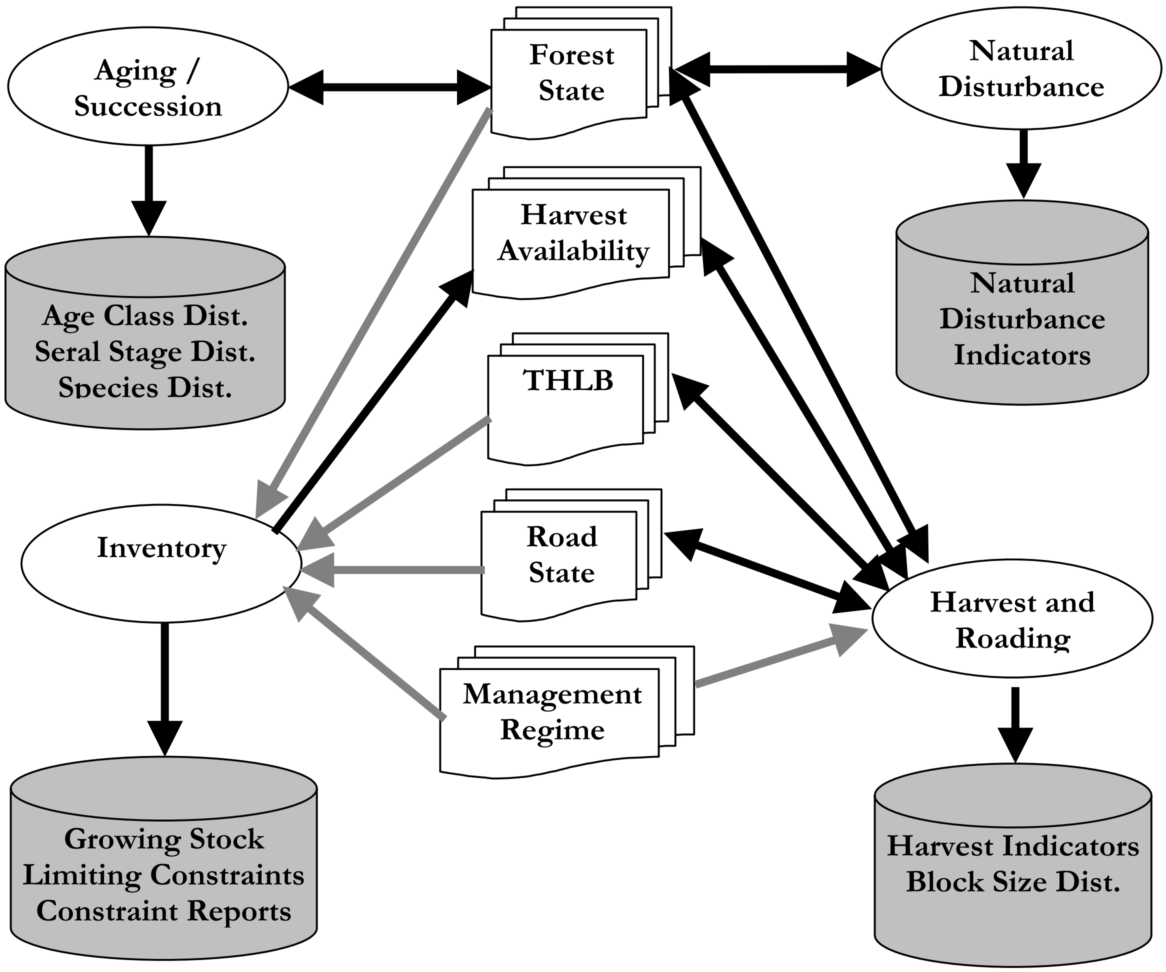


Figure 3. Overall conceptual design of the Morice Landscape Model landscape dynamics. Each main modeled process is shown as an oval, while the main parts of the landscape state (represented as spatial data layers and tables) are shown in the centre, and output files are shown as grey drums. Arrows indicate 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 tertiary) 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. The timber harvesting landbase (THLB) is modeled spatially as a percentage of each cell in the THLB. We compute analysis units (AUs) using the same set of rules as used in the timber supply review (TSR) 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.

In addition to the spatial information above, a variety of aspatial parameters and global variables are used in the MLM. Aspatial parameters include the AAC, minimum harvest age, management objectives, yield curves and species succession probabilities.

## 2.2 Spatial and Temporal Resolution

The MLM 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 MLM 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 (B.C. Ministry of Forests, 2002) for a description of analysis units, and other base inventories.

### *2.3.1 Roads*

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

### *2.3.2 Parameter Files*

In addition to the spatial information described above, a variety of parameters are used in the MLM. Influential parameters include tree growth curves, minimum harvest ages, annual allowable cut, and forest cover rules (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] Landscape units describe geographic regions approximately analogous to large watersheds.

## *2.4 Primary Landscape Dynamics Model Components*

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.

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.

### *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, zone 'A' Morice local resource use plan area (LRUP), 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 LRUP 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 Morice and Lakes IFPA (Beukema and Pinkham 2001). 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). For constraints that 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 identical management regimes, assumptions and uses the same data as the base Morice LRMP Timber Supply analysis done using FSSIM

(MoF 2002). Instead of harvesting portions of analysis units, as FSSIM does, the MLM 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). 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 Morice LRMP Timber Supply Analysis. Patch and road statistics from an aspatial parameterization of the MLM should be interpreted cautiously

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).
2. Assign priority of <u>new</u> harvesting to each map cell based on

- stand age.
- 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*

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 Morice TSA (Steventon, 2002). 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).

## 2.5 Crown Closure Class Estimate

Crown closure class is important for assessing certain ecological risk indicators. Hence, we applied an estimate of crown closure class based on an assessment of inventory data in the study area (Daust, unpublished report). Although crown closure is essentially a dynamic state variable, it does not influence any of the other dynamic components and the regression is effectively a static model (i.e. there is no feedback). Hence, to reduce complexity of the core dynamics model, this estimate is applied as a post-processing step using the time series of projected stand conditions.

The more significant variables were determined as age, site index and species (pure pine vs. all other species). The resulting mean and standard deviations of this analysis are shown in the following tables.

Table 2. Estimated mean canopy closure (in 10% classes from 0-10) as a function of stand age and site index for all inventory type groups except 28 (Pl).

| | Mean Site Index | | |
|---|---|---|---|
| **Age** | **0-8** | **16.1-24** | **8.1-16 and 24.1+** |
| **10** | 0.5 | 2.0 | 1.7 |
| **30** | 3.2 | 4.4 | 4.0 |
| **60** | 3.8 | 5.1 | 4.8 |
| **160** | 3.9 | 4.9 | 4.6 |
| **300** | 3.4 | 4.7 | 4.0 |

Table 3. Estimated mean canopy closure (in 10% classes from 0-10) as a function of stand age and site index for inventory type group 28 (Pl). Numbers in italics were taken from Table 2 above because there were insufficient data to estimate these values for ITG 28.

| | Mean Site Index | | |
|---|---|---|---|
| **Age** | **0-8** | **16.1-24** | **8.1-16 and 24.1+** |
| **10** | *0.5* | 1.6 | 1.4 |
| **30** | *3.2* | 4.6 | 4.2 |

| | | | |
|---|---|---|---|
| **60** | *3.8* | 6.0 | 5.6 |
| **160** | 3.3 | 6.0 | 5.6 |
| **300** | 2.1 | 5.4 | 4.0 |

Table 4. Standard deviations for mean canopy closures shown in Table 2.

| | | **Mean Site Index** | |
|---|---|---|---|
| **Age** | **0-8** | **16.1-24** | **8.1-16 and 24.1+** |
| **10** | 0.8 | 1.5 | 1.4 |
| **30** | 2.3 | 1.9 | 1.8 |
| **60** | 1.8 | 1.4 | 1.4 |
| **160** | 1.5 | 1.4 | 1.4 |
| **300** | 1.3 | 1.7 | 1.2 |

Table 5. Standard deviations for mean canopy closures shown in.

| | | **Mean Site Index** | |
|---|---|---|---|
| **Age** | **0-8** | **16.1-24** | **8.1-16 and 24.1+** |
| **10** | *0.8* | 1.5 | 1.1 |
| **30** | *2.3* | 1.7 | 1.8 |
| **60** | *1.8* | 1.3 | 1.6 |
| **160** | 1.7 | 1.2 | 1.6 |
| **300** | 1.0 | 1.3 | 1.8 |

## 2.6 Output Indicators

During processing, the core dynamics outputs 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, Goshawks, 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.

### *2.6.1 Timber Supply Indicators*

The timber model follows the SSTSM (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. All are means across the period and value at period:
- annual volume harvested
- area harvested
- area accessed (include area of non-contributing within the THLB)
- volume per hectare harvested
- percent of harvest target achieved
- mean age harvested
- estimated kilometres of roads constructed
- number of stream crossings (by stream class)
- harvest profile in terms of the proportion of harvested stands by leading species
- area and volume accounted for as non-recovered loss
- volume salvaged

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 that 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)

*2.6.2 Output Indicators*
A detailed listing of indicator files used for subsequent analysis is in Appendix 3. These files include indicators for coarse filter biodiversity, caribou habitat (winter and spring/summer), grizzly habitat (spring and summer/fall), marten, mountain goat, goshawk and timber details.

# 3.0 Model Linkages

## *3.1 Linkages with Species Habitat Models*

The MLM exports data to four species models which rate habitat suitability on the basis of the data received from the MLM. Three of the species models (grizzly bear, caribou, and marten) were originally developed for the Morice and Lakes Innovative Forest Practices Agreement. These three models are programmed in NETICA, a Baysian Belief Network program. NETICA determines the most likely habitat suitability of a piece of habitat given the state of variables (forest age and canopy closure, for example) provided by the MLM. Where the relationship between a particular habitat variable and habitat suitability is not clear, NETICA permits using probability estimates. For example, NETICA 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 fourth species model (northern goshawk) was originally used in the North Coast LRMP process, and has been revised as necessary to suit the more interior climate of the Morice LRMP area. The model is implemented as a SELES model rather than in NETICA because of the need to perform spatial analysis for nesting and foraging habitat. In essence, the output produces a list of all possible combinations of habitat characteristics, and each combination has a specific habitat suitability assigned.

All four models receive data from the MLM in the form of database text files that describe the characteristics of each 1 ha piece of the LRMP area. Before exporting data to the species programs, the MLM first groups individual 1ha. cells into sets of multiple cells with identical characteristics. This reduces the processing time required to run the species models.

Processing of MLM data in the NETICA models for grizzly bear, caribou, and marten 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.

Since the goshawk model is implemented directly in SELES, it can be run on output from the MLM without manual intervention, and this allows efficient analysis of all 100 Natural Case Landscapes to determine a Range of Natural Variability in goshawk habitat suitability (See Edie 2003).

Complete lists of the data variables exported from the MLM to these species models appears in Appendix 3. Edie (2003) presents more detailed summaries of species model structures and provides references with technical documentation of the models.

### *3.2 Linkages with other analysis*

In addition to exporting data specifically designed to drive the four species models, the MLM exports data that is 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 LRMP Table. Similarly, seral state data allow domain experts to examine implications for 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 Spatial Base Case*

The Spatial Base Case is intended to demonstrate the long-term effects on coarse filter biodiversity, and habitat for selected wildlife species of continuing with forest management policies assumed in the Morice TSR. Accordingly, the spatial base case simply applies the current policy used in the Morice TSR except that the MLM 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 likelihood of selecting a cell to initiate a block declines linearly until 2km from a road. Further distances are unavailable for harvest until road development occurs. Since there is little variance among runs, only a single replicate was required.

### *4.2 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 Variant within the LRMP area. The disturbance rates applied were based on disturbance history analysis for the Morice and Lakes area (Steventon, 2002). 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.

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# Appendix 1. Data inputs to MLM

| | Coverage | Comment |
|---|---|---|
| **Physiography** | | |
| Double Sided Water | twtra_mo | |
| Single Water Feature | twtr_mo | line grid |
| LRMP boundary | tlrmp_mo | |
| BEC - 1:20,000 scale | tbec | |
| **Forest Cover** | | |
| Inventory Type Group | fc_mo1102alb | |
| Projected Age | fc_mo1102alb | |
| Site Index | fc_mo1102alb | |
| Percent Pine | pcpine | an existing grid created by moriceprep.aml |
| Stems per hectare | fc_mo1102alb | |
| Logging History | f_fc_mo | logging attribute populated with act=L and actyr1 created by moriceprep.aml |
| **Roads** | | |
| Amalgamated roads | mor_road | |
| **Management Zones** | | |
| Landscape units | tflu | |
| Type ID | fc_mo1102alb | |
| Operability | f_oper | |
| Operating Areas | dmo_op_alb | from dmo |
| Operating Areas-Canfor | dfa_20021018 | from Jim McCormack Canfor |
| Morice LRUP Zone A | mor_lrup | |
| VQO | hubvqo2 | $MOMOF/nonstandard/tvli_dmo does not have water clipped in |
| Telkwa Cariboo | tcar_mo | |
| IRM | ? | What's left after other removals! |
| MPB Hazard Rating | m_mpbhaz | These are based on fc queries and therefore change with update. |
| SBB Hazard Rating | m_sbbhaz | |
| BBB Hazard Rating | m_bbbhaz | |
| **5-year development plan and blocks** | | These are all from TSR2 - IFPA data? |
| Updated forest cover | fc_mo1102alb | Updated FC from Canfor |
| Small Biz blocks | sbfep_fdp | IFPA small biz blocks are just line work |
| Canfor Blocks & Proposed | cfp_blks01alb | Sent by Barry Watson, Canfor |
| HFP blocks | hfp_blkharv | Use harvest as subclass from hfp_blocks02? Sent by Lyle McNab of HFP |
| **THLB** | | |
| Contributing Class | athlb_dmo | Contributing class |
| Inclusion factor | athlb_dmo | percent included in THLB |
| Ownership | f_own_mo | 61C, 62C, 69C as per Albert N. netdown code |
| Timber Supply Block | f_tsab | Ken? Most recent? - lines up with operating areas from dmo |
| Woodlots | woodlot_alb | More recent from dmo? - part of operating areas? Still being discussed - Liz S. |
| Agricultural Land Reserve | f_alr | |
| Recreate Areas | hub_rec | rec_netdown as per Albert's code from the tsr/wgis/hub_rec file had to be modified by moriceprep.aml. Bob C may have more recent. |
| ESA1 | fc_mo1102alb | |
| ESA2 | fc_mo1102alb | |
| Parks | qpark_mo | |
| PAS Goal 1 | qpasai1_mo | |

| | Coverage | Comment |
|---|---|---|
| PAS Goal 2 | lpasai2_mo | |
| Road buffer | road_buf | |
| **Riparian Buffers** | | |
| Riparian Reserves Zones | rrz_mo | merged all riparian reserve zones |
| Riparian Management Zones | rmz_mo | merged all riparian management zones |
| **MPB data** | | |
| Infestation Spot Data | | |
| | | |
| Stand Density | | |
| | | |
| Susceptability/Risk Rating | | |
| | | |
| Weather Stations | | |
| | | |
| | | |
| **Other Beetle data?** | | |
| Spruce BB | | |
| Balsam BB | | |
| FSSIM files | vol.dat | |
| | axs.dat | |

# Appendix 2: Timber Supply Review Alignment: Comparison of MLM and TSR Analysis results

### *Introduction*

It is important to be able to make transparent comparisons with MLM timber supply results and the results from the most recent timber supply review (B.C. Min. of Forests, 2002). This requires that the MLM can replicate the Timber Supply Review (TSR) results derived using FSSIM for the Morice Timber Supply Area (TSA). We call the process of matching indicators produced by these two models *TSR alignment*. Where indicators match closely, the assumptions and data used by the two models are likely to match as well. Where differences appear, then either the assumptions or data inputs differ in some undocumented or unexpected way, and further investigations may be required.

We undertook a detailed review of the TSR assumptions and data requirements applied in the Morice TSR, and adapted and calibrated the MLM to match as closely as possible the TSR results. This document describes the results of the TSR alignment, including areas in which it was not possible to achieve full alignment. The results presented in this appendix were derived as part of the mountain pine beetle projection analysis done for the Morice TSA (Fall *et al.* 2003).

### *Methods*

We first need to define what we mean by model *alignment*. First, model inputs must be the same, in particular the timber harvesting landbase. Ideally, precisely the same inputs should be used for the MLM as in the TSR. Unfortunately, there is some uncertainty as to the source of some of these inputs. Second, the behaviours and assumptions (explicit or implicit) of the two models must match. Lastly, model outputs (growing stock, harvest volumes and areas, mean age and volume harvested, etc.) should match. The following sections are organized to match the structure of the TSR analysis report. The first three sections correspond to Appendices 2 to 4 in (B.C. Min. of Forests, 2002), respectively. The results section addresses the graphs in Figures 9-15 in the TSR analysis report.

**(a) Model inputs: zones and analysis units**

We used the same set of management zones and analysis units as in the TSR. Overall, zones matched reasonably well (Figure 4**)**. Our estimate had slightly more partial retention VQO and caribou range, and less integrated resource management. This was likely due to differences in the data and methods used to estimate the percentages (e.g., how overlaps between zones are handled to determine the percentage of the THLB covered by the zone).

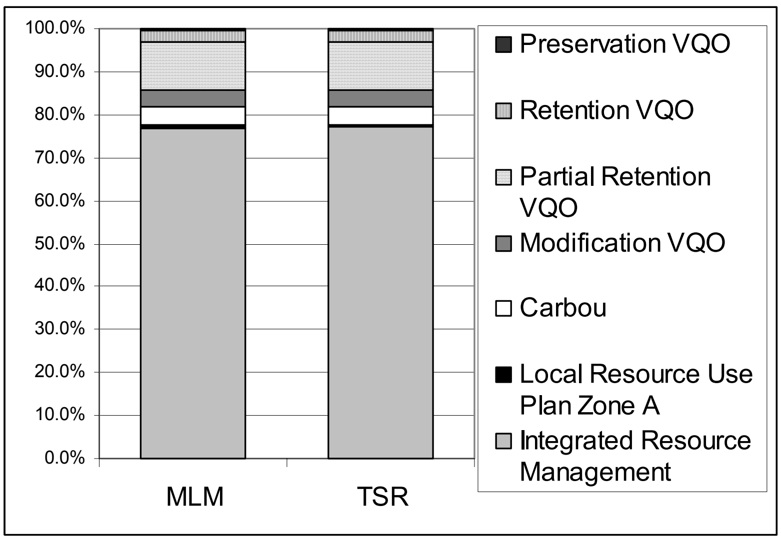



Figure 4. Distribution of THLB between resource emphasis areas.

One of our main objectives was to ensure that no analysis units were over or under-represented because otherwise the differential growth rates of modelled species would influence the results.

**(b) Model inputs: THLB**

A THLB inclusion factor was provided, which was produced at the same time as the netdown process for the TSR and represented the THLB as a percentage of each 1-hectare cell. Using this layer, we could not assess differences for each netdown category, but overall, the THLB from the layer given was 3,500ha (0.5%) larger than in the TSR.

The MLM models road development over time, reducing the THLB by an appropriate amount to account for new roads and landings. This was comparable to the amount of reduction due to future roads from the TSR.

**(c) Forest management assumptions**

We now describe how we captured the forest management assumptions in the MLM.

*(i)* *Utilization levels:* N/A (captured in volume tables).

*(ii)* *Volume exclusions for mixed species stands:* N/A (deciduous leading stands were excluded from the THLB. Exclusion of deciduous secondary components was captured in volume tables).

*(iii)* *Minimum harvest age:* same as in TSR report.

*(iv)* *Harvest scheduling priorities: harvest order*

Harvest order has a critical impact on model results. The TSR and MLM used the following ordering:

(a) Stands proposed within Forest Development Plans (first 10 years)
(b) Pine stands older than 120 years and spruce stands older than 140 years (first 130 years)
(c) Remaining stands older than culmination of mean annual increment age
(d) Stands older than minimum harvest age

Within each of these categories, harvest order was random.

*(v)* *Unsalvaged losses*

Non-recoverable loss (NRL) is specified as an annual volume loss in the Morice TSR. NRL is added to the annual harvest request. To be consistent with area-based harvesting and to facilitate natural disturbance sub-models, the AAC is specified as a curve of total annual volume or area to remove, including NRL (hence it may be more accurate to call it *annual allowable disturbance)*. In the TSR document, the AAC does not include the NRL volume, but the graph (Fig 14, B.C. Min. of Forests. 2002) showing mean area harvested does include the NRL area. The total NRL for the Morice TSR was 181,859 $m^3$ for the first 50 years (11,000 $m^3$ for fire, 8,000 $m^3$ for blowdown, 68,846 $m^3$ for mountain pine beetle, 30,310 $m^3$ for spruce bark beetle, and 63,703 $m^3$ for balsam bark beetle). After 50 years, this is reduced to 104,572 $m^3$ (11,000 $m^3$ for fire, 4,000 $m^3$ for blowdown, and 89,572 $m^3$ for insects).

*(vi)* *Silviculture attributes of young stands*

Inventory attributes have not been updated in the inventory for harvested stands in the Morice TSA, and such stands were marked as NSR and had a meaningless inventory type group. Using history information, such stands were identified, and an appropriate inventory type group and stand age was estimated as in the TSR report. However, there is some uncertainty that precisely the same initial values were generated (see point *(ix)* below).

*(vii)* *Basic silviculture and regeneration assumptions*

After harvesting, an analysis unit-specific regeneration delay of two years is applied, and a regenerated analysis unit is assigned to the cell.

*(viii)* *Immature plantation history*

Stands initially younger than 35 years are assumed to have been controlled for density and are placed on managed yield curves, divided into stands older and younger than 6 years.

*(ix)* *Not satisfactorily restocked areas*

Since inventory attributes of harvested stands had not been updated, identifying NSR was not straight-forward. See TSR report for details. Due to differences in the data provided, the amount of NSR differs somewhat between the MLM and the TSR (Table 6). The number of years assumed before reestablishment of backlog NSR was 10 years.

Table 6. NSR differences between TSR and MLM.

| | *MLM* | *TSR* |
|---|---|---|
| Backlog NSR | 19,539 | 5,595 |
| Current NSR | 14,042 | 16,930 |

*(x) Forest cover requirements – resource emphasis areas and landscape level biodiversity*
Forest cover constraints were applied as in the TSR, and shown in Table 7 and Table 8.

Table 7. Forest cover constraints (except for landscape level biodiversity).

| **Resource emphasis** | **Maximum allowable disturbance (%)** | **Green-up height (m)** | **Minimum retained area (%)** | **Minimum age for retention (years)** | **Land base to which constraints apply** |
|---|---|---|---|---|---|
| Zone 'A' Morice LRUP | 1 | 3 | | | THLB |
| VQO – **preservation** | 1 | 5 | | | Productive forest |
| VQO – **retention** | 5 | 5 | | | Productive forest |
| VQO **– partial retention** | 15 | 5 | | | Productive forest |
| VQO **– modification** | 25 | 5 | | | Productive forest |
| Caribou | 25 | 3 | 25 | 90 | THLB |
| Integrated resource management | 25 | 3 | | | TLHB |

Table 8. Forest cover constraints for landscape level biodiversity (applied to productive forest).

| **Biogeoclimatic unit** | **NDT Type** | **Old-seral requirement (%) starting in year** | | | **Age (years)** |
|---|---|---|---|---|---|
| | | 1 | 70 | 140 | |
| Atp | 5 | N/A | N/A | N/A | |
| CWHws2 | 2 | 6.7 | 8.1 | 9.4 | > 250 |
| ESSFmc | 2 | 6.7 | 8.1 | 9.4 | > 250 |
| ESSFmk | 2 | 6.7 | 8.1 | 9.4 | > 250 |
| ESSFmv3 | 2 | 6.7 | 8.1 | 9.4 | > 250 |
| MHmm2 | 1 | 14.2 | 17.1 | 19.9 | > 250 |
| SBSdk | 3 | 8.2 | 9.9 | 11.5 | > 140 |
| SBSmc2 | 3 | 8.2 | 9.9 | 11.5 | > 140 |
| SBSwk3 | 3 | 8.2 | 9.9 | 11.5 | > 140 |

*(xi) Wildlife trees and tree patches*: as in the TSR, volumes are reduced by 3.6%.

*(xii) Volume and height tables*: same as used in TSR.

**(d) Model behaviour: spatial patterns**
Since the TSR analysis was done aspatially, no spatial constraints or patterns can influence the results. In contrast, the MLM is a spatially explicit model. In order to compare its behaviour to the TSR, the MLM must be made to behave aspatially. To do so, the MLM must treat the THLB as a set of independent polygons that match as closely as possible the original inventory polygons. This influences the following parts of the MLM model:

(i) *Block size:* Since the MLM is a raster-based model, the minimum resolution for harvesting is the THLB portion of a single cell. In previous alignments, we have applied cutblocks as single cells, not contiguous patches. In this case, we match more closely the behaviour in FSSIM by harvesting areas of the same stand (same stand age and analysis unit) once a block is initiated. When applying a relative oldest-first rule, single-cell blocks is adequate. However, when selecting stands randomly from within classes, as in this case, it becomes more important to harvest entire stands to the degree possible.

(ii) *Access:* Road access cannot constrain harvesting, so all cells are treated as though they were close to a road.

(iii) *Adjacency:* Cutblock adjacency could not be explicitly modelled, but is addressed indirectly through surrogate cover constraints as in the TSR.

**(e) Model outputs**
The MLM outputs a range of indicators:

(i) *Age class*: hectares in 10-year age classes, stratified by whether THLB/non-THLB as in Figures 5 and 13 in the TSR analysis report.

(ii) *Seral stage distribution*: hectares in different seral stages (young, immature, mature, old) stratified by THLB, operable excluded, and inoperable.

(iii) *Zone thresholds*: hectares and proportion above and below the threshold age or height specified for each forest cover constraint. This is output for the entire zone and by reference subzone (e.g. biodiversity constraints are output by BEC variant and by BEC variant/landscape unit). This is useful to verify that the model is respecting the zone forest cover constraints.

(iv) *Growing stock*: standing volume and area stratified by THLB, mature (defined as stands older than minimum harvest age (MHA), available, and availability according to the constraints (e.g., forest cover; accessibility).

(v) *Harvest record*: volume and area harvested, mean volume per hectare harvest, mean harvest age, proportion of harvest in different zones, harvest profile, NLR area and volume, proportion of harvest in old, thrifty and managed AUs.

(vi) *Limiting constraints*: amount of THLB constrained by minimum harvest age, access, adjacency, and cover constraints. This is computed both in the order of rule application (e.g. if a stand is too young to harvest, then it is irrelevant if it is too far from a road to harvest) and overall. In the former, the sum of all constrained areas (which represents the total constrained portion of the THLB) shows the *actual* impact of a constraint. In the latter, cells with overlapping constraints contribute to more than one entry, identifying the *potential* impact of a constraint.

For the TSR alignment, we are primarily interested in the age class, growing stock and harvest record indicators.

**(f) Simulations**

The TSR analysis was conducted using a 10-year time step (but with 4 5-year steps in the first periods). The MLM can be driven either by a volume-based or an area-based AAC. The former is how the TSR analysis is done. However, the latter has different stability properties, which make it potentially more useful for comparing the impacts of natural disturbance on timber supply. If models are completely aligned, then the area-based and volume-based approaches should give identical results. We present the area-based results, followed by some volume-based results. For the area-based harvesting scenarios, the annual area targets were taken from the mean area harvested in the TSR analysis. All scenarios were run for 25 decades.

One goal of the MLM is to assess term timber supply impacts under a range of management option scenarios. To facilitate comparisons among scenarios and with the TSR, we need first to assess the independent effects of spatial patterns and constraints on timber supply results. Specifically, we want to assess the timber supply implications of applying road access constraints, using spatial blocks, and of applying a relative oldest-first harvest rule:

(a) Access constraints: In many districts, there are currently large areas that cannot be harvested in the short term due to access limitations. To capture access, we set an upper limit of 2km from a road as the maximum distance a block can be placed. In addition, preference for block selection declines starting at 200m (relative to other factors). That is, stands within 200m of a road have the same preference and this declines linearly to 0 at 2,000m. The logging sub-model constructs spur roads to blocks and updates road distance dynamically during processing. Access restrictions have the effect of influencing the order in which stands are harvested, and so may have timber supply consequences.

(b) Block size: The logging model is capable of applying a uniform block size distribution (e.g. 10-100ha) or a target block size distribution such as is specified in the Biodiversity Guidebook of the Forest Practices Code. To keep the analysis simple, we model a fixed target block size of 60ha. Using a spatial block size has the effect of modifying the order in which cells are harvested (e.g. the model cannot cut old single-cell blocks across the district).

Analysis of the first set of results showed that the variability between runs was close to 0 (since the logging sub-model is mostly deterministic). We ran single-replicate simulations of 25 decades for each combination of access constraint, block size, and AAC target type (volume-based or area-based).

## *Results*

**(a) Area based results**

Figure 5 shows the area and volume harvested by the two models. As designed, the area matches the TSR exactly, but the volume harvested is on average 32,360 $m^3$ (1.7%) more in the MLM than in the TSR. This was due to an average of 4.5 $m^3$/ha (~1.6%) more in the MLM than in TSR (Figure 6). Mean age harvested (Figure 6) is very close between the two models, with a mean difference of less than one 1 (but up to 44 years different in the $8^{th}$

decade). However, note that the mean age harvested is about a decade older in the MLM in the early decades.

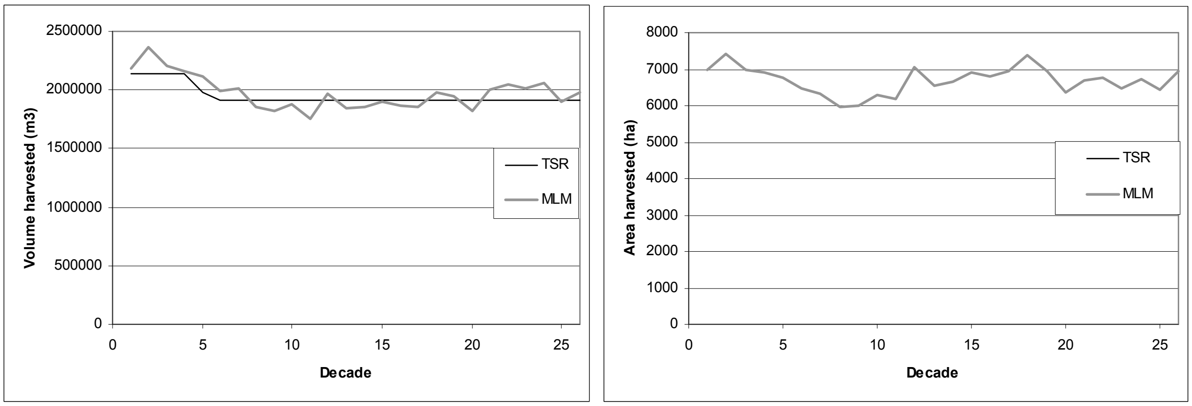



Figure 5. Volume and area harvested each decade by MLM (using an area-based AAC) and TSR. Note that the area harvested in the MLM using an area-based AAC is identical to TSR.

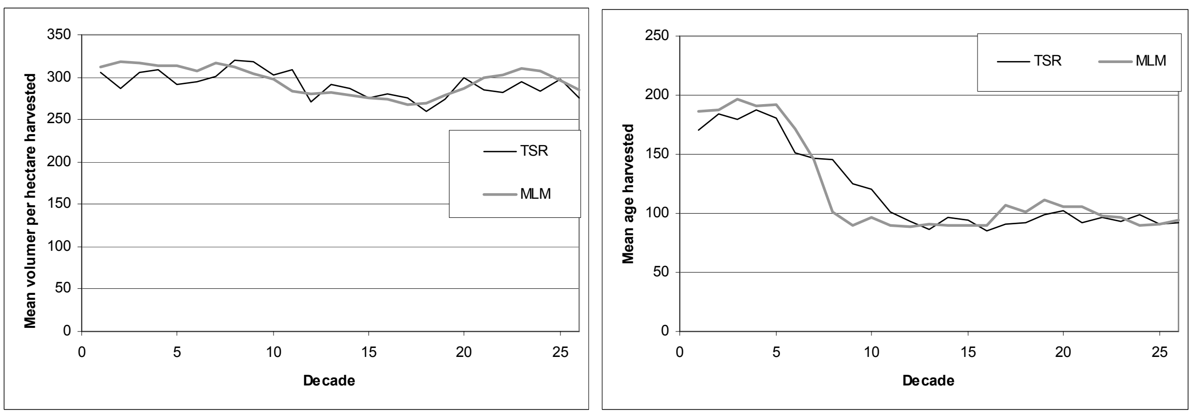



Figure 6. Average volume/hectare and age of harvested stands each decade by MLM (using an area-based AAC) and TSR.

The MLM has a slightly higher estimate of total and mature growing stock than the TSR in the early decades (Figure 7). In intermediate decades, this situation reverses, and in the long run the MLM estimates a higher level of growing stock than the TSR (except for the final couple of decades). On average, the MLM estimates 0.06% less total growing stock and 0.44% more mature growing stock, with differences of up to 4.8% and 9.0%, respectively, in any given decade. The differences largely lie in differences between the amount of area in each analysis unit.

To explore the growing stock in more detail, we analysed the growth rates in the two models, where growth is defined as the change in growing stock between two decades plus the volume harvested. The overall growth increment each decade is shown in Figure 7. The two models follow the same trend, with a low growth early in the horizon and increasing over time to a maximum around decade 10.

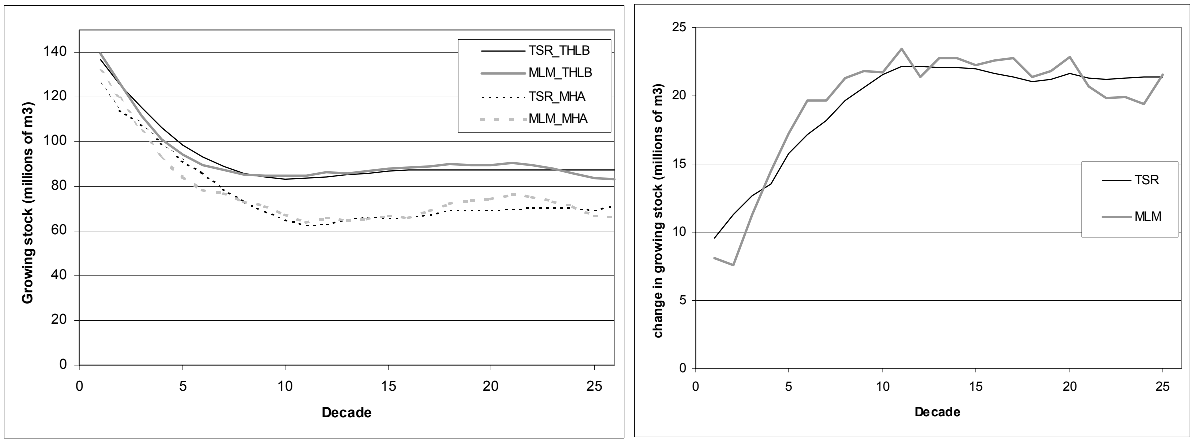



Figure 7. Growing stock for THLB (Total in THLB) and merchantable (mature defined as stands older than minimum harvest age (MHA)) stands (left) and change in growing stock (right) in the MLM (using an area-based AAC) and TSR models.

*Effects of spatial patterns, constraints and harvest order*

The effects of spatial patterns and constraints can be summarized as follows:

(a) Access constraints: Applying an access constraint had little effect on the growing stock and timber supply, with the exception that age harvested is a bit lower in the early periods and remains somewhat higher during the period of decline of age harvested. The similarity in this case is likely not a general result, and is specific to the particular configuration of stands and roads in the district.

(b) Block size: Using 60ha blocks had a moderate impact on timber supply. Figure 8 shows that the primary cause is that the mean age harvested is lower than in the TSR in the early decades, since isolated, small patches of old forest are harvested more gradually over time than when using single-cell blocks. This leads the mean age harvested to follow the TSR results more closely than in the aspatial base case. These changes cause a decrease in the mean volume/ha harvested in the early decades and an increase later. The effect of using an area-based AAC is a lower volume harvested and modest increase in growing stock (Figure 9).

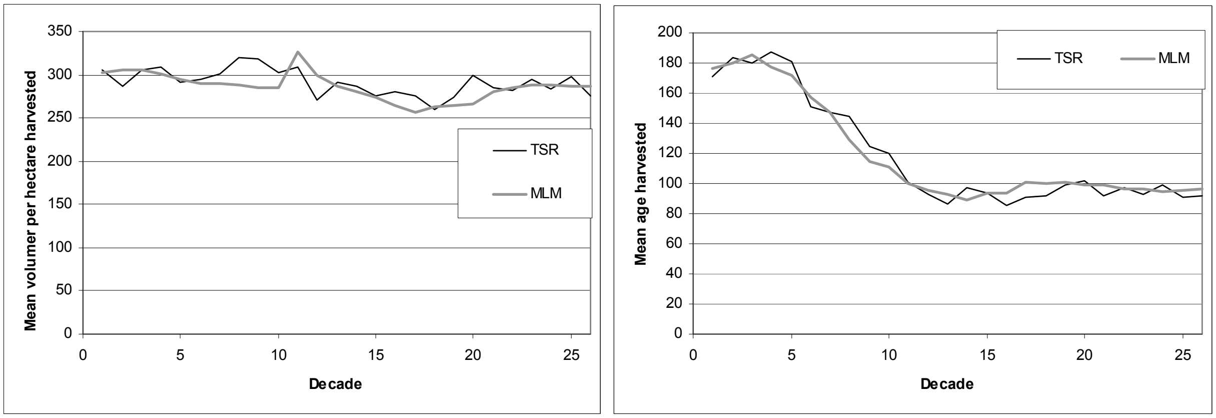



Figure 8. Average volume/hectare and age of harvested stands each decade by MLM using 60ha blocks and an area-based AAC and in the TSR.

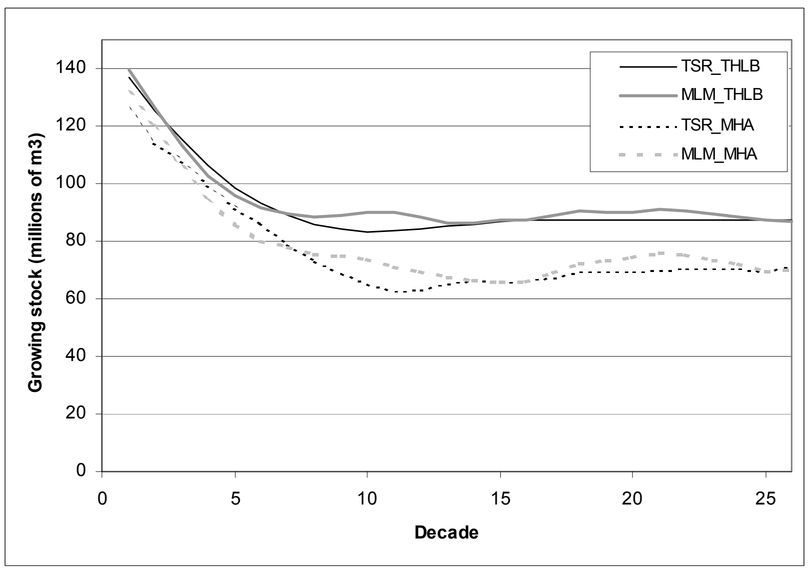


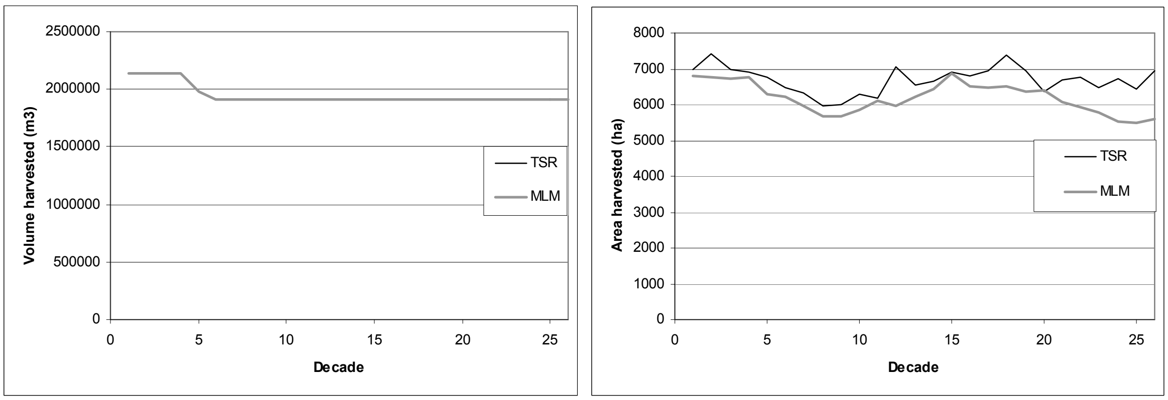

Figure 9. Growing stock for THLB (Total) and merchantable (mature) stands in the MLM using 60ha blocks and an area-based AAC and in the TSR.

(c) Spatial Base Case: Combining access constraints and block size resulted in effects that were very similar to the block size results above.

**(b) Volume based results**

Figure 10 shows the area and volume harvested by the two models. As designed, the volume now matches the TSR exactly, but the area harvested is on average 493.6 ha (7.4%) less in the MLM than in the TSR. This was due to an average of 23.5 $m^3$/ha (~8.1%) more in the MLM than in TSR (Figure 11). Mean age harvested (Figure 11) also deviates with a mean difference of 7 years (but up to 42 years different in the $7^{th}$ decade). The reason why the volume-based approach differs more than the area-based approach is due to the feedback between area harvested, age harvested and mean volume per ha harvested. Both version start with moderately older ages and higher volumes harvested than in TSR. In the area-based version, this does not change the overall pattern of harvest. However, in the volume-based version, this leads to a lower area harvested to meet the AAC. This in turn leads to older ages being harvested in subsequent decades, requiring less and less area to meet the AAC as the forest ages, mean volumes increase (and growing stock rises).

Figure 10. Volume and area harvested each decade by MLM (using a volume-based AAC) and TSR.




This begs the question of the underlying differences between the MLM and TSR. There are some differences in the initial ages, NSR allocation, size of THLB, and in the amount of forest allocated to each analysis unit. Note that the differences aren't large (as evidenced by the area-based results), only that the feedback caused by a volume-based AAC leads to a compounding of the effect over time.

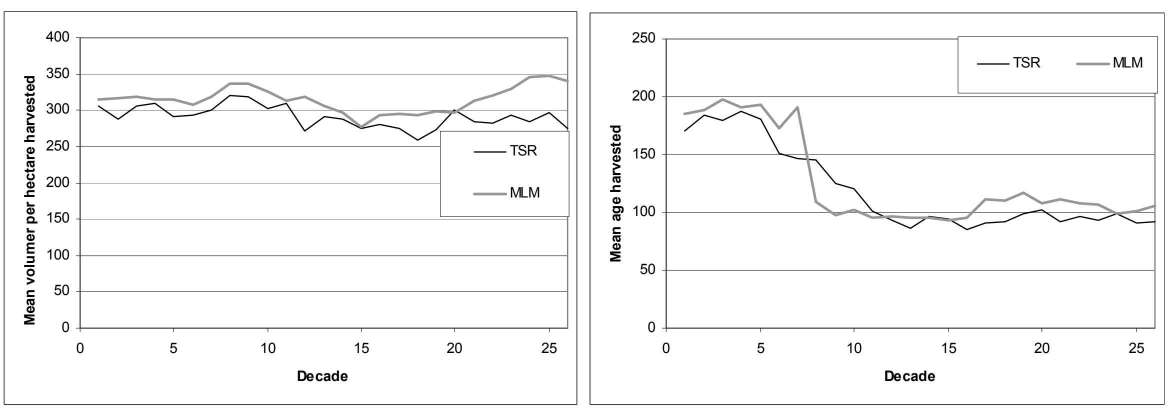



Figure 11. Average volume/hectare and age of harvested stands each decade by MLM (using a volume-based AAC) and TSR.

In this case, the starting estimate of total and mature growing stock is the same as in the area-based version. However, over time, as less area is cut, it rises to significantly higher levels than in the TSR, with 6% more overall, but about 10% in the final decades.

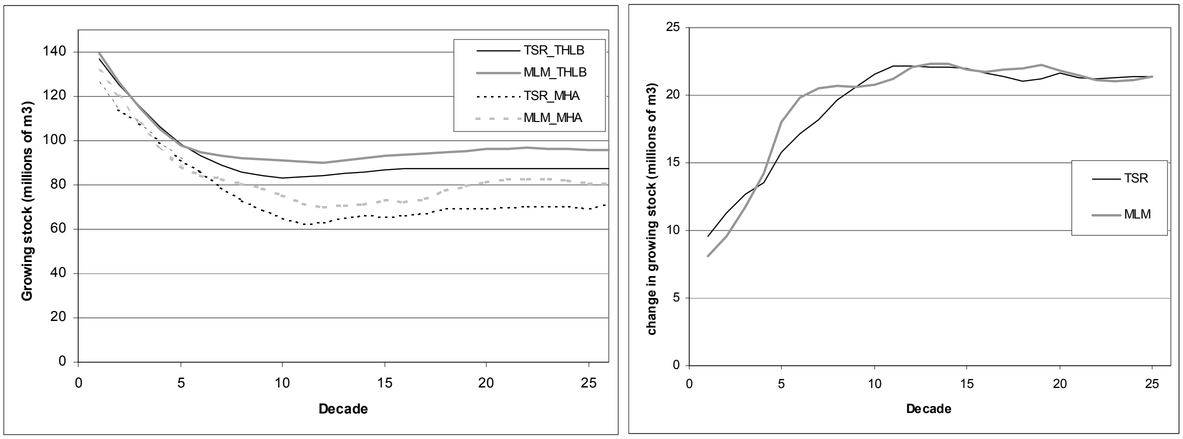



Figure 12. Growing stock for THLB (Total) and merchantable (mature) stands (left) and change in growing stock (right) in the MLM (using a volume-based AAC) and TSR models.

## *Conclusions*

Overall, the alignment of the MLM with the TSR analysis is reasonable using an area-based AAC. There is some uncertainty in the spatial THLB derived for the MLM and in differences in the GIS zone, initial stand age and analysis unit maps used in the two analyses. However, the indicators of harvest and forest regeneration are similar in both the MLM and TSR. Larger deviations occurred using a volume-based AAC target for the MLM, due to the same minor differences at the start, but compounding into increasingly large differences over time.

Our examination of the sensitivity of the results to road access constraints and block size showed that timber supply seems to be somewhat sensitive to applying spatial blocks. When using an area-based AAC, growing stock was stable. For the application of the MLM to the Morice LRMP, the results show that overall growing stock is stable enough in the spatial base case (using both area-based and volume-based AAC) to enable assessments of the relative impacts of various scenarios on timber supply.

# Appendix 3: MLM Indicator Files

The output indicators for the MLM are exported as a set of files either directly during simulation runs or after a post-processing step. Each file is a tab-separated file of columns, with the first row giving column headings. The first columns identified as "strata fields" specify the units to which the "result" fields apply.

NOTES:

(1) The total amount of productive forest declines slightly over time due to loss of forest from road construction
(2) Spur roads cannot be interpreted for aspatial scenarios.

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## *I. Biodiversity.txt* – Indicators for coarse filter biodiversity analysis

Strata Fields:
Year: output year
Replicate: replicate number
Ecosection: ecosection label
LU: landscape unit label
BEC: biogeoclimatic zone label
THLBContCls: either 0 (non-contributing) or 1 (timber harvesting landbase)
ALR: either 0 (not in agiculture land reserve) or 1 (in ALR)
Settlement: either 1 (not identified as settlement area) or 1 (identified as settlement area)
pemSS: predictive ecosystems mapping site series label
isForested: either 0 (not forested) or 1 (forested)
AgeClass5: age class: 0-4 (0-40, 41-100, 101-140, 141-250, 251+)

Result Fields:
Area: number of hectares in stratum

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## *II. CaribouWinter.txt* – Indicators for caribou winter habitat analysis

Strata Fields:
Year: output year
Replicate: replicate number
Ecosection: ecosection label
LU: landscape unit label
BEC: biogeoclimatic zone label
THLBContCls: either 0 (non-contributing) or 1 (timber harvesting landbase)
ALR: either 0 (not in agiculture land reserve) or 1 (in ALR)
Settlement: either 1 (not identified as settlement area) or 1 (identified as settlement area)
CarHerd: caribou herd identifier label
pemSS: predictive ecosystems mapping site series label
Spp1: dominant tree species name
Spp2: sub-dominant tree species name

AgeClass9: age class: 0-8 (0-20, 21-40, 41-60, 61-80, 81-100, 101-120, 121-140, 141-250, 251+)
siClass: site index class: 0-3 (< 1, 1-12.9, 13-24.9, 25+)
slopeClass: slope class: 0-3 (0-5%, 5.1-30%, 30.1-50%, 50.1%+)
aspectClass: aspect class: 0-2 (0: flat, 1: 45-315 degrees 2: 0-44 degrees or 316-360 degrees)
VentBuff: ventilation buffer (0: false or 1: true)
CCClass: canopy closure class: 0-10 (in 10% increments)
Dist2RdCls: distance to roads class: 0-4 (0-100m, 101-500m, 501-2500m, 2501-5000m, 5001m+)
MotWin: motorized winter access type label
PredRisk: predation risk type label
MgmtType: management type label
Glacier: glaciers (0: false or 1: true)

Result Fields:
Area: number of hectares in stratum

### *III.* ***CaribouCalving.txt*** – Indicators for caribou calving habitat analysis

Strata Fields:
Year: output year
Replicate: replicate number
Ecosection: ecosection label
LU: landscape unit label
BEC: biogeoclimatic zone label
THLBContCls: either 0 (non-contributing) or 1 (timber harvesting landbase)
ALR: either 0 (not in agiculture land reserve) or 1 (in ALR)
Settlement: either 1 (not identified as settlement area) or 1 (identified as settlement area)
CarHerd: caribou herd identifier label
pemSS: predictive ecosystems mapping site series label
Spp1: dominant tree species name
Spp2: sub-dominant tree species name
AgeClass14: age class: 0-13 (0-20, 21-30, 31-40, 41-50, 51-60, 61-80, 81-100, 101-110, 111-120, 121-150, 151-180, 181-200, 201-250, 251+)
siClass: site index class: 0-3 (< 1, 1-12.9, 13-24.9, 25+)
slopeClass: slope class: 0-3 (0-5%, 5.1-30%, 30.1-50%, 50.1%+)
CCClass: canopy closure class: 0-10 (in 10% increments)
Island: on island (0: false or 1: true)
Dist2RdCls: distance to roads class: 0-4 (0-100m, 101-500m, 501-2500m, 2501-5000m, 5001m+)
MgmtType: management type label
Glacier: glaciers (0: false or 1: true)

Result Fields:
Area: number of hectares in stratum

### *IV.* *Marten.txt* – Indicators for pine marten habitat analysis

Strata Fields:
Year: output year
Replicate: replicate number
Ecosection: ecosection label
LU: landscape unit label
BEC: biogeoclimatic zone label
THLBContCls: either 0 (non-contributing) or 1 (timber harvesting landbase)
ALR: either 0 (not in agiculture land reserve) or 1 (in ALR)
Settlement: either 1 (not identified as settlement area) or 1 (identified as settlement area)
pemSS: predictive ecosystems mapping site series label
Spp1: dominant tree species name
SppPct1: percent cover by dominant species
Spp2: sub-dominant tree species name
SppPct2: percent cover by sub-dominant species
Spp3: tertiary tree species name
SppPct3: percent cover by tertiary species
NPType: non-productive cover type label
NFType: non-forest cover type label
AgeClass14: age class: 0-13 (0-20, 21-30, 31-40, 41-50, 51-60, 61-80, 81-100, 101-110, 111-120, 121-150, 151-180, 181-200, 201-250, 251+)
MgmtType: management type label
CCClass: canopy closure class: 0-10 (in 10% increments)

Result Fields:
Area: number of hectares in stratum

### *V.* *GrizzlySpring.txt* – Indicators for grizzly bear spring habitat analysis

Strata Fields:
Year: output year
Replicate: replicate number
Ecosection: ecosection label
LU: landscape unit label
BEC: biogeoclimatic zone label
THLBContCls: either 0 (non-contributing) or 1 (timber harvesting landbase)
ALR: either 0 (not in agiculture land reserve) or 1 (in ALR)
Settlement: either 1 (not identified as settlement area) or 1 (identified as settlement area)
slopeClass: slope class: 0-1 (0-34%, 35%+)
aspectClass: aspect class: 0-2 (0: flat, 1:135-284, 2: 0-134 or 285-360)
pemSS: predictive ecosystems mapping site series label
AgeClass16: age class: 0-15 (0-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-80, 81-100, 101-110, 111-120, 121-140, 141-150, 151-180, 181-200, 201-250, 251+)

Dist2RdCls: distance to roads class: 0-4 (0-100m, 101-500m, 501-2500m, 2501-5000m, 5001m+)
isForested: either 0 (not forested) or 1 (forested)
MgmtType: management type label
Glacier: glaciers (0: false or 1: true)

Result Fields:
Area: number of hectares in stratum

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### *VI.* ***GrizzlySummerFall.txt*** – Indicators for grizzly bear summer and autumn habitat analysis

Strata Fields:
Year: output year
Replicate: replicate number
Ecosection: ecosection label
LU: landscape unit label
BEC: biogeoclimatic zone label
THLBContCls: either 0 (non-contributing) or 1 (timber harvesting landbase)
ALR: either 0 (not in agiculture land reserve) or 1 (in ALR)
Settlement: either 1 (not identified as settlement area) or 1 (identified as settlement area)
slopeClass: slope class: 0-1 (0-34%, 35%+)
pemSS: predictive ecosystems mapping site series label
AgeClass16: age class: 0-15 (0-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-80, 81-100, 101-110, 111-120, 121-140, 141-150, 151-180, 181-200, 201-250, 251+)
Dist2SalmonClass: distance to salmon stream class: 0-3 (0-100m, 101-200m, 201-500m, 500m+)
Dist2RdCls: distance to roads class: 0-4 (0-100m, 101-500m, 501-2500m, 2501-5000m, 5001m+)
isForested: either 0 (not forested) or 1 (forested)
MgmtType: management type label
Glacier: glaciers (0: false or 1: true)

Result Fields:
Area: number of hectares in stratum

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### *VII.* ***Goat.txt*** – Indicators for mountain goat habitat analysis

Strata Fields:
Year: output year
Replicate: replicate number
LU: landscape unit label
THLBContCls: either 0 (non-contributing) or 1 (timber harvesting landbase)
AlpineGoat: in alpine goat habitat (0: false, 1: true)
SubalpineGoat: in sub-alpine goat habitat (0: false, 1: true)

Dist2RdCls: distance to roads class: 0-3 (0-250m, 251-500m, 501-1000m, 1001m+)

Result Fields:
Area: number of hectares in stratum

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### *VIII. Timber.txt* – Indicators for detailed timber supply analysis

Strata Fields:
Year: output year
Replicate: replicate number
Ecosection: ecosection label
LU: landscape unit label
BEC: biogeoclimatic zone label
pemSS: predictive ecosystems mapping site series label
AU: analysis unit
AgeClass9: age class: 0-8 (0-20, 21-40, 41-60, 61-80, 81-100, 101-120, 121-140, 141-250, 251+)

Result Fields:
Area: number of hectares in stratum
GrowingStock: number of cubic metres of standing growing stock
VolHarvested: number of cubit metres harvested

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### *IX. GoshawkIndicators_LU_BEC.txt* – Indicators for goshawk habitat analysis (broken down by landscape unit and biogeoclimatic zone variant)

Strata Fields:
Year: output year
Replicate: replicate number
LUid: landscape unit id
LU: landscape unit name
BECid: biogeoclimatic zone id
BEC: biogeoclimatic zone name

Result Fields:
a: number of hectares in stratum
aForest: number of hectares of forest
aAlpine: number of hectares of alpine
aOtherNP: number of hectares of non-alpine non-forest area
aSettle: number of hectares identified as settlement area
aALR: number of hectares of agriculture land reserve
aPrtctd: number of hectares in protected areas
aContClIn: number of hectares of timber harvesting landbase
aContClOut: number of hectares of non-contributing landbase
aLog30: number of hectares of areas logged within last 30 years

aHrdEdge: number of hectares of hard forest edge (at least 2 height classes different)
aRdEdge: number of hectares of road edge (next to older forest)
mnElev: mean elevation in stratum
mnNest: mean nest habitat suitability
mnFrg: mean foraging habitat suitability
aNest0: number of hectares of nest habitat suitability class 0
aNest1: number of hectares of nest habitat suitability class 1
aNest2: number of hectares of nest habitat suitability class 2
aNest3: number of hectares of nest habitat suitability class 3
aFrg0: number of hectares of foraging habitat suitability class 0
aFrg1: number of hectares of foraging habitat suitability class 1
aFrg2: number of hectares of foraging habitat suitability class 2
aFrg3: number of hectares of foraging habitat suitability class 3
mpsNest: mean size of high (class 3) nesting habitat patches
mpsFrg: mean size of high (class 3) foraging habitat patches
npNest: number of high (class 3) nesting habitat patches
npFrg: number of high (class 3) foraging habitat patches
aNest25: number of hectares in high (class 3) nesting habitat patches > = 25 hectares in size
aFrg25: number of hectares in high (class 3) foraging habitat patches > = 25 hectares in size
aNest50: number of hectares in high (class 3) nesting habitat patches > = 50 hectares in size
aFrg50: number of hectares in high (class 3) foraging habitat patches > = 50 hectares in size
npNest25: number of high (class 3) nesting habitat patches > = 25 hectares in size
npFrg25: number of high (class 3) foraging habitat patches > = 25 hectares in size
npNest50: number of high (class 3) nesting habitat patches > = 50 hectares in size
npFrg50: number of high (class 3) foraging habitat patches > = 50 hectares in size

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### *X.* *GoshawkIndicators_Territory.txt* – Indicators for goshawk habitat analysis (broken down by hypothetical territories)

Strata Fields:
Year: output year
Replicate: replicate number
TerritoryId: territory id

Result Fields:
stBECid: biogeolimatic zone id of territory centre point
stBEC: biogeolimatic zone name of territory centre point
stLUid: landscape unit id of territory centre point
stLU: landscape unit name of territory centre point
stElev: elevation of territory centre point
a: number of hectares in stratum
aForest: number of hectares of forest
aAlpine: number of hectares of alpine
aOtherNP: number of hectares of non-alpine non-forest area
aSettle: number of hectares identified as settlement area
aALR: number of hectares of agriculture land reserve

aPrtctd: number of hectares in protected areas
aContClIn: number of hectares of timber harvesting landbase
aContClOut: number of hectares of non-contributing landbase
aLog30: number of hectares of areas logged within last 30 years
aHrdEdge: number of hectares of hard forest edge (at least 2 height classes different)
aRdEdge: number of hectares of road edge (next to older forest)
mnElev: mean elevation in stratum
mnNest: mean nest habitat suitability
mnFrg: mean foraging habitat suitability
aNest0: number of hectares of nest habitat suitability class 0
aNest1: number of hectares of nest habitat suitability class 1
aNest2: number of hectares of nest habitat suitability class 2
aNest3: number of hectares of nest habitat suitability class 3
aFrg0: number of hectares of foraging habitat suitability class 0
aFrg1: number of hectares of foraging habitat suitability class 1
aFrg2: number of hectares of foraging habitat suitability class 2
aFrg3: number of hectares of foraging habitat suitability class 3
mpsNest: mean size of high (class 3) nesting habitat patches
mpsFrg: mean size of high (class 3) foraging habitat patches
npNest: number of high (class 3) nesting habitat patches
npFrg: number of high (class 3) foraging habitat patches
aNest25: number of hectares in high (class 3) nesting habitat patches > = 25 hectares in size
aFrg25: number of hectares in high (class 3) foraging habitat patches > = 25 hectares in size
aNest50: number of hectares in high (class 3) nesting habitat patches > = 50 hectares in size
aFrg50: number of hectares in high (class 3) foraging habitat patches > = 50 hectares in size
npNest25: number of high (class 3) nesting habitat patches > = 25 hectares in size
npFrg25: number of high (class 3) foraging habitat patches > = 25 hectares in size
npNest50: number of high (class 3) nesting habitat patches > = 50 hectares in size
npFrg50: number of high (class 3) foraging habitat patches > = 50 hectares in size

## *XI. ClassStats.txt* – A variety of metrics for patch pattern analysis.

Strata Fields:
Year: output year
Replicate: replicate or map number
Type: patch type
LU: landscape unit name
BEC: biogeoclimatic zone name

Result Fields:
A: Area (ha)
PCTLAND: percent of the forest cover by the patch types
NP: Number of Patches
MPS: mean patch size (ha)
EPS: expected patch size (ha). Area-weighted mean patch size.

TE: total edge (metres): length of cell edges between two different types of cell)
AWMSI : area-weighted mean shape index. Same as MSI, but instead of dividing by the number of patches to get the mean, the sum of per-patch shape values is divided by the total area covered by the class.
MeanCCE: connectivity metric for between patch centroids: Mean interaction between patch pairs, where interaction is defined as the product of patch size divided by the square of distance between their centroids. Low values indicate small patches that are far apart, while large values indicate larger, closer patches.
SumCCE: sum of inter-patch centroid interactions.

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## ***XII. PatchStats.txt*** – A variety of individual patch metrics for patch pattern analysis.

Strata Fields:
Year: output year
Replicate: replicate or map number
id: Patch identifier

Result Fields:
bec: biogeoclimatic zone name
lu: landscape unit name
type: patch type
size: patch size (ha)
perim: patch boundary length (m)