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MODELING

Omineca Northern Caribou Project
Harvest Schedule and Disturbance Models for the Wolverine Caribou Herd Area

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ABSTRACT

Management of woodland caribou (*Rangifer tarandus caribou)* is a major concern in the Mackenzie and Fort St. James Forest Districts. Exploring the spatial and temporal impacts of various management scenarios on caribou habitat and timber supply is a primary focus of the CHASE Model developed by the Omineca Northern Caribou Project. The goal of the harvest-scheduling and natural disturbance sub-project is to support this effort by developing models (i) to generate timber harvest schedules that can incorporate a variety of constraints designed to mitigate timber harvesting impacts on caribou habitat and populations; and (ii) to implement empirical fire models consistent with fire ecology information and history for the area. The timber harvesting schedules represent long-term (i.e., 2-3 rotations) management policies that are examined spatially and temporally through the CHASE Model for impacts on caribou habitat and timber supply. The empirical fire models simulate natural disturbance scenarios and generate thresholds or targets for habitat supply that are used to evaluate the effectiveness of management policies within the CHASE Model.

The timber harvesting and empirical fire models were implemented using the SELES (Spatially Explicit Landscape Event Simulator) landscape modelling tool. SELES is designed to model landscape dynamics and processes that include stochastic elements. It does not include optimization procedures. Therefore, timber harvest schedules produced using these models are best viewed as strategic representations of a management regime. Similarly, each fire schedule represents one possible outcome for the landscape under a natural disturbance regime.

This document identifies the input data layers required by SELES to generate the harvest and fire schedules for the CHASE Model, and differentiates between those inputs that are derived directly from inventory data and those inputs that are generated by pre-processing models. Pre-processing models include a static SELES model to produce forest patch maps, an explicit roads model, and an ungulate winter range (pine-lichen winter range) model. Descriptions of the SELES model outputs, in the form of harvest and burn schedules, are provided. Descriptions of the SELES timber harvesting sub-models that (i) update stand ages; (ii) generate timber harvest schedules under various harvesting constraints; (iii) disturb pine-lichen winter range habitat that exists outside the Timber Harvesting Land Base; and (iv) build and maintain roads, and the empirical fire sub-model are presented.

A total of 15 different management scenarios, representing different target forest patch size distributions, cut-block adjacency constraints, biodiversity seral stage targets, flow constraints on pine-lichen winter range (i.e., percentage targets for amount of forest in young and mature age classes), and forest age constraints in the caribou calving range zone, were modelled and assessed for impacts on an area-based forest harvest target. In general, modelling cut-block adjacency as a hard spatial constraint had the greatest impact on timber harvest while modelling cut-block adjacency as a spatial target rather than constraint alleviated the impact. The other major impact to timber harvest appeared to be related to use of Natural Disturbance Unit biodiversity constraints rather than those specified by the biogeoclimatic ecosystem classification zone.

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INPUT DATA

The Wolverine Caribou herd area is approximately 988,000 ha in size, of which approximately 456,000 ha are operable productive forest in the timber harvesting landbase, and straddles the two forest districts. The forest primarily consists of lodgepole pine, fir and spruce leading stands. The biogeoclimatic zones in the area are BWBS (dk1), SBS (mk1, mk2, wk2, and wk3), ESSF (mv2, mv3 and mvp3), and ATp. It includes all or portions of 26 landscape units.

The landscape is represented spatially as a set of raster layers, with a resolution of 1ha/cell (100m X 100m). The spatial layers required as input to the model can be divided into those that derive directly from inventory and those that are generated in a pre-processing stage. Layers directly from inventory include:
(a) Inventory Type Group
(b) Stand Age
(c) Biogeoclimatic Zone
(d) Landscape Unit
(e) Biodiversity Emphasis Options
(f) Timber Harvesting Land Base Inclusion Factor (percentage of THLB in each cell)
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(j) Calving Range area
(k) Lichen Capability (Pine-Lichen Winter Range (PLWR) zone)
(l) Road state (existing and proposed)

Layers derived from pre-processing models include:
(m) PLWR density
(n) Ungulate winter range (UWR) zone
(o) Road building cost surface
(p) Identifier of nearest road segment (existing and proposed)
(q) Road backbone
(r) Cost to nearest road segment (existing and proposed)
(s) Location of nearest active road segment
(t) Stand patch map (patch id, patch age and patch size)

Patch map pre-processing model:

The patch maps were produced using a static SELES model. The goal was to produce units of forest that were relatively homogeneous in age (±20 years) and ranged in size from 20ha to about 80ha. Patches were created as close to 40 ha as possible, but larger patches were formed to combine patches that were too small. This step was done to make the harvest patterns more consistent with the current pattern of forest patches on the landscape and to avoid harvest units that were very small. Patch size and mean patch age were produced to help guide the harvest-scheduling model.

Explicit roads pre-processing model:

To handle roads in a spatially explicit manner, and to incorporate spatially varying road building cost, a suite of network processing models were employed. First the relative road cost layer was estimated as follows. In lake and alpine areas greater than 25ha in size, the cost was set to a relative value of 50. In other areas, cost was set to be the value of slope in percent (but with a max. at 50).

The current and proposed (mapped) roads were split into segments at forks. These segments were extracted and stored as a network. This network can be visited as harvest flows down to the segments that exit the study area by following the "road backbone" which ensure a unique path from any road cell to the nearest "exit" point off the study area. The cost to the nearest current and future road segment, as well as the cell location of those segments, was calculated so that the road network can expand as harvesting and road development proceed.

UWR pre-processing model:

This pre-processing model is computed at the start of each simulation run. It takes as input the pine-lichen winter range (PLWR) layer. It then performs a "majority rule" filter. That is, for each cell classified as PLWR, it filters out any cell for which the proportion of high value PLWR in a 500m radius circle is less than 1/3. The remaining are called "PLWR dominant" cells. This area is also restricted to the BWBS BEC zone in the Wolverine area.

For each PLWR dominant cell, the density of PLWR in a circle of one square km is computed. Finally, the UWR Zone is defined as cells that are within 3000m of PLWR dominant cells.

MODEL OUTPUTS

(a) Harvest and Burn Schedule Format

Files are used to represent the harvest and burn schedules produced. The first (*cellSchedule.txt)* outputs the run number, year, location (row, column), type (1 for harvesting, 2 for fire and 3 for disturbance outside the THLB in the PLWR zone), age, zone (in or not in the PLWR zone), BEC zone, ITG and patch id for each cell harvested or burned. The second (*patchSchedule.txt)* outputs the year, patch id, patch age and overall patch size for each patch harvested. Since fires burn independent of existing patch boundaries, it is not appropriate to enforce a patch schedule as is possible for harvesting. These files form a sequence of harvesting or burning that can be replicated. This approach is more general than producing layers that indicate the timing of cell or patch harvesting, since the sequence in a file can change over long time horizons whereas the sequence in a layer can only be repeated. This is important due to the interaction of different harvest constraints and due to the inherent stochasticity of wildfire. Furthermore, the inclusion of minimum harvest ages that vary across the landscape means that different stands have fundamentally different harvest rotations, which requires a flexible approach for ordering harvesting. In addition to providing a general approach to model harvesting over long time frames, this approach could also facilitate future scenarios that combine fires and harvesting. One disadvantage is that substantial disk space and memory may be required to store and process the cell schedule (and so usage of the patch schedule may be more practical in some cases).

To apply a schedule in the caribou habitat model, one needs simply to read in the files (cell or stand) row by row. Each row for the current year should be read and the appropriate cell or stand ages reset to zero.

(b) Additional Model Outputs

In addition to the schedule, these models output several statistical summary files. The block size distribution is output as the number of blocks and area covered by blocks in 10ha size classes (*BlockSizeDist.txt*) or according to the distribution classes (*BlockSizeDist.txt2*). The file *harvestRecord.txt* contains information on the area harvested each year (in total and in the IRM, Calving Range and PLWR zones), the mean harvest age, and the proportion of young, mature and old forest in each zone. In addition, each year, the number of unscheduled hectares available to harvest and unavailable due to one of the constraining factors is output to *limitingConstraints.txt*. The file *fireRecord.txt* contains information on the area burned each year (in total and in the IRM, Calving Ranges and PLWR zones).

MODEL DESCRIPTION

Stand Aging Sub-Model

This sub-model recurs annually and updates the stand age and patch age layers. It also tracks the amount of forest in the different strata for forest cover rules (e.g. amount of old forest in each BEC, landscape unit combination).

Harvest Schedule Sub-Model

The harvest schedule sub-model was designed to capture an area-based strategic harvesting regime. It has the following main components.

(a) Constraints

SELES is designed to model landscape dynamics and processes that include stochastic elements. It does not include optimization procedures. Thus, harvest schedules produced using these models are best viewed as strategic representations of a management regime. In this context, the harvest schedule model produced for the Wolverine Herd area has the advantage of flexibility in selecting constraints to apply on the harvest pattern. These constraints are specified in three inputs:

1. Minimum harvest age (MHA) is specified as a layer. Only stands at least as old as MHA can be harvested.

2. Biodiversity cover constraints are specified by biogeoclimatic ecosystem classification (BEC) zone according to the biodiversity guidebook of the forest practices code (FPC) (British Columbia Ministry of Forests. 1995). The constraints can be applied using biodiversity emphasis option (low, intermediate or high) or using a weighted average of the constraints (45% of the low, 45% of the intermediate and 10% of the high requirements). These are applied by landscape unit overlayed with BEC variant. Note that in the current version, we did not apply the reduction to the minimum old requirement in low biodiversity emphasis option areas as is generally done in the timber supply review (TSR) process. Also, the maximum young constraint can optionally be enabled or disabled. The constraints used are as follows:

BEC Zone	AT and ESSFmv3p	BWBSdk1, SBSmk1, SBSmk2, and SBSwk3	ESSFmv2 and ESSFmv3	SBSwk2
Young Age	40	40	40	40
Mature Age	120	100	120	100
Old Age	250	140	250	250
Maximum Young (Low)	≤ 100%	≤ 100%	≤ 100%	≤ 100%
Maximum Young (Int)	≤ 22%	≤ 54%	≤ 36%	≤ 36%
Maximum Young (High)	≤ 17%	≤ 40%	≤ 27%	≤ 27%
Minimum Mature (Low)	≥ 19%	≥ 11%	≥ 14%	≥ 15%
Minimum Mature (Int)	≥ 36%	≥ 23%	≥ 28%	≥ 31%
Minimum Mature (High)	≥ 54%	≥ 34%	≥ 42%	≥ 46%
Minimum Old (Low)	≥ 19%	≥ 11%	≥ 9%	≥ 9%
Minimum Old (Int)	≥ 19%	≥ 11%	≥ 9%	≥ 9%
Minimum Old (High)	≥ 28%	≥ 16%	≥ 13%	≥ 13%

Biodiversity constraints can alternatively be defined using the "natural disturbance unit" concept, which divides the area into NDU1 (Omineca Mountain: upper elevation areas) and NDU2 (Omineca Valley: lower elevation areas), as follows:

	NDU1	**NDU2**
Young Age	40	40
Mature Age	100	100
Mature Age 2	140	140
Old Age	250	250
Maximum Young	≤ 22%	≤ 45%
Minimum Mature	≥ 66%	≥ 33%
Minimum Mature 2	≥ 58%	≥ 23%
Minimum Old	≥ 39%	≥ 8%

3. Cut-block Adjacency (green-up) can either be applied spatially (as a specified buffer in meters, e.g. 400m) or as a forest cover constraint as used in the TSR process to represent adjacency: at most 33% of the forest can be under 20 years. Other projects have shown the difficulty of applying adjacency as a hard spatial constraint, and this option should not be used without assessing the ability of the model to reach the harvest target. Adjacency can also be specified as a "soft constraint", where it is an objective rather than an absolute rule. In this case, the relative

preference of harvesting in adjacency buffers is set very low, but harvesting can proceed if few other options exist.

4. <u>Resource emphasis area constraints</u> were applied in the PLWR (Lichen Capability) zone, Calving Range (in the intersection of Calving Range and CMS2 layers), and the integrated resource management (IRM) zone (everywhere not in the PLWR zone). The Calving Range constraint applies to the productive forest, the PLWR constraint applied to operable forest and the IRM constraint applies the forest in the THLB (all met by landscape unit).

   The Calving Range constraint specifies that at most 5% of the forest is less than 10 years old. This constraint can optionally be enabled or disabled.

   The cover constraints in the PLWR zone can be varied depending on the input parameter *FlowConstraint.* The following table provides the available options. In the case of PLWR70, we used the IRM maximum young constraint (since the constraint "at most 50% under 70 years" is equivalent to the minimum mature constraint of "at least 50% over 70 years"). The IRM constraint depends on how adjacency is handled, and may be "at most 33% under 20 years" (as shown) or "no constraint" (if adjacency is done spatially).

Constraint Name	Young Age	Maximum Young	Mature Age	Minimum Mature
PLWR Unconstrained	20	≤ 33%	70	≥ 0%
PLWR70	20	≤ 33%	70	≥ 50%
PLWR35	35	≤ 25%	70	≥ 50%
PLWR20	20	≤ 14.29%	70	≥ 50%
PLWR10	10	≤ 7.14%	70	≥ 50%

   The unconstrained case is the same as for IRM. All the other cases restrict at least 50% of the PLWR zone to be above 70 years old. In addition, the maximum young constraint is used to control the flow of harvesting in the zone, from the least constrained (at most 50% of the forest is under 70 years, which is identical to the minimum mature constraint) to the most constrained (at most 7.14% of the forest is under 10 years). Note that all of these constraints ensure that the PLWR zone will be harvested on at least a 140-year rotation. The difference between them is that the younger the "young age", the closer harvesting must be to even-flow management.

5. <u>Patch size distribution targets</u> are also specified separately for the Caribou Management Strategy 1 (CMS1), CMS2 and non-CMS zones. The target patch size distribution for each zone is controlled by the input parameters *PatchSizeDistTypeCMS1, PatchSizeDistTypeCMS2, and PatchSizeDistTypeNonCMS*, which can specify the distributions in the following table. When the patch size distributions for the CMS and non-CMS zones differ, the distribution for the non-CMS zone is adjusted to attempt to meet its target across the entire landscape unit, while meeting the CMS distributions in portions of the landscape unit (e.g. if CMS1 specifies large blocks, then the non-CMS distribution will reduce the proportion of large blocks on areas outside the CMS1 zone).

Distribution Name	1-40ha	1-60ha	41-80ha	41-250ha	81-250ha	251-1000ha	1000ha	251 – 5000ha
FPC	-	100%	-	-	-	-	-	-
Small	100%	-	-	-	-	-	-	-
Large	-	-	-	-	-	-	100%	-
BGB NDT2	35%	-	35%	-	30%	-	-	-
BGB NDT3	15%	-	-	15%	-	70%	-	-
CMS1 NDT2	35%	-	-	35%	-	-	-	30%

CMS1 NDT3	15%	-	-	15%	-	-	-	70%
NDU1	20%	-	10%	-	-	30%	40%	-
NDU2	5%	-	5%	-	-	30%	50%	-

The first is the distribution specified by the forest practices code. The second is intended for the calving range (CMS2) to produce small openings of 40ha. The third is a proposal to harvest in large blocks in order to minimize fragmentation of caribou habitat. The fourth and fifth are from the biodiversity guidebook (BGB) for BEC zones with natural disturbance types 2 and 3. The next two are recommendations for NDT2 and NDT3 from the Mackenzie LRMP Caribou Management Strategy, for BEC zones with NDTs of 2 and 3. The last two are designed around the natural disturbance units 1 and 2. The percentages refer to the amount of forested area and not the number of patches.

It is challenging to produce harvest blocks that follow existing stand boundaries, satisfy a target distribution and meet the various constraints. I chose to prioritize these objectives in the above order. That is, the patch map is used to follow existing stand boundaries as much as possible. This means that harvest blocks grow in size by joining one or more adjacent patches. Due to the granularity of the patches, forming 40ha blocks is not always possible, and blocks in this size class tend to be slightly smaller or larger than 40ha. Also, patches may cross zone (PLWR, Calving Range, CMS or BEC) boundaries and hence fall under multiple constraint sets. A single patch may have a portion that is unavailable in one zone, but available in another. I chose to make a patch available for harvest if all cells within it are available. This respects the cover constraints, but also makes it more difficult to produce schedules that satisfy rotation and patch size distribution targets. The alternative would be to make a patch available if any portion is available. This would allow the constraints to be violated sometimes.

(b) Harvest Level

The amount of forest (in area) to harvest each year is estimated using the minimum harvest age (MHA) layer. The mean MHA indicates the theoretical maximum rate of harvest, which is 1/meanMHA. For example, if the mean MHA is 100 years, then at most 1% of the forest can be cut annually in a sustained manner. However, due to the spatial pattern of stands, ordering of harvest and harvest constraints, it is unlikely that the theoretical maximum harvest rate could be achieved. A proper estimate of the sustainable harvest rate would require a level of analysis akin to a timber supply review. I ran a range of experiments using a constant annual harvest rate to determine a level that could be sustained over the 300 year time horizon, and determined that 90% of the maximum rate is possible. Thus the rate of harvest is 0.9/meanMHA, which is approximately 4,340ha/year in the herd area. Blocks are laid down until this harvest target has been met.

(c) Schedule Algorithm

The first step of harvesting is to identify which patches are available. Patches may be unavailable because they are (a) too young; (b) more than 3km from the nearest road; (c) locked up in a green up buffer; or (d) locked up due to the forest cover constraints.

Starting cells are selected from those available to harvest, with probabilities increasing with age and decreasing with distance from road. A target patch size is selected based on the input patch size distribution. It is not always possible to meet a target distribution. To attempt to come as close as possible, the target distribution is updated as blocks are scheduled, based on relative representation. For example, if smaller blocks become over-represented, then the probability of selecting a larger block increases. Once a cell has been selected, the entire patch to which it belongs is harvested to ensure a minimum block size. Additional adjacent patches are included in the block as necessary to reach the selected block size.

The study area currently has areas with few roads. Harvesting is initially limited by road access, which develops over time. This model does not explicitly deactivate roads; rather this is done in the post-processing model based on a parameter that specifies how long a road remains active since it was last used.

PLWR Disturbance Sub-Model

This sub-model was designed to apply a constant rate of disturbance in the portion of the PLWR zone *outside the THLB*. The intent is to capture the effects of combined natural disturbance and management in this area with the primary goal of maintaining lichen forage. To meet a steady flow of 50% of forest in the age range 70-140 years, the simplest method is to achieve a uniform age-class structure between 0 and 140. Each year, the model disturbs 1/140 of the forest using an oldest-first rule. Volume is not recovered, as this is in inoperable or operable-excluded (e.g. provincial parks) areas.

Road Building and Maintenance Sub-Model

This is an interacting suite of sub-models that manages dynamic road construction and re-activation given the pre-processed road network. During harvesting, each block must be connected to the road network (provided it is not already connected). To do this, first a spur (unmapped road) segment is created to the nearest mapped road segment (following the least-cost path). This mapped segment is marked as "newly activated" if it is current "proposed" or "reactivated" otherwise (i.e. it is already active).

After harvesting, a separate sub-model updates "road activation" by starting in all "newly activated" or "reactivated" segments. For each, the network is traversed to the nearest "exit" segment. Along the way, all segments are noted as "active". This may include some segments currently "proposed" may be activated in this way (i.e. segments between the initial segment and the nearest active segment). A record for each segment is output in the road activation file to be used for the road post-processing step.

A second sub-model is used to update the "distance to nearest road segment" information. During harvest, additional diffusion is used to update this information for any new spurs created. This sub-model does the same for any mapped segments that become newly activated.

Empirical Fire Sub-Model

The objective was to implement an empirical fire model driven by fire history information for the region, which consisted of return times and patch size distributions (by forest area) stratified by BEC variant. Two different return times were provided for the analysis (termed "old" and "new" return times). This input data is shown in the following table. There was no information for the alpine tundra zone. I assumed the same patch size distribution as for ESSFmv3 and a return time that was twice as long.

BEC	**Return Time**		**Patch Size Distributions (percent of area)**				
	Old	New	1-10	11-100	101-1000	1001-10000	> 10000
ATp	400	1000	0.7%	7.6%	30.5%	61.2%	0%

BWBSdk1	150	333	1.8%	19.1%	55.7%	23.4%	0%
ESSFmv2	200	152	0.7%	7.6%	30.5%	61.2%	0%
ESSFmv3	200	500	0.7%	7.6%	30.5%	61.2%	0%
ESSFmvp3	200	500	0.7%	7.6%	30.5%	61.2%	0%
SBSmk1	150	244	0.9%	7.5%	18.1%	55.7%	17.8%
SBSmk2	150	186	0.9%	7.5%	18.1%	55.7%	17.8%
SBSwk2	200	175	3.6%	22.0%	36.0%	38.4%	0%
SBSwk3	150	270	2.3%	16.5%	43.7%	37.5%	0%

I converted the patch size distribution provided from percentages of forest to percentages of patches in each size class. Although large (small) patches may make up a large (small) percentage of the forest, they tend to make up a relatively small (large) number of patches. The transformed patch size distribution (in terms of patch size frequencies) are input to the model, and are shown in the following table:

BEC	**Patch Size Frequencies (percent of patches)**				
	1-10	11-100	101-1000	1001-10000	> 10000
ATp	40.6%	40.1%	16.1%	3.2%	0%
BWBSdk1	44.3%	42.7%	12.5%	0.5%	0%
ESSFmv2	40.6%	40.1%	16.1%	3.2%	0%
ESSFmv3	40.6%	40.1%	16.1%	3.2%	0%
ESSFmvp3	40.6%	40.1%	16.1%	3.2%	0%
SBSmk1	49.8%	37.8%	9.1%	2.8%	0.5%
SBSmk2	49.8%	37.8%	9.1%	2.8%	0.5%
SBSwk2	60.4%	33.5%	5.5%	0.6%	0%
SBSwk3	54.4%	35.4%	9.4%	0.8%	0%

At simulation startup, the mean number of fire patches per year and expected number of patches over the time horizon are computed for each BEC zone. First, the mean patch size is determined from the patch size distribution. Mean number of fires per year is then: *Forest Size / (Return Time * Mean Patch Size)*, since *Forest Size / Return Time* is the expected area of forest to burn each year, which must also be equal to *Mean Patch Size * Mean Number of Fires.*

The fire model operates on an annual time step. Each year, and in each BEC zone, the computed mean number of fires are initiated. There is an option to select the number of fires stochastically from a negative exponential distribution. For each fire, a fire size class is selected from the patch size distribution using the frequencies as relative probabilities. A fire extent is selected for the size class from a uniform distribution. For example, if the fire size class was 40-250ha, then an extent is chosen randomly from the range [40,250]. Fires are assumed to be stand replacing, and so age is set to zero in burned cells. Fires spread from a burnt cell to a random number of the eight neighbours (including diagonals). Fires continue to spread until the chosen extent as been burnt (counting only forested cells, but spreading over non-forested cells). When a fire finishes, the actual size burned is used to update the target size distribution. This allows the model to match as close as possible the target distribution over the time horizon (e.g. if small fire patches become over-represented, the relative probability is selecting a small patch gets reduced).

Scenarios

The model is designed to run over long time periods (e.g. 300-400 years) and can be set up to apply either the old and new return intervals. This model is stochastic, with substantial variability between runs. Ideally, multiple replicates would be run (at least 10), and these used for further analysis. When using the results from a single run, one should keep in mind that this represents a single "possible future" that is consistent with the empirical fire cycles and patch size distributions, and that the actual results could vary significantly from the targets.

EXPERIMENT RESULTS

Scenarios Assessed

I ran 15 of the potential combinations of flow constraints, patch size distributions and adjacency options, as shown in Table 1. The patch size distribution for the non-CMS zone was the same as for the CMS zones unless otherwise indicated. Each scenario was output to a different directory, with directory names as shown in the table. All scenarios were run for 300 years with 5 replicates.

Table 1. Scenarios assessed. The primary differences relate to target patch size distribution, PLWR flow constraint, adjacency, biodiversity targets (by BEC or NDU) and calving constraint.

Scenario	Target Patch Size Distribution	Flow Constraint	Adjacency	Biodiversity Max Young Constraint	Calving Constraint
fpc	**FPC**	**PLWR Unconstrained**	**Cover constraint**	**BEC constraints using BEO layer** **No Max Young Constraint**	**No**
fpcAdj			**Spatially: 400m**		
fpcSoftAdj			**Spatially: 400m as target not constraint**		
bgb	**BGB* (NDT2&3)**		**Not Applied**	**BEC constraints using BEO layer** **with Max Young Constraint**	
lrmp	**CMS1: CMS1 (NDT2& 3)** **CMS2: Small** **NonCMS: BGB (NDT1&2)**				**Yes**
caribou Optimum70		**PLWR70**			
caribou Optimum35		**PLWR35**			
caribou Optimum20		**PLWR20**			
caribou Optimum10		**PLWR10**			
acmsAdj	**CMS1: NDU1&2** **CMS2: NDU1&2**	**PLWR Unconstrained**	**Spatially: 400m**	**NDU constraints**	**No**
acmsAdj70		**PLWR70**			
acmsNoAdj		**PLWR Unconstrained**	**Not Applied**		
acmsNoAdj70		**PLWR70**			

acmsSoftAdj	**NonCMS: NDU1&2**	**PLWR Unconstrained**	**Spatially: 400m as target not constraint**		
acmsSoftAdj70		**PLWR70**			

*Note that all NDT2 areas in the Klawli landscape unit in the Mackenzie forest district is treated as NDT3

Results and Discussion

Table 2 shows indicator results to assess the ability of the different scenarios to meet the harvest target. The rate was set using the fpc scenario in the previous version of the model as the highest level that could be sustained over 300 years. The revised model (primarily changing access management and some input layers) indicates that this level is at the threshold since the fpc scenario reaches 99% of the target. On average 11 periods were below the target by about 250ha each time (5.8%).

Table 2. Main indicators to assess ability of scenario to meet harvest target (which is set as an area-based target, with a rate of 90% of 1/mean min. harvest age).

Scenario	**Mean area harvested**	**Percent of Target**	**Periods Below Target (out of 60)**	**Mean Area Below Target in Sub-target years**
fpc	4295 ha	99.0%	11	247 ha
fpcAdj	3845 ha	88.6%	46	634 ha
fpcSoftAdj	4288 ha	98.8%	10	313 ha
bgb	4301 ha	99.1%	12	195 ha
lrmp	4330 ha	99.8%	8	77 ha
caribou Optimum70	4245 ha	97.9%	11	514 ha
caribou Optimum35	4259 ha	98.2%	17	283 ha
caribou Optimum20	4263 ha	98.3%	11	418 ha
caribou Optimum10	4267 ha	98.4%	11	400 ha
acmsAdj	3583 ha	82.6%	48	929 ha
acmsAdj70	3528 ha	81.3%	46	1040 ha
acmsNoAdj	4034 ha	93.0%	21	859 ha
acmsNoAdj70	3981 ha	91.8%	29	729 ha
acmsSoftAdj	4038 ha	93.1%	23	776 ha
AcmsSoftAdj70	3984 ha	91.8%	29	724 ha

The main distinction in the scenarios assessed relates to adjacency. When applying adjacency as a hard constraint, the model could not reach the target in most periods, often by quite substantial amounts. Applying adjacency as a target (soft constraint) alleviated this. Otherwise basic FPC rules could mostly meet the target, as could the BGB, and LRMP (all with over 98% of the target on average).

The caribou optimum rules appear to have a cost of approximately 1% over the above scenarios. The acms rules appear to cause the model to harvest closer to 7% less than fpc. This seems to be somewhat independent of the constraints imposed by PLWR flow constraint, since combining these results in another 1% drop.

It is important to bear these reductions in harvest in mind when interpreting results. The area of forest and THLB remain the same, so constraints that lead to less harvesting necessarily lead to the forest aging (i.e. the effective rotation is lengthened). A difference of 1 or 2% likely won't lead to large effects. The harvest target applied results in a rotation of approximately 109 years. A drop in harvesting by 10% would lengthen this to about 122 years (98.45 years / (0.9 * 90%)). In this respect, the scenarios form two clusters: those with hard adjacency constraints and those without.

CONCLUSION

The harvest schedule and disturbance models for the Wolverine Herd Area have been designed as a flexible and adaptable tool to support the Omineca Northern Caribou Project. We have applied a modelling framework that supports a diverse range of management scenarios to be assessed as well as fire disturbance. The results of the model can be used to drive landscape change in a Bayesian belief network built in Netica for assessing caribou sustainability over long time frames.

Our assessment of the harvesting scenarios shows that these models can produce insightful outputs directly. By assessing the degree to which the variety of constraints interact with the initial landscape structure and road network, one can see which constraints have the largest impact on the ability to meet a given harvest level.

REFERENCES

British Columbia Ministry of Forests. 1995. Biodiversity Guidebook. B.C. Forest Practices Code. Victoria, B.C.

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.