FINAL REPORT

Multi-species Habitat Supply in the Quesnel Timber Supply Area, British Columbia

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ABSTRACT

Habitat supply modeling for multiple, terrestrial wildlife species was integrated with Timber Supply Review (TSR) scenarios and applied to the Quesnel Timber Supply Area (TSA) in British Columbia. The ultimate goal was to provide information on selected wildlife for use in a multiple-account, trade-off analysis designed to support sustainable management of timber and other resource values. Objectives over this two-year project were to: (1) prepare a list of terrestrial vertebrate species that represent a cross-section of habitat requirements and indicators, (2) research an account of habitat needs for each species, (3) develop habitat supply models, (4) integrate the habitat supply models with TSR scenarios, stand structure, dead wood, Predictive Ecosystem Mapping and relative soil moisture, (5) apply the models to the Crown portion of the TSA, (6) summarize stand and habitat conditions (suitability, capability), and (7) draw interpretations regarding habitat elements and resiliency of wildlife habitat to extensive ecological change (mountain pine beetle, timber harvest) including the identification of potential constraints on habitat connectivity, access, seral stage distributions and juxtaposition.

Fourteen wildlife species were chosen for modeling. We retrieved species accounts and made extensive changes to habitat supply models available from previous work. These previously modeled species included moose, wolverine, marten, mule deer, caribou high-elevation, caribou low-elevation, mountain goat, and grizzly bear. We also developed seven new models to account for identified bird species (northern flicker, great blue heron, Barrow's goldeneye, rusty blackbird, northern goshawk, three-toed woodpecker and black-backed woodpecker). The model changes and the effort to integrate data from different models were necessary in order to address additional data sources anticipated as improvements to accuracy and spatial precision of the species models. In addition, since the area of application was extensively modified by the mountain pine beetle, we adjusted inputs to the wildlife models to better account for the realized and anticipated ecological changes resulting from the beetle attack.

Over the course of this project, we encountered many challenges, resolved those challenges, made a number of improvements to previously existing model components, and identified areas where improvement and future work could be focused. In general the model results stand as a "proof-of-concept" that multi-species habitat supply modeling can be efficiently linked to projections of timber supply and the results of which can be used to make interpretations about habitat supply as per the project objectives.

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A huge thank-you and enormous respect go to Phil Winkle for his masterful management of the project logistics and funding. A well managed project is fun to be engaged in and this was fun. Finally, we thank the entire QMC for their support of this work: Shawn Meisner (Tolko), Michelle Arcand (BC Min. of Environ.), Michael Pelchat (BC Min. For. and Range), Earl Speilman (West Fraser), Jon Erickson (Canadian Forest Products), Julie Steciw (BC Min. of Environ.), Bev Frittenburg (Integrated Land Management Bureau), and John Stace-Smithand. Funding came from our three partners in the forest industry: C & C Wood Products Ltd., Canadian Forest Products Ltd., and Pioneer Family Timber Partnership Ltd.

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INTRODUCTION

Background

Over the past decade much of British Columbia (BC) has undergone significant ecological change due to an unprecedented epidemic of mountain pine beetle (MPB; *Dendroctonus ponderosae*) (Eng et al. 2005). In addition, BC is experiencing chronic alteration of local and regional ecology due to global climate change (Pojar 2010). Many resource managers expect these two forces to eventually impact sustainable forest management strategies and lead to entirely new management paradigms. Considering the potential shifts required by forestry managers in the Quesnel Timber Supply Area (TSA), complex and challenging decisions will be required to balance the demand and supply of fibre from crown forests in a sustainable fashion along with social and ecological values. Management decisions will need to be founded on the most current information available, but also on insightful forecasts of future conditions ensuring the greatest utility of the choices made.

Within the Quesnel TSA the *Quesnel TSA Timber Supply and Environmental Values Mitigation Committee* (QMC) is preparing to undertake a multiple-account, trade-off analysis to forecast the effects of managing for timber supply and the other resources impacted by MPB. Trade-off analysis explores the cost of relaxing one goal in order to achieve an increase in another goal. Typically the procedure is viewed as competitive, where one resource must lose out for the desired values of another to be achieved (Maness 2007). This competitive aspect amongst goals does not necessarily have to be the case. Large landscapes with well documented resource values provide the means for planning (and implementing) management activities to produce forests with combinations of attributes to sustain desired outcomes promoting multiple resources simultaneously (Maness 2005). Among the list of inputs for a multiple account analysis required for the Quesnel TSA is wildlife habitat and corresponding population factors for specified wildlife species.

The importance of wildlife habitat within the Quesnel TSA has been expressed in strategic and tactical plans prepared over the past five years (Province of BC 2007, 2009a, Buell et al. 2006, Anonymous 2006). Numerous efforts have also been made to identify species most impacted by the MPB and to prioritize conservation and management of wildlife species within the Province (Bunnell et al. 2004, Province of BC 2009b, 2004, Pierre 2007). In 2008, habitat supply modeling of 13 wildlife species was undertaken over a large portion of the central interior of BC (McNay and Sutherland 2008, Sutherland and McNay 2008) and that work provides a foundation for this application in Quesnel TSA. Initially, the species to be modeled were expected to be selected from the TSA planning documents and/or based on the work completed by McNay and Sutherland (2008). It was recognized however, the best product for a trade-off analysis would be those species that have local priority and so revision to the species list was implemented.

McNay and Sutherland (2008) used a Bayesian habitat supply modeling framework for the central interior work and this approach was applied again for the Quesnel TSA (Figure 1). The Bayesian framework integrates well with Timber Supply Review and forest estate planning models providing synergies for the subsequent completion of multiple accounts analysis (Figure 2; McNay 2005, McNay and Sutherland 2009).

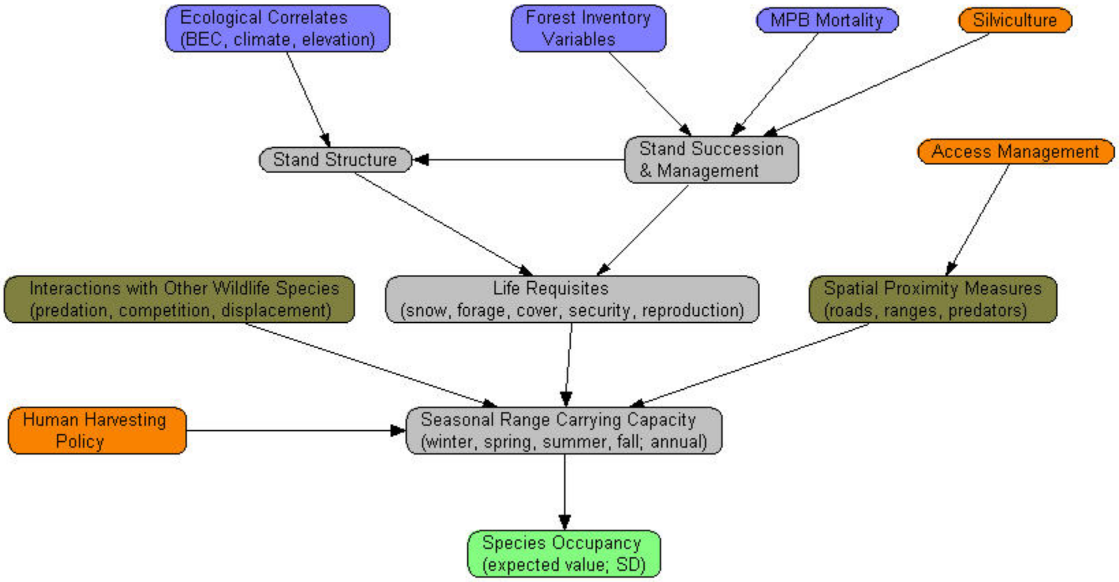

Figure 1. An general influence diagram for modeling species occurrences in response to environmental correlates, the effects of MPB on habitat variables, and species interactions. Colours reflect different types of variables where inputs are orange, blue, or olive, summary nodes are grey, and the final outcome is green. Each node identified as an input in the figure can be replaced with multiple inputs, and corresponding relationships enabling the assessment of more complex issues (from Sutherland and McNay 2008).

The Bayesian habitat supply modeling approach that was applied is founded on deriving species occupancy probabilities based on functional ecological relationships. Sub-components of the models therefore necessarily focus on the supply of specific life requisites for these animals and associated key environmental correlates (i.e., model input variables) including, but not limited to, such habitat elements as coarse woody debris, snags, patch sizes and distribution, and connectivity. These variables can be tracked within the framework and used by themselves as medium-filter indictors of biodiversity. Additionally, in conjunction with field surveys, they provide the means to generate hypotheses and therefore the basis for evaluating the success of modeling predictions and the accuracy of data input layers.

An additional strength of this modeling approach is that it provides flexibility for incorporating different types of data sources. Expert-based information can be used to formulate relationships linked to predicting future forest conditions and empirical data can be used to train model relationships where sufficiently large data sets are available to produce meaningful outcomes (Nyberg et al. 2006). In the Quesnel TSA, the QMC has supported the development a large collection of natural resource based inventories and model products including, among others, predictive ecosystem mapping, stand structure modeling and deadwood modeling; all of which have good utility for habitat supply modeling.

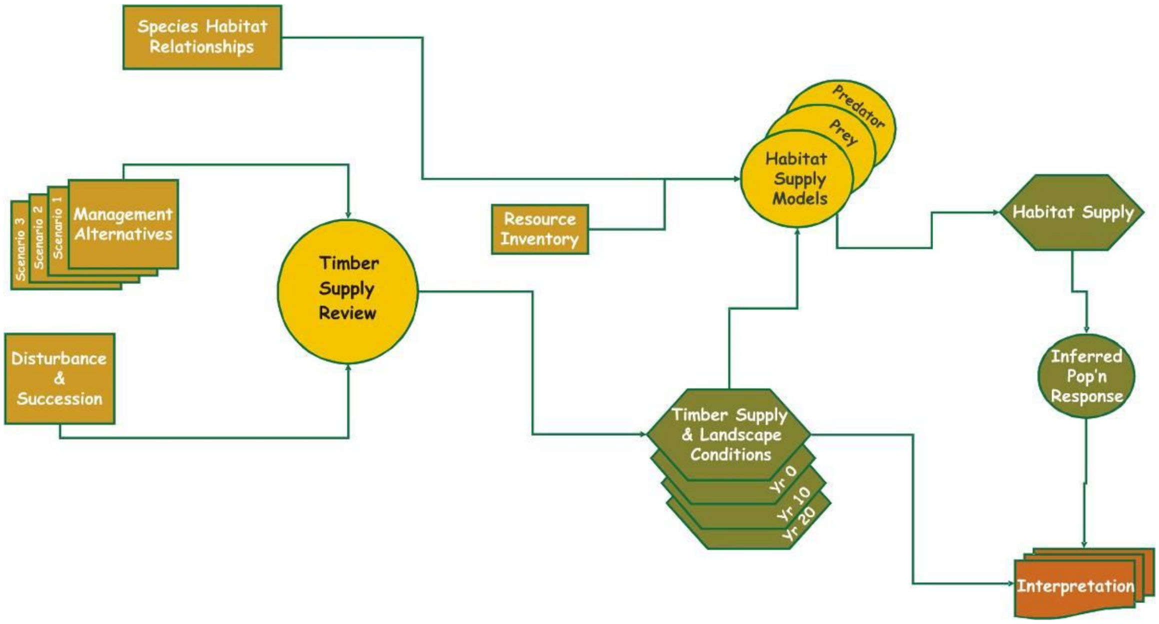

Figure 2. A conceptual integration of timber supply review options with habitat supply models (adapted from Jones et al. 2002).

Objectives

The project goal was to develop detailed species habitat supply models to allow the assessment of the probable effects of MPB attack, and current and proposed timber supply review management scenarios, on wildlife habitat occupancy over time. Project objectives included:

1. Identifying a set of terrestrial vertebrate species, that:
    a. represent a broad cross section of habitat requirements for sensitive and indicator species in the TSA; and,
    b. have been identified as focal species through higher level plans (Quesnel Sustainable Resource Management Plan, Province of BC 2007) and strategic planning activities (Type 3 Silviculture Strategy, Buell et al. 2006) undertaken in the TSA.

Based on the species list derived in Objective 1 subsequent objectives include[1]:

- Complete and apply species habitat suitability (supply) models for all 14 identified terrestrial vertebrate species to Natural Disturbance, base case and the TSR4 scenarios for years 5, 10, 15, 20, 50 and 80 from current (2009).
- Report out on ecosystem indicators (stand conditions, coarse filters) and modeled species results (indices of suitability and capability, area of suitable habitat under base case, TSR4 scenarios, Natural Disturbance).
- Describe habitat elements important to species and identify important elements currently lacking in the QMC data set.
- Document habitat suitability assessment methods and relative risk to modeled species as determined by harvest scenario results.
- Provide models and data in a format suitable for use in the Future Forest Ecosystems Scientific Council funded project “Integrating Climate Change Adaptation Strategies with Sustainability and Socioeconomic Objectives for the Quesnel Timber Supply Area”.
- Complete a report on the methods, ecosystem indicators and interpretations of habitat supply results including spatial maps. Discuss aspects of risk associated with the TSR4 scenarios for modeled species with respect to flows of critical habitat components.
- Develop recommendations, including rationale for any specific wildlife survey, monitoring requirement or data enhancement identified within the scope of the project. Present a summary of results in a Work Shop with local licensees, MFR and MOE representatives.

STUDY AREA

The Quesnel TSA (Figure 3) is approximately 2 million ha and orientated in an east/west direction through the interior of BC; a distance of ~340 km. The study area, conforming to Crown Lands, comprises 78.6% of that area (1,632,760 ha; Table 1 and Table 2, Figure 3).

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[1] Through the implementation of activities, additional objectives and associated tasks were substituted to improve the value of the final modeling product. The approach towards species selection was updated by incorporating local and provincial scale information even though it required greater effort than initially planned for the project (objective 1b) (McNay and Sulyma 2009). We also spent additional time investigating the integrity of QMC data sets to ensure compatibility of them within the Bayesian modeling framework. Background metadata had to be researched and “cross walk” tables developed for several datasets to ensure they could be incorporated into the model framework (e.g. predictive ecosystem mapping and stand structure modeling - objective 2b). Finally, additional effort, in particular coordination with other contractors/agencies, was required to enable the incorporation of timber supply review products and stand structure model products into the habitat supply models (objectives 2b, and 3a).

Table 1. The modeling study area (1,632,760 ha) based on Ownership and Schedule codes 60N, 62C, 63N, and 69C.

TFL	OWN	SCHEDULE	Ha	Definition
	40	N	84	Private Crown Grants (due to AU 99 overlap)
	60	N	1541	Crown Ecological Reserves
	62	C	1393415	Crown Forest Management Unit (TSA)
	63	N	201040	Crown – Provincial Park Class A
	69	C	36680	Crown Miscellaneous Reserve >100ha

Table 2. Area excluded from the modeling study area (444,529 ha) and the associated Ownership and Schedule codes.

TFL	OWN	SCHEDULE	Ha	Definition
	40	N	106479	Private Crown Grants
	50	N	601	Federal Reserves
	52	N	4961	Indian Reserves
	61	C	1371	Crown UREP >100ha
	61	N	752	Crown UREP <100ha
	69	N	2238	Crown Miscellaneous Reserve <100ha
	72	B	3	Crown – Schedule ‘B’ land, TFL
	77	N	30922	Crown – Awarded Woodlot licence
	99	N	81	Crown Miscellaneous Lease <100ha
TFL52	40	N	1112	Private Crown Grants
TFL52	62	C	34143	Crown Forest Management Unit (TSA)
TFL52	63	N	5	Crown – Provincial Park Class A
TFL52	69	C	175	Crown Miscellaneous Reserve >100ha
TFL52	69	N	256	Crown Miscellaneous Reserve <100ha
TFL52	72	B	259025	Crown – Schedule ‘B’ land, TFL
TFL52	77	N	2405	Crown – Awarded Woodlot licence

The study area falls within the Central Interior ecoprovince with the eastern half of the TSA encompassing both the Central Interior and Southern Interior Mountains ecoprovinces. The study area is more finely delineated by the Western Chilcotin Upland, Nasko Upland and Quesnel Lowland ecoregions which typify the landscape of high, rounded shield volcanoes separated by wide valleys found in the south-western portion of the study area with the remaining area being a mixture of flat to rolling uplands and lowlands.

Much of the upland and lowland areas are comprised of the Montane Spruce (MS), Sub-Boreal Pine-Spruce (SBPS), and Sub-Boreal Spruce (SBS) biogeoclimatic zones Meidinger and Pojar (1991). The Alpine Tundra (BAFAunp) and Engelmann Spruce-SubAlpine Fir (ESSF) zones are nearly exclusively found in the southwest portion of the study area where the Itcha Ilgachuz Provincial Park is located.

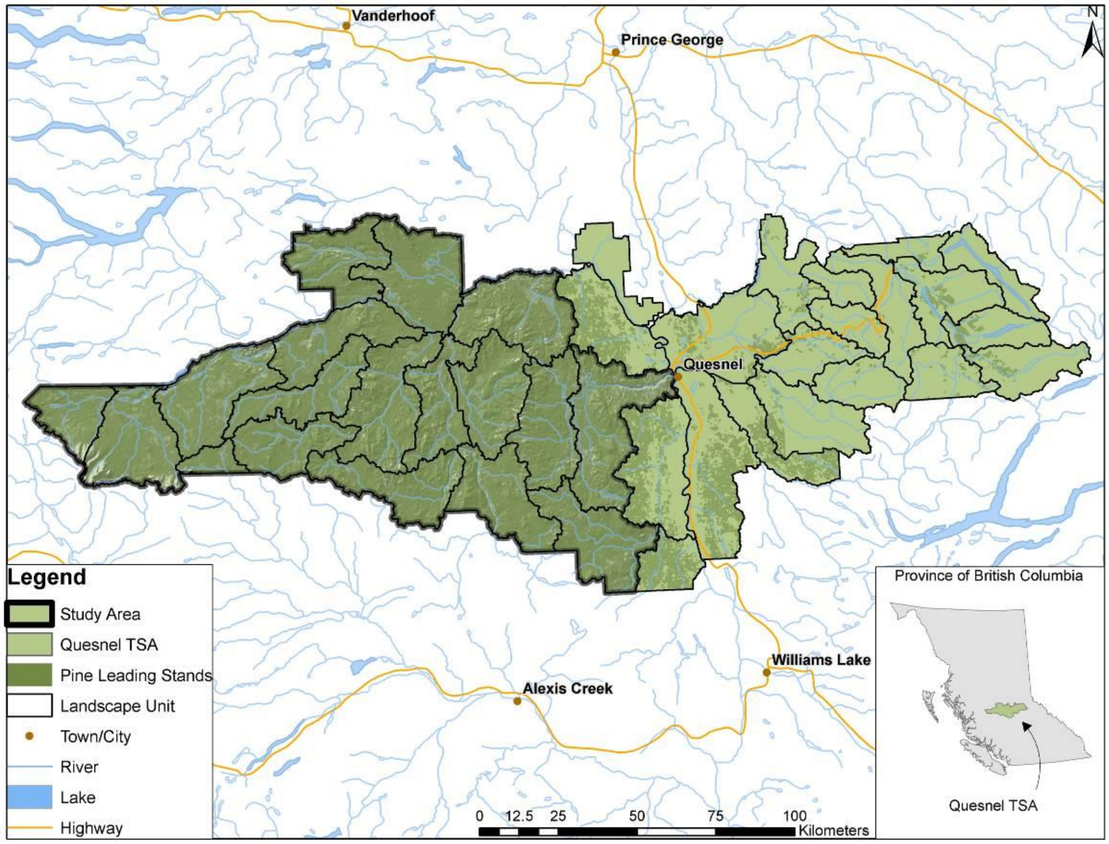

Figure 3. The Quesnel Timber Supply Area (TSA) in the central interior of British Columbia showing the pine leading stands and landscape unit boundaries which formed the study area boundary in the western portion of the TSA.

The MS zone, 25% of the study area, is also situated in the south-western portion of the study area, wrapping around the ESSF zone and extending eastward along the southern boundary of the TSA. The elevations of the MS zone range from 1100 m to 1650 m with the lower elevations being wetter than the higher elevations. Overall this area is within the rain shadow of the Coast Mountains and therefore receives relatively minor (300 – 900 mm/yr) precipitation and typically moderately deep snow packs of 60 to 100 cm. Forests dominated by lodgepole pine are extensive in the MS with occurrences of subalpine fir (*Abies lasiocarpa*) and spruce (*Picea* spp.) in wetter climatic areas.

The SBPS is the dominant zone in the study area (55%) supporting extensive dry lodgepole pine stands occurring in the upland regions. Abundant wetlands is the other notable forest ecosystem occurring in the lowland areas and supporting other tree species such as hybrid spruce and trembling aspen which ring the perimeter of the wetlands. The coastal mountain rain shadow persists across the zone where the mean annual precipitation ranges between 335 to 580 mm.

Filling in the remainder of the study area is the SBS zone, 18% of the study area, a much wetter zone than either the MS or SBPS zones. It has a continental climate of warm wet summers and severe winters producing deeper snow packs with the more abundant precipitation. Rich productive forests produce a combination of both coniferous and deciduous species such as hybrid white spruce (*P. glauca*), subalpine fir, trembling aspen (*Populus tremuloides*), lodgepole pine, black spruce (*P. mariana*), paper birch (*Betula papyrifera*) and black cottonwood (*Populus trichocarpa*). Their presence dictated by site characteristics and succession stage of the forest stands.

Table 3. A list of the landscape units (LU) occurring within the study area, the bolded LUs form the boundary between the pine-dominated west and the east sections of the Quesnel Timber Supply Area.

Study Area Landscape Units	Landscape Unit Area (ha)	Area of Pine Leading Stands (ha)	Percent of LU Area with Pine Leading Stands
Baezaeko	83245	65644	79
Baker	**94168**	**58434**	**62**
Chine	61230	44955	73
Clisbako	63922	51204	80
Coglistiko	55289	46260	84
Downton	14742	9903	67
Eliguk	39630	25016	63
Euchiniko	58949	41826	71
Kluskus	77266	48638	63
Marmot	52946	37030	70
Pan	75536	44882	59
Pantage	**78615**	**52069**	**66**
Pelican	78579	58306	74
Ramsey	**70618**	**51619**	**73**
Snaking	64687	51235	79
Tibbles	68890	51832	75
Toil	51775	44569	86
Wentworth	66425	53676	81

METHODS

Species Selection

Recommendations for a list of terrestrial wildlife species were presented to representatives of the QMC (including Quesnel forest licensees, Ministry of Forests and Range, Ministry of Environment) and the University of British Columbia in a workshop held in Quesnel on January 18, 2010. The list was based on planning documents prepared over the past five years for various activities in the TSA (Province of BC 2007, 2009a, Buell et al. 2006, Anonymous 2006) and on previous habitat supply modeling in MPB impacted areas of central interior BC (McNay and Sutherland 2008). Within the workshop concerns were raised that additional sources of information needed to be considered. A subcommittee was formed to re-evaluate the species list and ensure the inclusion of the additional sources of information.

Species Habitat Model Development

Habitat supply models were prepared using a suite of integrated modeling approaches including ecological influence diagrams based on Bayesian Belief Networks (BBNs), Geographic Information Systems (GIS), data management tools, and validation processes. The models represent summaries of overall range quality for terrestrial wildlife based on supply of life requisites, competition for resources, displacement effects resulting from anthropogenic influences, likelihood of mortality, and relative likelihood of species occurrence. In this sense models are multi-trophic and, depending on the species selected, form links from outputs of one species (e.g., prey) to inputs of others (e.g., predator). Prediction of modeling factors (i.e. life requisites, competition factors, and displacement factors) were based on the spatial location of key ecological correlates selected from the available GIS datasets. Where empirical information was lacking regarding relationships, we used professional judgment from those with experience conducting research, inventory, and management (see Species Accounts, attached under separate cover). We forward the notion that such information is sufficient for strategic-level purposes since it is that same information which would ultimately be used to make decisions in the absence of a more formal approach. More on Bayesian models in ecology and natural resource management is provided by McCann et al. (2006).

Where possible, we used previously constructed models that were collaboratively developed in workshop sessions – or models that were revised but based on that foundation. These models were used to predict occupancy probability for northern caribou (*Rangifer tarandus caribou*) in low-elevation winter ranges and mountain caribou in late winter ranges (McNay et al. 2006), mountain goat (*Oreamnos americanus*) winter range (Hengeveld et al. 2004), and grizzly bear (*Ursus arctos*) summer range (McCann and McKinley 2004). The models of caribou and mountain goat range have been broadly applied and tested with empirical observations of animal occurrence; we refer to these models as gamma-level models. Other models were developed by the modeling crew directly from the species account information and relying mostly on professional judgment; we refer to these models as alpha-level models. Beta-level models are those that have been applied in at least a few situations, adjustments having been made to parameters to achieve a good-fit to the expectations of those having good knowledge of both the study area and the species. Alpha- and beta-level models available from previous applications were moose (*Alces alces*), mule deer (*Odocoileus hemionus*), American marten (*Martes americana*) and wolverine (*Gulu gulu*). To the extent possible we followed guidelines for development and updating Bayesian models as recommended by Marcot et al. (2006).

Input Data Preparation

Input data preparation for the models continued to follow previously documented procedures used to forecast the dynamics of habitat values resulting from hypothetical disturbance regimes (see Model Processing and Sequence of Activities, attached under separate cover). The key environmental correlates (e.g., forest cover, topographic position, ecological zone etc.) that were required as inputs came largely from the BC Vegetation Resources Inventory database and the BC Terrain Resource Information Management program (Table 4 and Table 5). However, several of the inputs to these model runs were different from past runs or new to the process entirely; these are described below.

Table 4. A list of data inputs contributing to case files used by Netica™ in processing causal-web models for the species modeled in the study area.

Input Variable	Description	Time-step Dependent	Data source
Stand age for leading species	Projected age of the stand (projected for each time step)	Yes	TSR4
Stand height for leading species	Projected height of the stand (projected for each time step)	Yes	TSR4
Species Type for leading/secondary species	Species code for species in each layer	No	VRI
Species composition for leading/secondary species	Percentage of each species in each stand	No	VRI
Disturbance history	Year and type of last disturbance	Yes	VRI, TSR4, BCMPB
Inventory type group	Tree species composition	No	VRI
Site Index	Measure of tree height at 50 years of age	No	VRI
Site Class 5M	Calculated from Site Index values	No	VRI
Non-Forest Descriptor	Indicates a forest polygon is potentially productive for supporting commercial forests	No	VRI
Non-Productive Code	Coded value identifying non-productive areas	No	VRI
Non-Productive Descriptor	Descriptor of non-productive areas	No	VRI
Cumulative Kill %	Cumulative mortality of pine from 2009 to 2026	Yes	BCMPB
MPB - age since death	Calculated age of pine since death	Yes	VRI, BCMPB
NLT	Number of trees > 25 cm dbh	Yes	Stand Structure
NST	Number of trees 11 – 25 cm dbh	Yes	Stand Structure
NTT	Number of trees < 10 cm dbh	Yes	Stand Structure
Aspect	Aspect of a slope in degrees	No	DEM[b]
Slope	Landscape slope in degrees	No	DEM
Elevation	Elevation in metres above sea level	No	DEM
Topographic Curvature	Concave upward or downward curvature of landscape	No	DEM
Solar Radiation	Summer and winter solar radiation inputs as influenced by topography, latitude, and date	No	DEM
MR2	Moisture Regime	No	Cariboo PEM
Roughness	Terrain ruggedness	No	DEM
Ice & Bare Areas	Non-vegetated surfaces	No	BTM[c]
Proximity to First Nations Settlement		No	BTM
Proximity to Human Development		No	BTM
Winter Precipitation	Precipitation sum for December, January, and February	No	PRISM[d]
FHV	Fisher Habitat Value	No	WHR[e]
BBHV	Black Bear Habitat Value	No	WHR
LHV	Lynx Habitat Value	No	WHR
WHV	Wolverine Habitat Value	No	WHR
BGC	Biogeoclimatic (BGC) variant classification	No	BEC[f]
PTR	Proximity to Roads	Yes	TSR4, que_roads.shp
SiteMC_S1	BEC Site Class	No	TEM/PEM

[a] VRI refers to BC Vegetation Resources Inventory program

[b] DEM refers to a digital elevation model from the BC Terrain Resource Information Management program: http://ilmbwww.gov.bc.ca/bmgs/trim/index.html#

[c] BTM refers the BC Baseline Thematic Mapping program: http://ilmbwww.gov.bc.ca/cis/initiatives/ias/btm/index.html .

[d] PRISM refers to Oregon State University's PRISM Group precipitation modeling: http://www.prism.oregonstate.edu/

[e] WHR refers to Wildlife Habitat Ratings: http://www.env.gov.bc.ca/wildlife/whr/

[f] BEC refers to a spatial coverage of the Biogeoclimatic Ecosystem Classification system for BC (Meidinger and Pojar 1991).

Table 5. A list of Natural Disturbance data inputs contributing to case files used by Netica™ in processing causal-web models for the species modeled in the study area we used. Only the data inputs which specifically changed for the Natural Disturbance are listed, Table 4 contains a list of the remaining data inputs.

Input Variable	Description	Data source
Stand age for leading species	Projected age of the stand calculated by the Seles Disturbance Simulator	TSR4, Seles
Stand height for leading species	Projected height of the stand calculated in the bbn's	VRI, TSR4, Seles
Disturbance history	All disturbances removed.	TSR 4, VRI, BCMPB
Cumulative Kill %	Percent mortality set to zero	BCMPB
MPB age since death	Age set to zero	VRI, BCMPB
NLT	Set to unclassified and calculated in the bbn	Stand Structure
NST	Set to unclassified and calculated in the bbn	Stand Structure
NTT	Set to unclassified and calculated in the bbn	Stand Structure
Remnant Ages	Remnant Ages set to zero	TSR 4, VRI, BCMPB
Proximity to Human Development	Removal of anthropogenic influences	BTM
Proximity to First Nations Settlement	Removal of anthropogenic influences	BTM
SiteMC_S1	BEC Site Class; reassign all anthropogenic related site classes to the zonal site series for a given BEC label	TEM/PEM
PTR	Proximity to Roads, used state value #3 where < 10ha road density within 100 m.	TSR4, que_roads.shp

[a] VRI refers to BC Vegetation Resources Inventory program

[b] DEM refers to a digital elevation model from the BC Terrain Resource Information Management program: http://ilmbwww.gov.bc.ca/bmgs/trim/index.html#

[c] BTM refers the BC Baseline Thematic Mapping program: http://ilmbwww.gov.bc.ca/cis/initiatives/ias/btm/index.html .

[d] PRISM refers to Oregon State University's PRISM Group precipitation modeling: http://www.prism.oregonstate.edu/

[f] BEC refers to a spatial coverage of the Biogeoclimatic Ecosystem Classification system for BC (Meidinger and Pojar 1991).

Prognosis Stand Structure Modeling

Incorporation of Stand Structure Modeling with Habitat Models

With the exception of the goat model, the BBNs were modified to incorporate stand structure data as inputs to help derive stand structural stage, stem densities and size distributions (i.e., DBH class) as they relate to specific species requirements. We used the stand structure data to generate spatially referenced summary tables of stand structural characteristics for both natural stands and managed stands.

We used natural stand structure tables provided by Ian Moss (Tesera Systems Inc.) adjusted for MPB kill as indexed in the VRI data set and managed stand structure tables (no MPB adjustment was modeled for managed stands) to represent regenerating stands. We summarized the natural stand tables, for each time step and unique stand ID, by categorizing the living component of the stand (number of stems) into DBH categories (≤10 cm; >10 to ≤25 cm; >25 to ≤50 cm; >50 to ≤100 cm; >100 cm) by broad tree classification (conifer or deciduous). We also estimated lead and secondary tree species (based on stem densities) and percent composition, total stems, total volume, and a weighted average stand height. We updated each stand structure time step table with site index from Moss' data (to account for missing data in the VRI) and the time step canopy closure for the stand based on the original stand condition prior to imposing MPB effects (MPB effects on stands were modeled by Ian Moss outside of Prognosis and preand post-MPB tables were provided). We used the pre-MPB canopy estimates as impacts to canopy closure are estimated within the Netica models as a net down to the original canopy.

We summarized the managed stand table in a similar fashion, however only one resultant table (rather than a table for each time step) was produced as it could not be readily determined as to which ages of regenerating stands would be required in each time step. Unlike the natural stand summary tables which only required a spatial link based on unique stand ID, the managed stand tables maintained both unique stand ID and stand age (categorized into 5-year age classes) for spatial linkages. We reprocessed the TSR4 scenario age grids into identical 5-year age classes in support of the spatial link to the managed stand table.

We imposed a switch between natural and managed stand structure tables within our modeling of scenario time steps by creating a cumulative harvest grid that for each time step and scenario indicated if a harvest event occurred in the current or in a previous time step and if so, directed the model to obtain stand structure information from the managed stand table. Prior to model runs, an alignment of the stand structure data was required to account for discrepancies in assumed stand ages used in Prognosis (see Challenges Encountered During the Modeling Process below). As part of this alignment we generated an estimated ‘recent harvest’ grid to account for TSR4 updating of the land base to 2009. The recent harvest grid was merged into all cumulative harvest grids to ensure that once a stand was considered to be in a managed state that it always remained as a managed stand for the remaining time steps.

Dead Wood Modeling

Modeling was improved by the inclusion of a more detailed component supplying information about coarse woody debris and snag numbers. Tree death is a component of the stand structure modeling and was used to generate a dead wood (standing dead and CWD) model. Dead wood information can be used in a variety of ways because many species depend on coarse woody debris or dead standing snags for protection from thermal extremes, as security cover, as natal dens, as cavity nests, as support structures for external nests, or for foraging. The functional habitat type that dead wood provides is dynamic over time as dead wood characteristics change, and is dependent on piece size (Delong et al. 2008). Depending on accumulations, dead wood may also restrict movement of some species or occupy the growing space of other vegetation such as forage for ungulates.

We used the stand structure output’s recruits of dead trees resulting from Prognosis’ tree mortality algorithm and the subsequently imposed MPB mortality accomplished by Ian Moss, as the basis for a Dead Wood model. We used the Tipsy Snag Probability Model equations and CWD Volume Decay Model equations in a stand alone Visual Basic module to fall dead trees and decay away CWD volume. We used Tipsy’s species default values for both Snag Probability and CWD Volume Decay. We tracked five tree species in the Dead Wood model (hemlock, pine, cedar, other conifers and hardwoods) and numbers of snags or cubic meters of CWD by five DBH diameter classes <=10 cm, >10 to <=25 cm, >25 to <=50 cm, >50 to 100 cm, and >100 cm). We also estimated and assigned decay classes (fresh, intermediate, old) to both snags and CWD based on years dead or years down, respectively.

Development of the Dead Wood model was time-consuming and complex. Since tree death does not occur in every five year time step of the Prognosis output, the data tables had to be expanded so that a record was available for each Prognosis time step regardless of whether a tree death event occurred or not. This was to ensure that the years since death (or years down for CWD) could be tracked correctly and applied to the Tipsy equations over the entire simulation. For each unique stand and Prognosis time step, the Dead Wood model 'looked back' at all previous time steps, tallied the number of trees that died by tree species groups and diameter classes in each previous step, determined the number of years the trees had been dead in each previous step relative to the current step, applied the Snag Probability equations, used the probability of standing to determine the number of dead trees still standing or fallen (i.e., 1 – P of standing) by tree species groups and diameter classes (partial dead trees were allowed), and summed the results across all previous steps and the current step to arrive at an estimate of standing snags for the current step.

Prognosis' tree mortality (and MPB induced mortality) provided recruits to the snag component; however the recruitment into CWD had to be determined based on the results of the Snag Probability equations. For each unique stand and Prognosis time step, in the process of 'looking back' at all previous steps, the Dead Wood model tracked, for each previous step, cumulative volume down by tree species group and diameter classes where cumulative volume down was estimated as the sum of 1 – P of standing * total volume of snags by species groups and diameter classes. CWD recruitment for previous time steps was estimated as the differences between two successive time steps' cumulative volumes down, for each species group and diameter class. Time step estimates of CWD recruitment were then processed with the CWD Volume Decay Model equations in an identical fashion as dead tree recruitment.

At each time step we assigned the remaining snags and CWD to decay classes based on years dead for snags and years down for CWD (Huggard 1999, Delong et al. 2005, Delong et al. 2008). Few tree species have empirical data available for determining the time parameters to apply in the transitions through decay classes. We applied the following time boundaries for transitions through decay classes:

Snags:

- Snags are 'fresh' if they are <=5 years dead, except for cedar which is fresh if <= 7.5 years dead.
- Snags are 'intermediate' if they are >5 and <=27.5 years dead, except for cedar which is intermediate between >7.5 and <= 32.5 year dead.
- Snags are 'old' if they are >27.5 year dead, except for cedar which is old if >32.5 years dead.

CWD:

- CWD is 'fresh' if it's <=12.5 years down, except for cedar which is fresh if <=17.5 years down.
- CWD is 'intermediate' if it's >12.5 years and <=32.5 years down, except for cedar which is intermediate if it's >17.5 years and <= 37.5 years down.

- CWD is 'old' if it's >32.5 years down, except for cedar which is old if >37.5 years down.

We summarized the results of the Dead Wood model by collapsing tree species groups into conifer and deciduous categories and 1) summarizing numbers of snags by decay class and DBH class (30 output variables), and 2) summarizing volumes of CWD by decay class and DBH class (30 output variables). We applied the Dead Wood model to both the natural stand Prognosis output (modified by MPB impacts) and the managed stand Prognosis output.

A consequence of using the Prognosis data to model dead wood is that there are no dead wood legacies – stand simulations start with no dead wood. For the natural stand dead wood results we initialized each unique stand with dead wood legacies based on its own tree growth and tree death trajectory. We applied the Dead Wood program to the natural stand Prognosis data without MPB effects factored in, but stopped all recruitment of dead trees after 65 years (year 2073 in the simulation) and allowed the Dead Wood model to run to the end of the projection (year 2158). This allowed the dead trees and CWD that accumulated over the first 65 years to continue to follow their specific fall and decay schedules and transitions through decay classes. We then used records from this process to update the Dead Wood tables with dead wood legacies. For example, we used records for year 2078 from the above initialization procedure to update the natural stand Dead Wood table for year 2009, records for year 2083 to update the natural stand Dead Wood table for year 2013 etc. Updating a natural stand Dead Wood table was accomplished by adding the initialization values to the table, field by field, unique stand by unique stand. This procedure avoided simply adding constants to represent dead wood legacies, was specific to each unique stand based on its own growth and death trajectories, and allowed the legacies to maintain their own specific trajectories for falling of dead trees and decay processes through time. We did not initialize the managed stand Dead Wood table as this would involve assumptions as to the amount of dead wood left behind from harvesting.

Incorporation of Dead Wood Modeling with Habitat Models

Incorporation of TEM and PEM Information with Habitat Models

The model runs described in this report mark the first time that Terrestrial Ecosystem Mapping (TEM) and Predictive Ecosystem Mapping (PEM) information were included as influences to the multi-species habitat supply models. As was done with past modeling projects (e.g. CHASE, Brumovsky 2004) we used TEM and PEM information to provide improved resolution when identifying forage potential for various species.

We identified all unique combinations of site series and biogeoclimatic variants in the study area and assigned forage descriptions as required by the BBNs. There were a number of sources of TEM and PEM information available for the study area. Where there was overlap between TEM and PEM information we gave precedence to the TEM information as TEM is directly interpreted from air photos while PEM is a modeled product (Province of British Columbia 2006). Because of this, we considered TEM to be a more accurate source of information[2].

Improvement of Moisture Regime Information

Past applications of the multi-species habitat supply models have made use of a moisture regime input calculated using ArcGIS Spatial Analyst's raster hydrology tools. For this work, we made use of hydrological modeling that was performed for the development of the Cariboo PEM project. This modeling uses a more complex, and presumably more accurate, algorithm than the ArcGIS tools when predicting where water will be shed and where it will gather on the landscape (MacMillan et al. 2008).

The moisture modeling we used was expressed as a scale of relative moisture known as the Quinn wetness index. We compared the Quinn classes to our past modeling to estimate where they equated to standard moisture classes ranging from 'very-xeric' to 'sub-hydric'.

Incorporation of Winter Habitat Model for Mountain Goat

The mountain goat was selected as one of the species for the multi-species habitat supply in the Quesnel TSA due to its declining numbers throughout the province of BC and its' limited distribution. The preparation of data for mountain goat involved a series of spatial analyses not common for other BBNs. Data preparation for the winter mountain goat model used DEM-derived grids already developed for the other habitat models, as well as the prepared BTM, BEC and VRI data sets. Much of the preparation involved creating intermediate grids required for the model such as:

- Size – depicting the location of winter escape terrain.
- Amount of Effective Forage Terrain (AEFT) – classifying the amount of effective forage terrain.
- Percent of escape terrain effectiveness (PET) – representing the amount of effective escape terrain within the AEFT.
- Forage weighted distance buffer (FWDB) – identifying the distance between forage and escape terrain.

A previous goat modelling project provided the MS Access Database with Netica Manager to export a case file for processing in the mountain goat BBN and importing of the results. Changes were made to the Netica Manager to account for data inputs required by the BBN.

Incorporation of Natural Disturbance Modeling with Habitat Models

A scenario depicting an estimation of species occurrence under a simulated natural disturbance regime was also modeled. We simulated a hypothetical landscape free of

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[2] The Quesnel PEM information grouped sites into generalized classes more than are normally seen in PEM. For example, no discrimination was made between rivers and lakes in the PEM, all hydrologic features were simply classified as water.

human influence on which to apply our models to gain some perspective on the potential for species occurrence prior to anthropogenic disturbance. Rather than trying to re-create past conditions, we created this situation by removing all human constructs from our model inputs (e.g. roads, communities, mines etc.). Then, using the Spatially Explicit Landscape Event Simulator (SELES) (Fall 1999), we aged the landscape by 400 years allowing only fires to disturb the landscape. This generated a random, mixed-age snapshot of the study area where all evidence of forest harvest had been removed through growth and wildfire. As SELES is a stochastic model, the results of the natural disturbance simulation vary between model runs. To allow for a statistical assessment of the stochastic properties, we ran five replicates of the natural disturbance scenario.

Though we have applied similar natural disturbance scenarios in the past (McNay et al. 2003), some departures from past methodology were necessary. Historically, these simulations were applied in the Prince George and Mackenzie TSAs where wildfire parameters have been defined according to Natural Disturbance Units by DeLong (2002). These units and their associated parameters were not developed for the Quesnel TSA. As a result, we used fire parameters based on Natural Disturbance Types (NDT; Province of British Columbia 1995). Parameters relating to the distribution of wildfires among various size classes were calculated empirically based on all recorded wildfire events in the NDTs of the Quesnel TSA. Greater detail on the derivation of fire parameters and inputs to the natural disturbance scenario is provided under separate cover (see Empirical Derivation of Wildfire Distribution).

Creation of Time-step Based Information on Forest Stands

Information on forest stands came from multiple sources (i.e., VRI, TSR4 modeling resultant, and stand structure modeling). Where the data sources did not already exist in raster format they were either:

- Converted to an integer format then converted to a raster;
- Converted to raster after integer codes were assigned unique values (a lookup table was developed to later obtain the text values); or
- Converted from Ascii format to raster.

Once the individual rasters were created they were combined into a forest cover raster called FC_ID, a unique identifier was assigned to each record and a dBASE table exported. The FC_ID.dbf was imported into a MS Access database where further processing was completed to create the final table for use by Netica Manager. The FC_ID raster and associated data table were time dependant so individual rasters were developed for each time step in the simulation (Table 4 and Table 5). More detail on how the FC_ID data inputs were created is provided under separate cover (see FC_ID Raster and Layer Table Development).

Model Implementation

The modeling procedures used here largely follow those described in detail by Sutherland and McNay (2008) (also see Model Processing and Sequence of Activities, attached under separate cover). Software used to implement the modeling included ArcMap (Environmental Systems Research Institute, Redlands, CA), Netica (Norsys Software Corp., Vancouver, British Columbia), and MS Access (Microsoft Corp., Redmond, Washington).

We applied the procedures to a base case and three TSR4 scenarios. The base case represented forest conditions updated to 2009 for prior forest harvesting but without a TSR4 modeled harvest for the year.

The scenarios were evaluated at six time steps covering the first 80 years of the TSR4 simulations (Province of British Columbia 2010). The first four time steps each represented five years of modeled harvesting activity (2009 – 2013, 2014 – 2018, 2019 – 2023, and 2024 – 2028). The remaining two time steps each represented 30 years of modeled harvesting (2029 – 2058 and 2059 – 2088). TSR4 data represented annual harvest events for years 2009 through 2028 and then decadel harvest events for all subsequent time periods. Due to the protocols employed in the TSR4 simulations, stand ages are updated for the first year of the decadel time steps and the span of forest age succession over the reporting period is 70 years.

The three TSR4 scenarios assumed the current MPB infestation in the Quesnel TSA will continue as predicted by Walton (2009) but modeled harvest under the following assumptions:

Scenario 1:

1. Salvage of MPB-afflicted pine will continue at the level of the current AAC (5.28 million m^3 per year) until all of the salvageable pine has been harvested (14 years).
2. Maintain harvest of non-pine leading (predominantly spruce) stands at a sustainable level (600,000 m^3 per year over the entire projection).

Scenario 2:

1. Minimize the harvest of non-pine volume while salvaging dead pine.
2. Subsequently, utilize the reserved non-pine to alleviate the harvest level decline.
3. Alter minimum harvest criteria to increase mid-term timber supply.

Scenario 3:

1. Cease salvage of dead pine immediately.
2. Start harvesting non-pine leading stands at approximately the 2008 harvest level (4.3 million m^3 per year).

Modeling Sequence

We were able to run the models on all time steps and natural disturbance simulations concurrently (with each model run operating on a separate workstation) since the time step modeling was delivered to us in a completed state and the natural disturbance simulations are effectively stand-alone products. Each model application followed the same sequential procedure (Table 6). Every application was divided into four separate ‘runs’ where the models of each run were partly dependent on the build-up of results from preceding runs. A detailed procedure for completing a model application is attached under separate cover (see Multi-species Habitat Supply Model Run Procedure).

Raster layer information for the required inputs of a single run was combined in a single resultant raster where every unique combination of the input values received a unique identifier. The resultant and its associated attribute table were the spatial link to which all model results for the run were joined. The attribute table was exported to an MS Access database where a custom Access Form called the 'Netica Manager' classified the information in the attribute table into a 'case file' that contained all of the information needed for the Netica BBNs to evaluate the species model on a cell-by-cell basis.

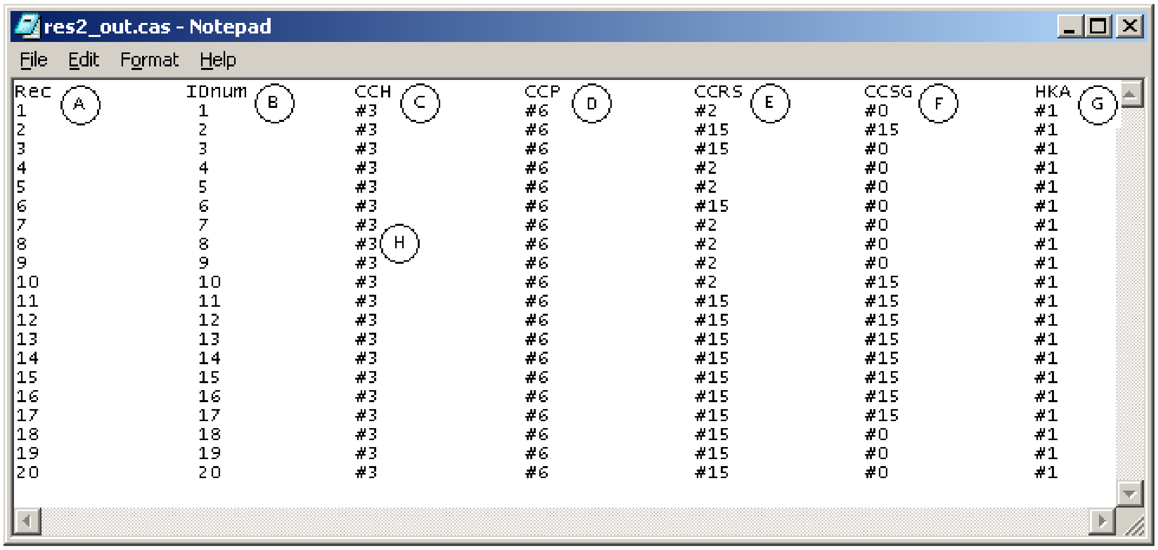
A case file consists of lists of records (i.e., one record for each set of 1-ha cells with unique combinations of inputs) containing columns (i.e., one column for each input node) specifying the existing condition or state of the input nodes. An example of the case file used for the Fisher Winter Forage model is shown in Figure 4.

The case file for the run was then processed by the Netica BBNs to produce model results. Resultant values for each model were collected into a fixed-width text file. Netica BBN results were then joined onto the attribute table used to generate the case file in MS Access. This was again performed using the Netica Manager form.

From this point, the model results were exported as dBASE tables and used to create rasters of model results using scripts in ArcView. For each species, we produced two resultant maps: (1) the probability of occurrence of each species; and (2) the standard deviation of the expected value. This concluded the execution of the run and made it possible to being the process all over again for the next run in the model sequence.

Table 6. Sequence of model implementation for developing estimates of species occurrence throughout the West Quesnel study area.

Model Run Sequence	Model Name	Description
1	Alal	Full species model for moose
	Odhe	Full species model for mule deer
	Oram	Winter habitat model for mountain goat
	Interception	Forest canopy interception
*Spatial processing for: distance to wolverine dens, distance to cover (interception), and patch size (interception)		
2	Maam	Winter model for marten
	Gugu_denning	Denning habitat map for wolverine
*Spatial processing for: distance to forage (mape), distance to predation risk (rata)		
3	Rata_late_winter	Component model for caribou, high-elevation in late winter
	Rata_lo_winter	Component model for caribou, low-elevation in early winter
4	Gugu	Full species model for wolverine
	Urar_sum	Component model for grizzly bear, summer
5	Nogo	Nesting model for northern goshawk
	Attw	Nesting and foraging model for three-toed woodpecker
	Bbwo	Nesting and foraging model for black-backed woodpecker
	Nofl	Nesting and foraging model for northern flicker
	Bago	Nesting model for Barrow's goldeneye
	Gbhe	Nesting model for great blue heron
	Rubl	Nesting model for rusty blackbird



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Rec    IDnum   CCH   CCP   CCRS   CCSG   HKA
1      1       #3    #6    #2     #0     #1
2      2       #3    #6    #15    #15    #1
3      3       #3    #6    #15    #0     #1
4      4       #3    #6    #2     #0     #1
5      5       #3    #6    #2     #0     #1
6      6       #3    #6    #15    #0     #1
7      7       #3    #6    #2     #0     #1
8      8       #3    #6    #2     #0     #1
9      9       #3    #6    #2     #0     #1
10     10      #3    #6    #2     #15    #1
11     11      #3    #6    #15    #15    #1
12     12      #3    #6    #15    #15    #1
13     13      #3    #6    #15    #15    #1
14     14      #3    #6    #15    #15    #1
15     15      #3    #6    #15    #15    #1
16     16      #3    #6    #15    #15    #1
17     17      #3    #6    #15    #15    #1
18     18      #3    #6    #15    #0     #1
19     19      #3    #6    #15    #0     #1
20     20      #3    #6    #15    #0     #1
```

Figure 4. Example of case file format. In this figure, the format and content of a typical case file can be seen. Tabular and spatial linking fields are represented by (A) and (B), as are columns describing state values for each input node (C) through (G). Actual state values used to describe landscape conditions in the BBN are prefaced by a '#' character (H).

Post-Processing of Model Runs

After the completion of the four runs comprising a model application, the rasters that had been produced underwent several post-processing steps to finalize their format. These procedures are described under attached separate cover (see Multi-species Habitat Supply Model Run Procedure).

1. Low elevation winter range for woodland caribou that is more than 20km from high-elevation winter range was deemed no longer functional due to the distance that must be covered to reach it (based on professional judgment). As a result, all predicted low-elevation caribou winter range that lay beyond the 20km threshold was removed from model results.
2. Lakes that are greater than 250ha in area were also removed from model results.
3. An ArcView script formatted outputs into deliverable format by combining model results with expressions of the results' standard deviations and added fields describing the information in provincial standard format (RISC 2008)

The resultant was used to produce small- and large-scale habitat maps[3] by first classifying the expected occupancy value in ArcMap using specific intervals for each species (Table 7). These same classes were applied with SAS (Statistical Analysis

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[3] Example maps are provided under separate cover.

System; Cary, North Carolina) to summarize the amount of area in each class for each species in each modeled scenario. The data summary was exported to Excel where graphs were made to reveal the percent change in habitat for each species through time using current (2009) as the basis to determine change. We also calculated the mean and standard deviation of the amount of area that occurred in each habitat class for each species across the five simulations of natural disturbance using a standard normal statistical approach available in SAS.

Table 7. The intervals of expected occupancy values (number of animals/km^2) used to classify modeled habitat for terrestrial wildlife species.

Species	Classified Habitat Occupancy Rating				
	Nil	Poor	Low	Moderate	High
Wolverine	0	2.5	5	10	50
Grizzly Bear	0	5	10	20	60
Caribou	0	25	50	100	200
Mountain Goat	0	125	250	500	1000
Moose	0	150	300	600	1200
Marten	0	200	400	800	1600
Mule Deer	0	6250	12500	25000	50000
Northern Goshawk	0	25	50	100	200
Three-toed Woodpecker	0	375	750	1500	3000
Great Blue Heron	0	375	750	1500	3000
Northern Flicker	0	400	800	1600	3200
Black-backed Woodpecker	0	675	1350	2700	5400
Rusty Blackbird	0	2000	4000	8000	16000
Barrow’s Goldeneye	0	4125	8250	16500	33000

RESULTS

Species Selection and Species Accounts

A detailed account of the subcommittee activities and their recommendations for the list of species to be modeled as part of the Quesnel multi-species habitat supply modeling is presented under separate cover (see Species List for the Quesnel Multi-species Habitat Supply Modeling Project). Fourteen terrestrial vertebrate species were recommended. These species were selected after review of nine studies and ranking schemes. It was acknowledged that additional species could be chosen however there are a high number of species in the Quesnel Forest District and each species represents it own needs only and the modeling is based on our understanding of these needs. Consideration in this selection was given to species that are keystone meaning that if they are provided for other species can also be assumed to benefit and considered better provided for. Single species approaches are not recommended as the sole strategy to guide forest resource management. Single species need to be complemented by modeling of ecosystem indicators more likely to conserve ecosystem integrity and biological diversity than an approach that is the sum of a number single species needs. This interplay between coarse filter ecosystem indicators and fine filter single species has been guiding biodiversity conservation in BC. It is in that context single species have been selected for habitat modeling.

Three strong cavity excavators are recommended for inclusion. They are; (1) three-toed woodpecker (sensitive to harvesting), (2) black-backed woodpecker (strongly linked to larger pine) and (3) northern flicker (responsible for most cavities and considered a keystone species). A single, secondary-cavity user is recommended: (4) Barrows goldeneye (identified as a priority under the Conservation Framework (CF) and BC is home to a majority of the global population). Three open nesters are recommended for modeling. They are: (5) great blue heron (dependent on large older nest trees near wetlands and lakes and were identified under the Identified Wildlife Management Strategy (IWMS)[4]), (6) rusty blackbird (identified as a priority under the CF and is associated with black spruce bogs and dead trees in standing water), and (7) northern goshawk (expected to be affected by large scale salvage harvesting and was included in the FIA rational). Four ungulates were recommended for modeling: (8) moose (socially important in the land use plan and FIA rational), (9) mule deer (socially important in the land use plan and FIA rational), (10) mountain caribou (noted in the CF as well as by COSEWIC[5], the land use plan, and FIA rational), and (11) mountain goat (though of limited distribution was identified under the CF and FIA rational). Grizzly bear (12) are identified by the CF, IWMS, and FIA rational. Two smaller furbearers were also recommended: (13) the American marten (pine marten are sensitive of older forest fragmentation) and (14) wolverine (identified under the CF and IWMS). Species models previously developed are available for 7 out of the 14 species. Sandhill crane, American White Pelican and Harlequin duck met the criteria but are considered appropriately modeled with other aquatic species during a later phase of this project. Species accounts for these three bird species are provided in the Appendices.

Dead Wood Modeling

As a measure of the performance of the Dead Wood model, results are presented without incorporating TSR4 harvesting impacts on the supply of dead wood attributes. For natural stands over the base case and six time steps that we report on, total number of snags >10 cm DBH summed over conifer and deciduous species and decay classes, ranged from a minimum of 0 to a maximum of 1469. Total volume of CWD >10 cm DBH summed over conifer and deciduous species and decay classes ranged from a minimum of 0 to a maximum of 545 m^3.

The distribution of snags >10 cm DBH by decay class and categories of natural stand age were estimated across the time step reporting years by pooling data and calculating average numbers for each natural stand age category (Figure 5).

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[4] http://www.env.gov.bc.ca/wld/frpa/iwms/index.html

[5] COSEWIC stands for Committee on Status of Endangered Wildlife in Canada.

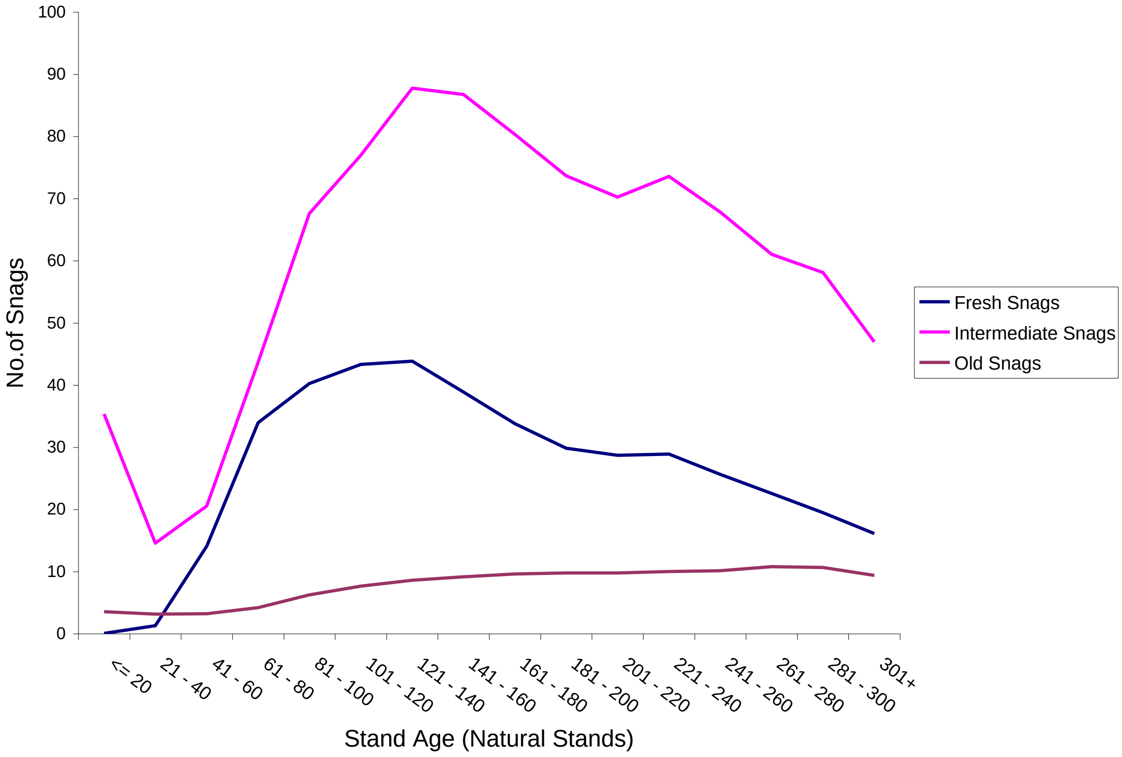

Figure 5. Number of snags per hectare >10 cm DBH estimated from the Dead Wood model applied to Prognosis natural stand structure model results. Data are pooled over simulation years 2009, 2013, 2018, 2023, 2028, 2058 and 2088 prior to incorporation of TSR4 harvest schedules.

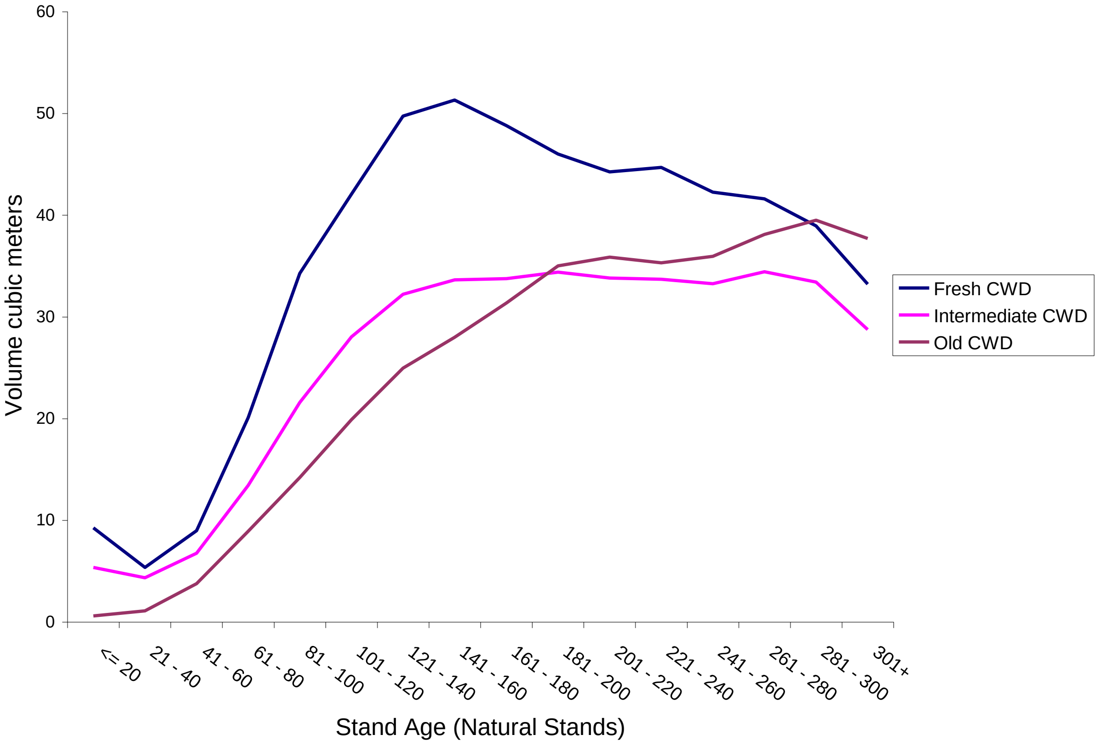

Figure 6. Volume (m3) per hectare of CWD (coarse wood debris) >10 cm DBH estimated from the Dead Wood model applied to Prognosis natural stand structure model results. Data are pooled over simulation years 2009, 2013, 2018, 2023, 2028, 2058 and 2088 prior to incorporation of TSR4 harvest schedules.

Species Habitat Model Development

Influence of MPB and Timber Supply on Habitat Supply

DISCUSSION

The actual results have at least one major qualification in that the many new input data sources led to so many changes in the overall structure of species models that the models themselves essentially reverted to alpha-level or untested condition. A more realistic and hence interpretive result will require a full assessment of the species models (including some modification of parameters where required). Below we discuss our interpretation of the qualified model results insofar as they point out important habitat elements to consider in the development of timber supply scenarios (and in particular as these elements would be affected by both the MPB and the management of MPB-killed timber). We also discuss challenges encountered during the application of the multi-species habitat supply models, potential resolution to those challenges, and the improvements made to the habitat supply models and their implementation as a result of this work.

Assessment of Species Habitat Model Results

Important Habitat Elements

Challenges Encountered During the Modeling Process

Input Data

Issues with input data were confined to the integration of new products (i.e. deadwood, stand structure, and TSR4 projections). The process of taking the products of an existing model and integrating it into the workflow of our own models presented obstacles which were overcome through the cooperation of the modeling teams involved.

Application of the stand structure data was complicated by a difficulty in determining the correct initial stand ages for the Prognosis stand projections. While the stand's projected age to 2008 was used as the initial stand age in Prognosis, preparation of the VRI data for the TSR4 simulations involved updating the data for recent disturbances and resulted in a number of forest stands being initialized as much older natural stands in Prognosis than they actually were. Since natural stands were grown forward in Prognosis from their initial age it was not possible to 'back up' in the stand structure tables to obtain stand data for an earlier age. To resolve this inconsistency in initial stand ages (and associated stand structure attributes), we created a control table to point to the most appropriate stand structure data, either natural stand or managed stand, at the outset of the habitat supply modeling. We employed a ‘fuzzy’ link by maintaining a spatial link to natural stand data based on the simulation year (rather than stand age) and accepted natural stand data when it was +/- 5 years of the updated VRI stand age (1,254,207 ha in the model study area). In all other cases, initial stand data was obtained from the managed stand tables (168,263 ha in the model study area). Since stand structure modeled stands at a lower resolution than the VRI (i.e., 16,733 stands in Prognosis versus 94229 stands in VRI), the initial assignment of stand structure tables was done on the level of grid cells rather than at the stand level. As harvest events occurred on the landscape through time, an increasing area of the land base was referenced to the managed stand structure table. As a consequence of our alignment of the stand structure data, 220,107 ha of the model study area’s land base that initially referenced the natural stand structure data was <= 47 years of age. This represents a departure from the Quesnel TSA Rationale for AAC determination (Snetsinger 2011) that considered all stands <= 47 years of age to be managed stands.

TSR4 simulations specified that back-log NSR will be restocked or reclassified within five years. As a consequence, harvest projections resulted in harvest events occurring where no stand level data was available in the VRI. We addressed this issue by determining a ‘forest footprint’ from analysis of the TSR4 scenario age grids. We identified all cells on the land base where stand ages were permanently zero (208,209 ha indicating no forest) and cells with stand ages greater than zero at some point in time (1,422,470 ha indicating the presence of forest). We used the ‘forest footprint’ grid to control the application of stand and stand structure data over the landscape since the Prognosis model essentially grew forests everywhere. For identified forest cells lacking stand level data in VRI, we used data from the stand structure modeling to fill in missing stand attributes such as lead and secondary species and percent composition. We also identified a small area (20,138 ha) with the model study area where stand ages were greater than zero but static through time. Due to the small area of such stands, we did not differentiate between them and stands that undergo age progression. As such, some discrepancies will exist between the stands’ ages and their stand structure attributes.

Application of stand structure data for the Natural Disturbance scenarios was not straightforward. The natural stand structure table provided by Ian Moss represented 150 years of growth forward from the initial stand age and hence individual stands did not have the complete array of ages that could be encountered at the end point of the Natural Disturbance model. We used our unified natural stand structure / dead wood tables for the time step runs and additional unified records from simulation years 2138 through 2158 to create a sample base from which input records for Natural Disturbance modeling could be derived. We pooled records based on stand age categories (<10, 5, 10, … 395, 400+) and site index (<15, >=15) to create 158 records to represent the land base under natural disturbances; however this represents a significant generalization of forest conditions.

Modeling Extent

The study area was defined by administrative boundaries rather than natural ones. As such, the habitat quality inside the study area can be affected by conditions outside of it (e.g. woodland caribou low elevation winter habitat is modeled as being within 20km of high elevation winter habitat, ideally there would be some measure of confidence that we aren't removing low elevation habitat when there might be some high elevation within 20km just outside the study area). In past applications of the modeling tools used in this project, the study area was large enough that these boundary conditions only affected a small proportion of the total area modeled. In other types of models where influence distances are shorter (e.g. CHASE) a 5km buffer is extended around the study area to absorb these edge-effects, leaving the area within the study area unaffected.

Neither of these strategies for mitigating edge-effects was applicable to this project. Because the TSR projections of future stand conditions were only produced for the Quesnel TSA we did not have all of the necessary information to be able to meaningfully extend the study area boundary. As such, it is possible that outside influences may be acting on the species modeled that we were not able to account for without having TSR projections for a wider area.

Modeling Refinements

The Bayesian Approach

The Bayesian modeling approach provides biologists, modelers and managers with several benefits (Marcot et al. 2006, McCann et al. 2006). In particular, the simple representation of complex systems as intuitive influence diagrams promotes understanding, involvement and collaboration amongst stakeholders. BBNs are also well-suited to incorporate information from diverse sources and allow system knowledge and understanding (the beliefs) from multiple disciplines and from those with widely varying backgrounds to enter the model. For those tasked with taking research results forward to a wider audience, a simple diagram rather than an unwieldy formula enhances the “face validity” of the model (i.e., does it fit with preconceived notions and make sense) and hence its acceptability.

For modelers, BBNs do have limitations. They handle time and hence, the temporal feedback loops that are often prevalent in real systems, poorly (McCann et al. 2006, Nyberg et al. 2006). BBNs themselves are static models; temporal dynamics (changes through time) are generally handled outside of the BBNs and enter the BBN as a new set of inputs. The need to specify the complete probability structure of variables and their relationships can be daunting to implement. The underlying Conditional Probability Tables can quickly become large and at times require probabilities be assigned to rare, poorly understood or novel events. These problems are addressed through elicitation of expert judgment, a process that must be rigorously applied if bias is to be avoided. As with all models, BBNs are unlikely to incorporate all sources of causality, uncertainty and variability or enumerate these without error or inaccuracies.

Modeling potential (capability)

Improvements Made to Existing Models/Procedures

While some of the tools and processes that were used in this project were pre-existing, none were used before undergoing improvements and/or standardization. These efforts had their most notable effects on the input data and the species models.

Input Data

The spatial inputs and modeling processes used to express the influence of coarse woody debris and snags in the species models was wholly re-created for this exercise. Previously there was no dedicated model input for dead wood; rather it was estimated from other inputs (stand composition, MPB history, and biogeoclimatic information). The current work as discussed earlier, utilized dead wood predictions from a more advanced algorithm generated by WI based on Prognosis stand structure model outputs of tree mortality. See Deadwood Modeling (attached under separate cover) for a description of improvements made to the model in general and with respect to MPB.

New moisture information in the form of the Quinn Wetness Index modeling performed for the Cariboo PEM project. Previously, site moisture was estimated used a flow accumulation algorithm available in ArcView's Spatial Analyst extension. Much like the deadwood data, the Quinn Wetness Index was produced with a more advanced algorithm than the previous method. The ArcView method considers only the area upslope of a location and is therefore purely a measure of potential flow accumulation. By contrast, the Quinn method considers upslope area as well as slope to estimate wetness due to accumulation and residence time of the water at the site (MacMillan et al. 2008). Use of the new moisture information improves the model input by being a better measure of relative site moisture instead of simple flow accumulation.

The current work in the study area marks the first time that PEM information contributed to the species models of this HSM. Use of this information improved the resolution and ability of the models to identify food sources for moose, mule deer, woodland caribou, and grizzly bear.

Species Habitat Models

In terms of the species models, improvements were made in their format and model architecture. Models (and by extension input data) were also standardized to improve their readability and allow one raster input of each type to be applicable for all models requiring it. Any differences in classification for an input node are handled in the CPTs of that model. For example, several species models make use of an input node for slope information but consider different ranges of slope to be important. After standardization, the states of the slope node in one model will be identical to the states in another model with differences in classification managed by CPTs.

New model inputs (number of stems, number of snags, and volume of CWD by diameter class) discussed above were accommodated through a realignment of the model relationships responsible for their interpretation. Similarly, the incorporation of MPB was realigned in several important ways. The models now respond to a more realistic interpretation of the impact MPB has on stands. Previously, stands heavily affected by MPB were assigned as entirely killed at some point in time. For any killed stand that is harvested, this may be a reasonable simplification; however for MPB events on the scale experienced recently, many killed or partially-killed stands will be unrecoverable losses and will experience a novel trajectory in terms of habitat type. The models now incorporate the extent of MPB impact (% cumulative kill per time step and % pine in the stand), and hence recognize when there are living remnants retained within the stand either due to <100% mortality of pure pine stands or due to stands being a mixture of species. This living component of a MPB-impacted stand is retained in the model through accounting for age succession of the live component (the TSR4 scenario age grids continue to age MPB impacted stands until a harvest event occurs) and the incorporation of 'effective forest age' integrates living remnants with new regeneration and canopy characteristics that influence snow interception. The gradual loss of MPB mortality influence on stand characteristics (i.e., regeneration becomes the dominant influencing factor) is incorporated through explicit accounting of the time since death. Under this formulation, time since death due to MPB is a stand-specific weighted average generated for each time step:

$$\Sigma(\%\text{kill} * \text{years since death}) / \Sigma(\%\text{kill})$$

Directions for Future Work

Opportunities for further refinement of the existing tools and directions for future work were identified as work progressed on this project. They are identified below in terms of the portions of the HSM that they affect.

Input Data

Overall quality of HSM products will be improved in future model applications through the verification of the deadwood model. Subsequently, production of deadwood model results for natural disturbance simulations would follow and contribute to better model results. Introduction of stump modeling would also beneficially affect future HSM applications.

The natural disturbance simulations rely on accurate fire parameters in order to realistically emulate natural wildfire conditions on the landscape. As described in the Methods section we empirically calculated fire distribution among five fire size classes based on historical data. Two major assumptions must be made when using historical data that may be leading to inaccurate results:

- Fire suppression activities have not significantly affected the size of wildfires.
- The historical fire record is both complete and accurate in its reporting of fires and their sizes.

By using empirically-derived fire distributions, it qualitatively appears that we may be simulating large fires (>1000ha) too frequently on the landscape. For example, in natural disturbance simulation 1, ~68.5 % of forested land in the year 2409 was <100 years of age due to fire (671,753 / 979,839ha) and 51.2% was <50 years of age (502,205 / 979,839ha). Investigations into this situation have confirmed that a strong majority of burned forest was burned by a few large fires during each of the natural disturbance scenario's decadal time steps.

As was done in applications of the CHASE model, it would be preferable to address this condition with fire distributions determined by someone with knowledge of fire regimes in the Quesnel TSA. Attempts were made to gain such information but were not successful in the time available. Future work will attempt to verify the fire distribution through renewed efforts to benefit from local knowledge with modifications made to the parameters as necessary.

Other places where input data could be improved are as follows:

- Run deadwood model to generate information for input to natural disturbance scenario;
- Run stand structure model to generate time-step dependant stand tables;
- Change study area extent so results near the TSA boundary are influenced by neighboring environmental conditions; and
- Run simulations to have MPB impact provincial park and other no harvest zones;

Species Accounts

Species Habitat Models

Model testing

It would be desirable to assess model results with independently collected empirical information. It would be efficient if this could be done to the extent possible with data that are already collected. Some current ideas (incomplete list) are as follows:

- Test canopy closure node results against data within VRI;
- Test snow zone predictions against Cortex snow zone layer or, better yet, against historic weather data;
- Dig up sources of animal occurrence data (best would be resource selection functions) as a foundation for assessing species resultants;
- Compare density of grizzly with those of Hamilton et al.

MANAGEMENT IMPLICATIONS

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