Provincial-Level Projection of the Current Mountain Pine Beetle Outbreak:

Documentation of revision to the model resulting in BCMPB.v3

by:
Marvin Eng, Research Branch, BC Forest Service
Andrew Fall, Gowlland Technologies Ltd.
Josie Hughes, Research Consultant

April 21, 2006

1.0 Introduction and Purpose of this Document

Over the past three years we have developed a model that produces a provincial-level projection of the current mountain pine beetle outbreak and allows an examination of the implications of our management response to that outbreak. While the management model is intended to produce output that can inform provincial-level, strategic decision-making, it does represent our management response in a reasonably detailed way. Documentation from previous years describes the basis of the management model. Rather than repeat this here, we focus on aspects that have changed over the past year, and refer interested readers to the prior documents for the core of the model that remains unchanged.

This document is intended both for people interesting in learning about new behaviours in the management model, as well as potential users of BCMPB. For the latter, we include descriptions of the various parameters used to control management at provincial and management unit scales. We also include an appendix describing the changes made to the beetle projection model (Appendix 1). This is done for completeness of understanding rather than with the intention that the infestation model might be modified by users of the model. Finally, we include our current shelf life model (Appendix 2 BCMPB Shelf-Life Model version 3). This model describes our understanding of shelf life parameters at the time of the development of the results presented. Significant amounts of work are currently underway that may improve the shelf life model.

During the first year of the project we concentrated on developing a management model that represented “leading edge” beetle control efforts. In the second year of the project we began to more fully specify the salvage harvesting components of the model in an attempt to better understand non-recovered loss implications. This year we are introducing additional detail that we believe is needed to adequately reflect the response of the existing forest industry and possible “new” industries to the outbreak.

In the main body of this document we:

- briefly review the existing management model;
- outline the enhancements made this year; and
- describe the parameters that need to be specified to make the enhancements to the model effective.

2.0 Description of the version 2 management sub-model

A detailed description of the existing model (BCMPB.v2) can be found in the main report and appendix 2 at http://www.for.gov.bc.ca/hre/bcmpb.

In summary, the model is an inventory projection (simulation model) that operates on an annual time step simultaneously in each management unit (TSA or TFL). Each year of the simulation there is a “planning” sub-step and a “harvesting” sub-step.

Note that much of the behaviour of the management model is expected to be a result of interactions between management specific parameters and the “shelf-life” characteristics of the dead wood. A separate sub-model, described in Appendix 2 BCMPB Shelf-Life Model version 3, specifies the rates of deterioration of dead pine.

2.1 Planning sub-step

- Assign a Beetle Management Unit (BMU) “strategy” (monitor, suppression, holding action or salvage) to each BMU based on the nature of the outbreak and the available resources (harvesting and single tree treatments). Once a unit is assigned to salvage, it remains in that strategy for the remainder of the simulation.
- Determine the availability for harvest of each cell, within the THLB, based on:
    - total volume in the stand (green + salvageable dead >150 m^3/ha)
    - distance from a road (<2 km)
    - nature of Visual Quality constraints for the cell within its Landscape Unit.
- Determine suitability of the cell for salvage based on:
    - percentage pine (>50%)
    - percentage mortality (>50% of the pine)
    - volume of sawlog quality dead pine (>100 m3/ha)

2.2 Harvesting sub-step

The model attempts to achieve a volume based harvest target (m^3/year) that is specific to each management unit. Where there are suppression or holding action BMUs in a management unit the harvest is directed to those units in an attempt to slow the spread of the outbreak. Priorities within and among BMUs are specified in Appendix 2 of the full model documentation and are based on the BMU strategy and the state of the infestation in a cell. Where the BMU strategy is “monitor” or “salvage” harvest priority is based on the nature of the forest alone.

Priorities are determined based on

- the distance a cell is from a road (no effect from 0 to 500 metres then linear decrease in preference from 500 to 2 000 metres)
- the total volume (green + dead salvageable sawlogs) in the cell (linear increase above 150 m^3/ha)
- salvageable dead volume in a cell (linear increase above 100 m^3/ha)

Effectively the priority is “highest volume, closest to road”, but stratified according to the priorities within and among BMUs in a give management unit (see

Appendix 2 of the full model documentation). For example, if a management unit has a mixture of BMU types, then harvesting will focus first on areas of detectable attack in suppression units before focusing on salvage opportunities in salvage units.

3.0 Version 3 Enhancements

The main enhancements made in the third year were to the harvesting sub-step.

3.1 Generalizing Forest Cover Constraints

Version 2 of the model limited forest cover constraints to visual quality objectives. There was interest in including other constraints, in particular for ungulate winter range. While it was not feasible to create a completely general approach to handling constraints, as would be done in a timber supply model, we generalized constraint handling to enable a range of different types (e.g. ungulate winter range forest cover constraints in addition to the VQO constraints). We allow as input a general cover constraint layer along with a file that specifies the constraint details. Constraints are assessed and updated in the planning sub-step and affect the availability for harvest of cells. In addition, constraints are monitored by the logging sub-step during a given year to ensure they are met.

One key limitation at present is that constraints cannot be overlapping because all must be specified as zone types in a single constraint layer. In general, this is not a huge limitation if the most constraining zone for a given cell can be used, especially over a short time horizon of 1-2 decades. Another limitation is that recruitment of stands in zones that violate the constraint at simulation start is not modelled. This can be a fairly complex process to capture adequately, and we felt that it wasn’t warranted over the time horizon for BCMPB.

3.2 Distance to the Mill

We added “distance to the mill” as a factor in the determination of harvest priority for a cell during the harvesting sub-step. In a fashion analogous to “distance to a road” there is a (short) distance to the mill over which there will be no preference “penalty”. After that the penalty for the distance to the mill increases linearly as distance increases up to a specified maximum penalty.

3.3 Separate (Alternative) Industries

A key addition to the harvesting model was to accommodate three "separate industries" based on the kind of wood (commodities) they require or are licensed to harvest:

- non-pine
- pine “sawlogs" (live pine and pine that has been dead a short enough time that it still is of “sawlog” quality)
- pine “other” (wood that has passed the sawlog shelf-life but is still useable for other products, notably pulp, OSB, and bio-energy).

Each of these industries is modelled as a separate “partition” - a separate portion of the harvest target. A harvest target is specified for each industry in each management unit and year of the projection these industries are modelled sequentially, first non-pine harvest, then pine sawlogs then pine “other.” Unmet harvest from the preceding partition is carried over into subsequent partitions. This allows automatic “switching” from one industry to a subsequent one as harvest opportunities become limited.

As a default, the total harvest target for the "non-pine" and "pine sawlog" industries are equal to the pre-expedited uplift AAC and the "pine other" cut is the amount of the expedited uplift. This is only applied in those management units where such an uplift has been determined.

As a default (base-case), the harvest target for the "non-pine" industry, at the beginning of the projection, is the minimum of

- the amount of non-pine billed from Oct 1, 2004 to Sep 30, 2005, and
- the amount of pine that would be harvested if “the profile” was harvested; i.e. (PineVolume/TotalVolume)*AAC

A set of “calibration” runs was run to ensure that the “non-pine” industry does not over-achieve its harvest target because both of the other industries will harvest non-pine volume as an incidental “by-catch” of their operations. Alternative scenarios may involve modeling some shift to increasing pine harvest as the infestation progresses in a management unit.

The "pine sawlog" industry is allowed to switch to non-pine harvest once the volume of sawlog quality pine is too low to support harvesting. The "pine other" industry is not allowed to switch from a harvest priority of non-sawlog quality dead pine. That is, this industry is stuck with pine of continually deteriorating quality for the entire projection period. Enabling (or disabling) industries to switch harvest priorities and ensuring that harvested volumes do not exceed the AAC is controlled through a set of harvest priority and cut accountability parameters, respectively.

Each industry has specified preferences for the various “commodities” defined as: non-pine, live pine and the dead pine commodities specified in the shelf-life sub-model (Appendix 2 BCMPB Shelf-Life Model version 3). The non-pine and dead pine industries (first and last) base preferences of selecting stands for harvest on distance from road and/or mill and volume of different commodities as specified in an input file (e.g. by default, the non-pine partition focuses on volume of non-pine, while the dead pine partition focuses on any volume of dead pine except NRL). The pine partition additionally stratifies harvestable cells according to BMU ratings and MPB state (i.e. endemic, low, etc.)

3.4 Volume Increment (Growth and Yield)

In previous versions of the model, we did not “grow” trees over the course of a simulation. That is, volume of live wood was not incremented due to stand growth. This may lead to an underestimate of the amount of live volume standing at the end of a simulation, as well as an underestimate of the amount killed by MPB, available for salvage and lost. To address this, we estimated volume increments across the province using site index and species (inventory type group). The level of detail for growth and yield applied in a timber supply analysis was not feasible. To ensure full coverage, we took an empirical approach based on inventory ages, volumes, species and site index. Additional complication for projecting volume is due to the partial disturbance caused by MPB attack. To handle this, we scale growth increments based on residual proportion living (i.e. we assume that dead trees do not change the growth rates of live trees).

One side effect that is important during interpretation is that total volume across all classes (non-pine, live, standing dead, logged, etc.) is not constant when volume incrementing is enabled. Hence, interpreting changes as percentages of original volume must be done with caution.

4.0 Parameters requiring specification

The new parameters requiring specification for the management sub-model are (in the file DefaultSensitivityDefs.sel):

- Preference penalties for increasing distance from road
    - MinNoEffectDist2Road (default: 500m): distance from road before any penalty is applied.
    - MaxDist2Road (default: 2000 m): distance from road beyond which harvesting is not permitted.
- Preference penalties for increasing distance to the mill
    - NoEffectDist2Mill (default: maximum of Dist2Mill layer, which leads to no penalty): distance from mill before any penalty
    - MaxEffectDist2Mill (default: maximum of Dist2Mill layer): distance from mill at which penalty reaches maximum
    - pMaxDist2MillEffect (default: 0.1): maximum penalty based on distance to mill.
- Volume incrementing
    - IncrementVol (default: FALSE): whether or not to increment volume over time due to stand growth

The following input files can be redirected to different inputs in a scenario (by setting the appropriate script variable). These are generally in the folder Background\mInputFiles:

- Initial BMU strategies
    - $BMUStrategies$ (default: BMUStrategies): specifies starting BMUstrategies. All will be recalculated, except those salvage units (as salvage BMU remain salvage for the duration of a run).
- Harvest target for each year of the simulation and each “industry” in each management unit (AAC files):

  - $AACVolName_NonPine$ (default: AACVolumeBase_NonPine): specifies file for harvest level for the first industry (assumed to focus on non-pine harvest).
  - $AACVolName_Pine$ (default: AACVolumeBase_Pine): specifies file for harvest level for the second industry (assumed to focus on pine sawlog harvest).
  - $AACVolName_Salvage$ (default: AACVolumeBase_Salvage): specifies file for harvest level for the third industry (assumed to focus on pine non-sawlog harvest).
- Harvest preferences for each “commodity” for each industry, and cut accountability for each “commodity” for each industry:
  - $CommodityPref$ (default: CommodityPref): specifies relative preferences for different volume strata (e.g. non-pine, live pine, sawlog salvage, etc.) as well as which volume counts towards the AAC for each separate industry.
- Constraint specification:
  - $Constraints$ (default: Constraints): specifies file that specifies constraints to apply to the zones in the FCConstraints input layer. Each constraint is specified by a line in the file that gives the zone id (or legend label), the threshold proportion, threshold age and flag to indicate if the forest considered is restricted to the THLB or all productive forest. Each constraint is interpreted as the minimum proportion of forest to be maintained above the age threshold.

Shelf-life parameters, while not part of the management model *per se* also require specification.

The following subsections describe some additional details regarding some of these parameters.

4.1 Shelf-life

The commodities specified within the model are different types of harvested volume:

- non-pine
- live pine
- dead pine suitable for sawlogs
- dead pine suitable for chip-based industries
- non-recovered losses (suitable for no industry)

The rate of deterioration of dead pine, from sawlogs to chips to NRL, is specified based on a shelf-life model. The current parameters used in that model are detailed in Appendix 2BCMPB Shelf-Life Model version 3. The shelf-life model has the capability to accept a specification for up to 5 dead pine commodities (including NRL) in 3 moisture zones.

We currently have a specification for 3 dead pine commodities in 2 moisture zones, dry and wet. We interpolate a third, moist, moisture zone.

Dry Subzones

	% of Volume in the Commodity				
Time Since Death	**sawlogs**	**chips**	**Commodity 3**	**Commodity 5**	**Commodity 5**
0	100	100			
1	75	90			
10	50	75			
20	10	50			
24	0	0			

Wet Subzones

	% of Volume in the Commodity				
Time Since Death	**sawlogs**	**chips**	**Commodity 3**	**Commodity 5**	**Commodity 5**
0	100	100			
2	80	90			
7	50	70			
15	10	50			
18	0	0			

Adjustments can easily be made to the existing parameters and for additional commodities (including names).

4.2 Harvest Priorities

4.2.1 Distance to road

Current parameters for distance to road penalties are:

0 to 500 metres	no penalty
500 to 2000 metres	linear increase in penalty with distance
> 2000	no harvest

4.2.2 Distance to mill

Current parameters for distance to mill apply no penalties (i.e. disable this feature). Suppose one wanted to apply the following penalties:

0 to 20 kilometres	no penalty
20 to 100 kilometres	linear increase in penalty with distance
> 100 kilometres	100 kilometre penalty

Then the parameters could be set as follows:

- NoEffectDist2Mill= 20000
- MaxEffectDist2Mill = 100000
- pMaxDist2MillEffect= 0.1

4.2 Harvest Targets

The base case harvest target for 2006 for each industry in each of the 22 “pine units” is specified in the table below. These are currently considered to be "raw" targets. To the extent possible transfers of volume have been accounted for in these harvest targets. There are some obvious discrepancies that need to be sorted out. For example 100 Mile House has been billing nearly 2 million m3/year for the last 2 years even though the AAC is only 1.334 million m3/year . Quesnel has only billed 3.4 million m3/year in the year ending 05/09/31, when the AAC was 5.28. This begs the question, what should the "other commodities" target for 2006 be?

Harvest Targets (‘000s m^3) for 2006 in the “pine units”

	Commodity Type			
Mgmt. Unit	Non Pine	Pine Sawlogs	Pine "other"	Total Target
100MileHouse	347	987	-	1,334
Arrow	392	158	-	550
Boundary	351	349	-	700
Bulkley	214	668	-	882
Cranbrook	278	696	-	974
DawsonCreek	1,054	806	-	1,860
FtStJames	926	1,552	551	3,029
Golden	325	160	-	485
Invermere	230	368	-	599
Kamloops	1,915	2,437	-	4,353
KootenayLake	476	205	-	681
Lakes	369	2,593	200	3,162
Lillooet	174	462	-	636
Mackenzie	1,136	1,914	-	3,050
Merritt	525	2,289	-	2,814
Morice	531	1,430	-	1,961
Okanagan	1,889	1,486	-	3,375
PrinceGeorge	1,492	2,886	974	5,352
Quesnel	542	2,706	2,032	5,280
RobsonValley	187	416	-	602
Vanderhoof	600	4,768	1,195	6,564
WilliamsLake	848	2,920	-	3,768
Totals	15,009	32,279	4,952	52,241

Pine units are TSAs where pine is >10% of the THLB volume – PG TSA specified by district

Based on the calibration done to ensure that "incidental by-catch" (e.g. of non-pine during salvage) is accounted for, the targets we actually applied in the base case were as follows:

Harvest Targets actually applied ('000s m^3) for 2006 in the "pine units"

	Commodity Type			
Mgmt. Unit	Non Pine	Pine Sawlogs	Pine "other"	Total Target
100MileHouse	0	1,334	-	1,334
Arrow	0	550	-	550
Boundary	0	700	-	700
Bulkley	0	882	-	882
Cranbrook	0	974	-	974
DawsonCreek	558	1,302	-	1,860
FtStJames	0	2,478	551	3,029
Golden	0	485	-	485
Invermere	0	599	-	599
Kamloops	0	4,353	-	4,353
KootenayLake	221	460	-	681
Lakes	0	2,962	200	3,162
Lillooet	0	636	-	636
Mackenzie	0	3,050	-	3,050
Merritt	0	2,814	-	2,814
Morice	0	1,961	-	1,961
Okanagan	0	3,375	-	3,375
PrinceGeorge	0	4,378	974	5,352
Quesnel	0	3,248	2,032	5,280
RobsonValley	0	602	-	602
Vanderhoof	0	5,369	1,195	6,564
WilliamsLake	0	3,768	-	3,768

4.3 Commodity Preferences and Cut Accountability

Default values for commodity preferences and cut accountabilities for each industry and each commodity are specified in the following table:

	Commodity Preference			Cut Accountability		
Commodity	Non Pine	Pine Sawlog	Pine Other	Non Pine	Pine Sawlog	Pine Other
Non Pine	1	0.01	0	1	1	1
Green Pine	0	1	0	1	1	1
Sawlogs	0	1	0.95	1	1	1
Chips	0	0	1	1	1	1
Unspecified Commodity 3	0	0	0.5	1	1	1
Commodity 4	0	0	0.25	1	1	1
Commodity 5	0	0	0.125	1	1	1
Non-Recovered Loss	0	0	0	0	0	0

To apply a different set of preferences or cut accountability, either the default input file (CommodityPref.txt) can be directly modified, or a new file can be created and the script variable $CommodityPref$ set in the scenario file to redirect input (recommended).

4.4 Constraint Specification

Constraints are controlled by both the input layer FCConstraints and the input file. By default, only VQO constraints are applied. Hence the FCConstraints layer is simply the VQO layer. The default constraint file is as follows. For guidance, constraints for deer, moose and constraints are included in the file (but would only be applied if an appropriate constraint layer is loaded in a scenario. To add new constraints requires revising the legend file associated with the FCConstraint layer (e.g. to add CWS for community watersheds). Then a new line can be added to the constraint file. As with the commodity preferences, to apply a different set of constraints, either the default input file (Constraints.txt) can be directly modified, or a new file can be created and the script variable $ Constraints $ set in the scenario file to redirect input (recommended).

Zone	**MinAbove**	**AgeThresh**	**THLBOnly**
IRM	0.75	12	TRUE
VQOm	0.75	20	FALSE
VQOmm	0.75	20	FALSE
VQOpr	0.85	20	FALSE
VQOr	0.95	20	FALSE
VQOp	0.99	20	FALSE
UWRdeer	0.3	100	FALSE
UWRmoose	0.3	100	FALSE
UWRcaribou	0.5	250	FALSE

Appendix 1 Updates to the Beetle Projection Model

This year, significant effort has gone into redesigning and completely documenting the BCMPB model. Many of these changes make the model more useable, transparent, and easily subject to sensitivity analysis, but do not actually change projection results. In addition, we have made some substantive changes to the beetle projection component of BCMPB. This document presents a brief overview of substantive changes. Contact authors for more complete year 3 results and documentation.

For easy reference, this document has the same structure as the technical documentation of the beetle projection model from year 2 of the BCMPB project (http://www.for.gov.bc.ca/hre/bcmpb/BCMPB_Appendix3_MPBProjectionModel.pdf). We note here only those aspects of the model that have changed, so this document is best considered an addendum to the Year 2 technical documentation.

Changes to the projection model are summarized very briefly in the following list. See section references for more thorough explanations:

- New forest cover data and depletion information (Section 1.1).
- Data from outside the LRDW used to parameterize the transition model (Section 1.1).
- Gridding artifacts in the forest cover data are now left in place (so the amount of pine volume is correct, but small part of that volume is immune to beetle attack) (Section 1.2).
- “Climatic suitability” is defined by current beetle range rather than biogeoclimatic zoning (Section 1.3).
- Elevation added as a predictive factor (Sections 1.3, 2, 4 and 5)
- Factor classification scheme refined, and model structure altered to allow sensitivity analysis to factor classification. The model is relatively sensitive to classification decisions (Sections 1.3, 4, and 5).
- The method of converting aerial survey polygons and spot data to a severity grid (of % pine killed) has been improved so that infestation severity classes are represented in the correct proportions, and severe infestations are not artificially created in small habitat patches (Sections 1.4 and 1.5)
- A “Very Severe” infestation class has been added to reflect changes in the aerial survey data and in the observed behaviour of the outbreak (Section 1.5).
- “Down-up” sequences in the infestation time series are filled in. For example, a three year sequence of *severe-endemic-moderate* becomes *severe-moderate-moderate* (Section 1.6).
- Through the Chilcotin plateau in 2003, some areas assigned a “low” infestation rating are reassigned as “endemic” (Section 1.6).
- Net down harvesting between 1999 and 2003 is directed to known depletion areas (identified by change detection analysis of satellite imagery) (Section 1.7).
- Assume uniform wind (since the wind information we had last year did not improve predictive capacity of model) (Section 3.2).

- Long-distance dispersal only allowed from areas where infestation severity ≥ moderate, and cumulative % pine killed ≥ 30% (Section 3.3).
- Short-distance dispersal is uniform within 1 km (because more complex dispersal function did not improve predictive capability of the model) (Section 3.4).
- Explicit "worst for beetles" and "best for beetles" assumptions made about undefined cases in the start and progress transition tables (Sections 4 and 5).
- The effect of climate investigated, but found to be uninformative or a counter-intuitive predictor about the progress of this outbreak. Further investigation seems warranted, and meantime climate is not included as a factor in this version of BCMPB (Section 5).

1 Data Preparation Steps

1.1 Get age and percent pine from forest cover database

Forest cover data differed from last year in several respects. A new cut was taken of the forest cover database in fall 2005. The forest cover database has not been updated to reflect much of the recent logging, so depletion information was derived separately from satellite imagery, etc.

Last year, only data available in the LRDW was used to parameterize the beetle model. This year, we parameterized the model using data from all areas. The reason for this change is that some of the best information on infestation subsidence comes from Tweedsmuir Park, where this outbreak is oldest. Forest age and percent pine information in this area is poor, but we do have cumulative kill, infestation severity, elevation, and beetle pressure information.

1.2 Address data inconsistencies

Last year, we edited the forest cover information by setting timber volume = 0 m^3 in places where age = 0, and pine volume = 0 m^3 in places where percent pine = 0. This year, we did not make either of these changes. There are ~16 million ha wherein there is some pine volume, but no percent pine. This is an artifact of converting forest cover information from polygons to a grid. These bits of pine volume are ignored by the beetle projection model (and are thus effectively immune to attack).

1.3 Classify habitat types

Last year, beetles were not allowed in the following biogeoclimatic zones:

- AT, BWBS, CDF, CWH, MH, SWB

As this outbreak is proceeding, it is becoming more apparent that the biogeoclimatic zone delineations do not accord well with mountain pine beetle range, especially in the north where beetles are now found in areas of the boreal white and black spruce zone (BWBS). This year, we limit future attack to occur within the current observed beetle range, instead of using a biogeoclimatic constraint. Beetle range is defined as the minimum convex polygon around mapped infestations. We assume that >2 years of persistence is necessary to reliably indicate the northern limit of beetle range. In 2001 there are 1,520 infested ha (95 cells) mapped between ~57.4° to 59.3° north, and in 2002 there are another 208 ha (13 cells). Since these very few northern beetles did not persist, we do not take them as a reliable indicator that pine near the Yukon border is suitable for beetles.

The classification of age and percent pine has changed since last year, and we have added an elevation factor to the model. The model has been restructured so that factor classes are easy to alter, and can be set differently for the infestation start and infestation progress submodels. We conducted an array of sensitivity analysis to various factor classification options. We found that the model is fairly sensitive to decisions about factor classification. Changes to the classification scheme since last year (including elevation) increase projected kill in 2014 by 60 million m^3 (~4%). Basically, the classification scheme this year is more specific and refined, allowing the model to more precisely distinguish between areas suitable for beetles and areas that are not. Less "smearing" of the data has the practical effect of increasing kill in the short term, and shortening the time until the outbreak subsides. Contact the authors for complete documentation of the factor classification and sensitivity analysis results.

1.4 Assign beetle infested area to suitable habitat

If we accept the unprocessed aerial overview survey at face value, we find that it is not uncommon for beetles to occur in unsuitable areas, including lakes and rivers well as forested area without pine. Last year, we dealt with this issue by first calculating the area killed by beetles on a 1200 by 1200 m grid. The area killed within each 400 m cell was then:

$$\mathrm{AreaKilled}_{400} = \mathrm{Min}\left(\frac{\mathrm{AreaKilled}_{1200}}{\mathrm{Number\ of\ Suitable\ Cells}}, \frac{\mathrm{CellArea} * \mathrm{PercentPine}}{100}\right) \quad \text{Eq. 1}$$

where $\mathrm{AreaKilled}_{1200}$ is the total area infested in the 1200 metre cluster, CellArea is the area of the 400-metre cell (160,000 m^2). Beetles that could not be assigned to suitable habitat by this method were discarded.

This year, we have altered the method for assigning infestation severity significantly. The new method is detailed in the following paragraphs. The net effect of this new method is to make our gridded maps a more faithful representation of the aerial survey data. Infestation severity classes are represented in the correct proportions, and severe infestations are not artificially created in small habitat patches.

We begin again with a 1200 m grid ("Fishnet"), but this time we tabulate the area within each severity class in each cell (instead of converting aerial survey severity classification to "infested area").

Fishnet cells may also contain small infestation "spots" of ¼ ha each. To convert these spots to infested area, we assume spot area is severely infested, so 30% of stems within the spot area are red-attack. We then assume infestation spots are concentrated in otherwise uninfested area (not included in aerial survey polygons). The proportion of stems kill within the otherwise uninfested area is therefore:

propKill = spotArea*HaArea*svMidvalues[Severe]/areaNotOtherwiseInfested

To assign a severity class to this otherwise uninfested area we classify propKill using the svThreshold values. Except in fishnet cells containing a remarkably large number of spots, this procedure assigns an endemic severity to otherwise uninfested area in fishnet cells containing spots.

Each fishnet cell contains 9 16 ha forest cover cells. Some number of these forest cover cells may be unsuitable for beetles because they contain no pine or the forest is less than 60 years old. To the extent possible, we first assume that uninfested area belongs in these unsuitable cells, and then endemically infested area. For each unsuitable cell in turn, we first check whether uninfested + endemically infested area > 0. If so, we assign first uninfested area and then endemically infested area to the unsuitable cell. We reduce uninfested or endemically infested area left to assign by up to 16 ha, and we count the assigned endemic area as “lost”. “Blame” for this lost area is assigned equally among all the types of unsuitable cells within the fishnet.

For example, consider a fishnet cell that contains 4 cells unsuitable because they are too young, and another unsuitable because there is no pine (i.e. 5*16 = 90 ha unsuitable). 36 ha of the fishnet is not infested, 36 ha is endemically infested, and the rest (72 ha) is moderately infested. After first 2 unsuitable cells are assigned uninfested area, we have 58 ha unsuitable area left rate, and only 4 ha of remaining uninfested area. In the next unsuitable cell, 12 ha of endemic area is “lost”. 4/5ths of this loss is “blamed” on the forest being too young, and 1/5th is blamed on having no pine. The next unsuitable cell is assigned entirely endemic area, and blame is assigned the same way. At this point, we are left with one unsuitable cell and only 8 ha of endemic area left to assign. We assign the endemic area to the unsuitable cell, and note that another 8 ha of infestation will be lost from the other severity classes.

Next, suitable forest cells are processed in random order. While there is area of any severity > NoMPB left we prefer to assign severity > NoMPB. The probability of assigning any severity class is proportional to the area left to assign in this class. Once a severity class is selected, the area left to assign in that class is decreased by 16 ha or area left to assign, whichever is less. If area left to assign is <16 ha, the difference is counted as an over-assignment to this severity class. The difference is subtracted from area in other severity classes, and is counted as an under-assignment to these other classes. Thus, total under-assigned area is equal to total over-assigned area. However, since we preferentially under-assign the NoMPB severity class, the process causes a net increase of infested area (Figure 1).

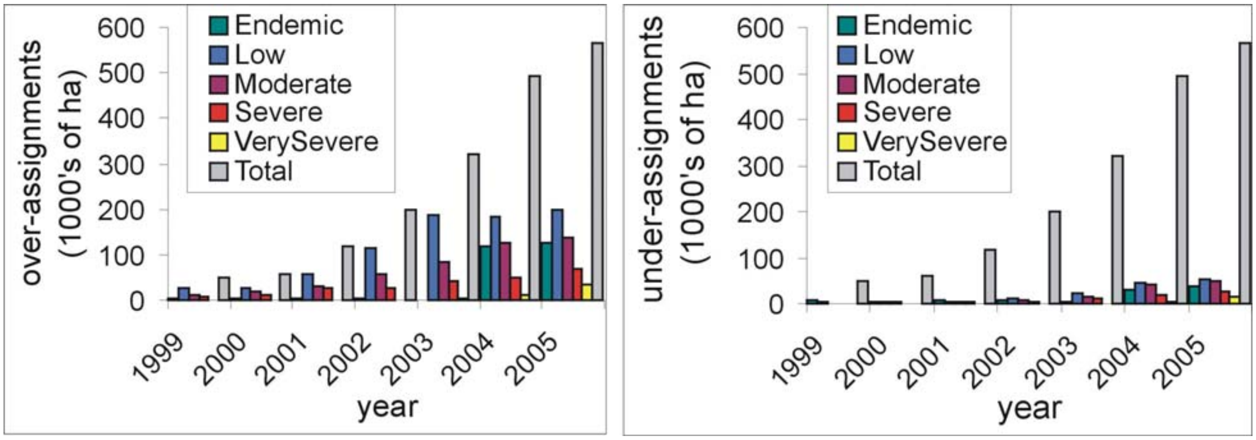


Figure 1: Area gains and losses due to gridding artifacts. Over-assignment and under-assignment occur because each 400 by 400 metre cell can only be given a single severity rating. Total over-assignments are equal to total under-assignments. However, there is a net gain of infested area because cells are designated infested as long as there is any remaining infested area to allocate. Thus, the NoMPB class is preferentially under-assigned.

Finally, remaining area to allocate is assigned to remaining unsuitable cells, and blame is allocated equally among all unsuitable cells. Total area not assigned is shown in Figure 2. The distribution of blame is shown in Figure 3. The output layers *OmitLocs#* show unsuitable cells where some infested area was lost.

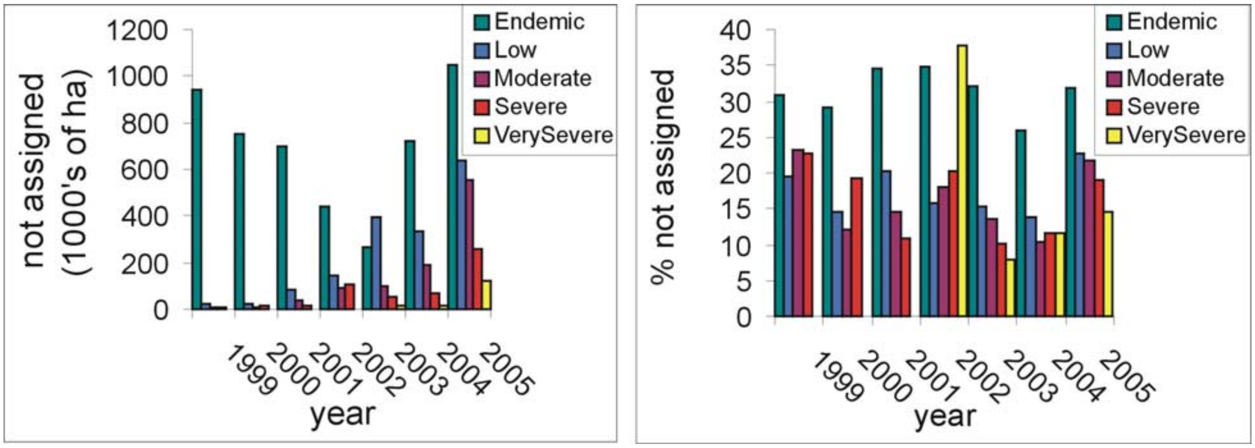


Figure 2: Area losses due to habitat unsuitability.

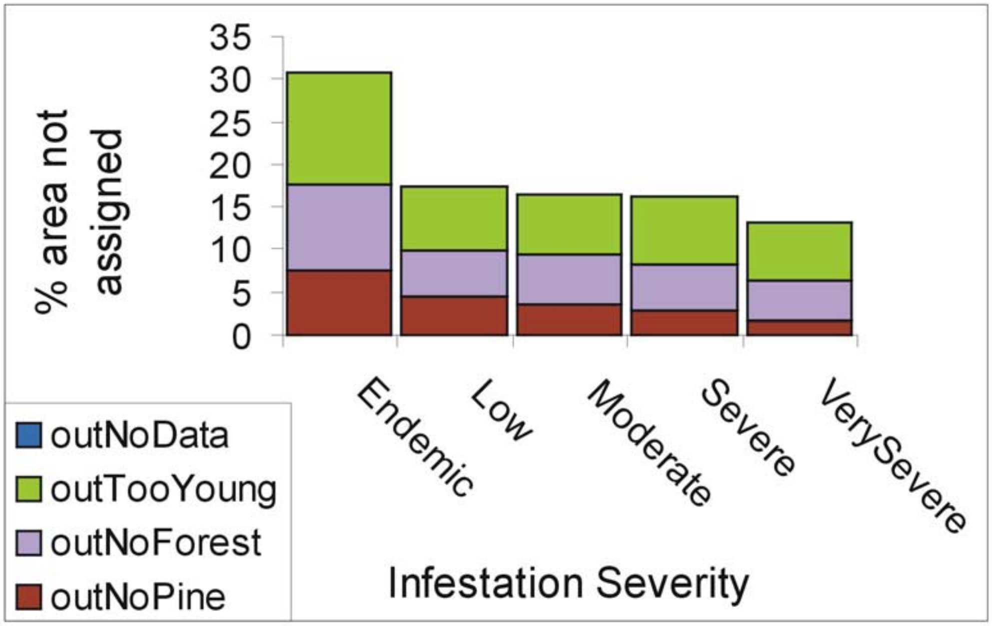


Figure 3: The distribution of unsuitable habitat types responsible for area loss.

1.5 Classify infestation intensity

Infestation severity classification also differs from last year. We assume the infestation severity classes in the aerial survey data are defined as follows:

	Lower	Mid	Upper
Very Severe	0.5	0.75	1
Severe	0.2	0.3	0.499999
Moderate	0.1	0.15	0.199999
Low	0.01	0.05	0.099999
Endemic	0.000001	0.005	0.009999
None	0	0	0

Table 1: Infestation severity classification scheme.

The aerial survey data is an estimate of % stems killed, and we are looking for an estimate of % pine killed. To convert from % stem severity to % pine severity:

% stems killed = mid value of % stem severity class*100
% pine killed = % stems killed / % pine
% pine severity class = % pine killed, classified according to Table 2.

1.6 What does "severe" really mean?

This year, there are even more places where the aerial survey data infestation severity ratings suggest that more than 100% of pine has been killed. Like last year, we simply edit out infestations after cumulative kill has reached 100%.

This year we have added two more data editing steps. One aspect of the overview survey data is the frequency with which infestations flash on and off over time. For example, an area may be severely infested one year, not infested the next year, then very severely infested the year after. Frankly, we don't believe this happens to real infestations. Instead, we assume the effect is mainly an artifact of spatial inaccuracy in the overview survey data. Randomly shuffling infestation within fishnet cells does not help. Because we do not believe down-up sequences happen in real infestations, we fill them in. endemic-noMPB-any severity or any severity-noMPB-endemic sequences are allowed. Other down-up sequences are filled in with the lowest bracketing severity class (*EditDownUpThreshold = Low)*. For example, low-endemic-moderate becomes low-low-moderate.

Finally, we observe that large areas of the Chilcotin plateau were assigned a low infestation severity in 2003, before the "trace" or endemic infestation category was introduced. In fact, we believe these areas were endemically infested. Thus, in the Chilcotin forest district where 2002=NoMPB, 2003=Low, and 2004=Endemic or NoMPB we set 2003 = Endemic (*2003ChilcotinEditYear=4)*. Table 2 contains a summary of the 3 severity editing procedures described here (CumKill, DownUp, and Chilcotin, in order). Figure 4 contains more information about DownUp changes, and Figure 5 contains CumKill information.

year	noChanges	DownUp	Chilcotin	CumKill
1999	217633	0.00	0.00	0.00
2000	262778	5.25	0.00	0.91
2001	318954	4.83	0.00	1.48
2002	407447	4.70	0.00	2.96
2003	494385	5.17	2.04	6.59
2004	587167	5.08	0.00	10.77
2005	563373	0.00	0.00	20.75

Table 2: Tabulation of beetle data changes (number of cells, or % cells changed). Note also that the cumulative kill tabulation includes places where infestation severity is not actually changed, but the meaning of that severity class is altered. For example, VerySevere (75%) becoming VerySevere (40%) is counted as a change. See Figure 5 for more details.

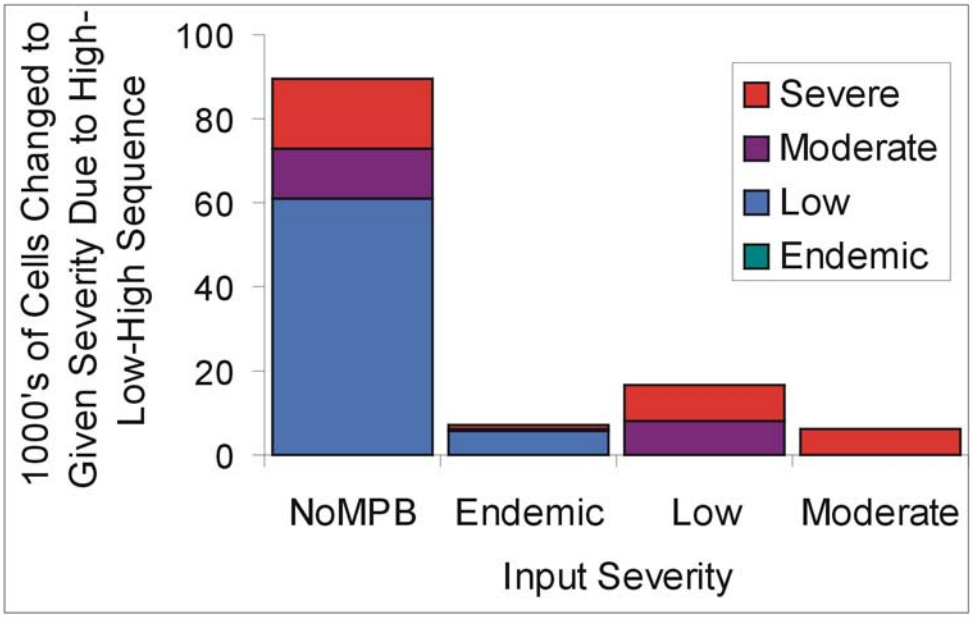


Figure 4: Changes made to fill in high-low-high sequences in the infestation severity time-series.

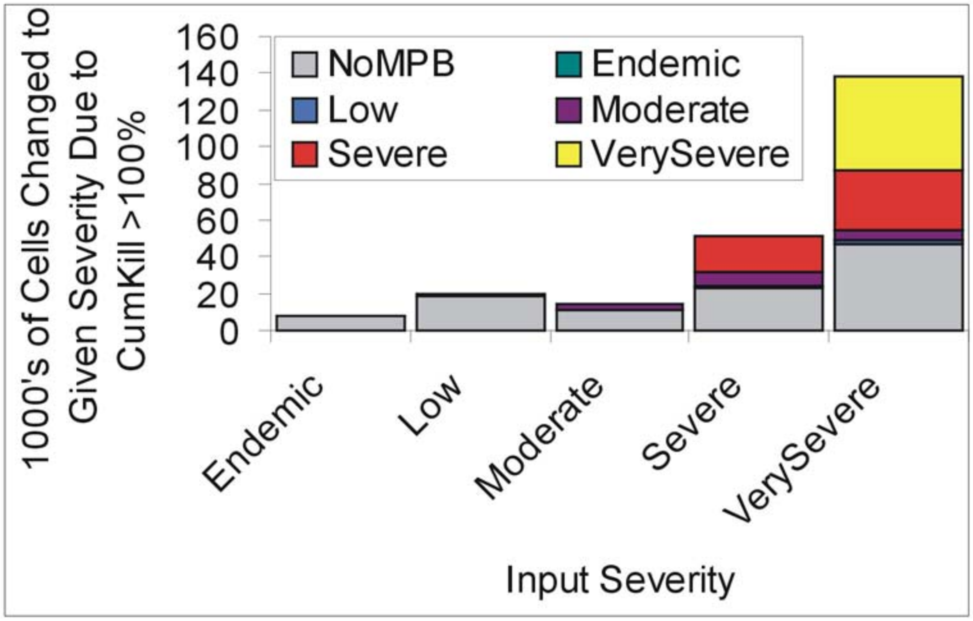


Figure 5: Changes made so cumulative kill over time does not exceed 100%. A transition from a state to the same state (e.g. VerySevere to VerySevere) indicates and instance where amount left to kill was greater than the mid-value of the next lower severity class but not as much as the mid-value of this class (e.g. 30% < AmountLeftToKill < 75%). In these cases the severity map is not altered, but the amount actually killed is less than the mid-value of the severity class.

1.7 Net down to account for harvesting since 1999

Like last year, we run the management model from 1999 to 2004 to account for recent harvesting. Between 1999 and 2004 the management model is directed to only cut in those areas we know have been depleted (by comparing 2002 and 2004 versions of the forest cover data, and change detection analysis of satellite images). We don’t have any information about the spatial location of logging in 2005, so the management model logs using normal beetle management rules.

2 Projection Model Overview

The only change to the basic modeling approach is that elevation has been included as a predictive factor.

3 Calculation of beetle pressure

The basic approach to beetle pressure remains the same, but there have been several minor changes in the calculation this year.

3.1 Get number of “source” beetles

No change.

3.2 Tabulate wind speed and direction

Since the wind speed and direction information we used last year did not improve the predictive capability of our model, this year we assume a uniform wind that blows at 3.6 m/s equally often in all directions. The model retains the capacity for running more complex wind scenarios.

3.3 Long-Distance Dispersal

Last year, we assumed that a constant proportion of beetles travel long-distance, regardless of the state of the source infestation. This year, we assume that only “sufficiently severe” infestations are effective sources for long-distance dispersal. The first reason for this assumption is that a sensible beetle should only risk long-distance dispersal if local host resources have been depleted. Also, if beetles must attack in groups to be successful, the dispersal of a few beetles from minimally infested areas is unlikely to be a significant source of spread. More tangibly, we can do a better job of predicting the 1999-2004 spread if we only allow long-distance dispersal from areas where infestation severity ≥ moderate, and cumulative % pine killed ≥ 30%.

In other respects, the calculation of long-distance dispersal pressure does not differ from last year.

3.4 Short-distance dispersal

Last year, the distribution of short-distance dispersers among cells within 1 km depended on distance to the neighboring cell and cumulative kill, susceptility, age and percent pine of the neighboring cell. We found that this more complex short-distance dispersal function did not do a better job of predicting observed pattern than a simple uniform dispersal function. This year, we use a uniform short-distance dispersal function in the base case. The model retains the capacity for more complex short-distance dispersal.

4 Infestation start model

Since 2005 survey data has been added to the model since last year, a new factor has been added (elevation), some changes have been made to the dispersal calculations, and the factor classifications have changed, the precise relationships between various factors and infestation start probability are different this year. In general, the trends are as follows. Please contact the authors if you would like more detailed information:

- Start probability is low at low elevations (< 600 m), highest at intermediate elevations (>600 m), and declines as elevation increases even further. Low elevation areas are concentrated along river valleys through the Okanagan, and may be too hot, dry, and sparsely forested for beetles to thrive.
- Start probability increases with increasing percent pine.
- Start probability is highest at intermediate ages (100-140 years), but the effect of age is weak.
- Start probability increases with increasing long-distance dispersal pressure (strong relationship)
- Start probability increases with increasing short-distance dispersal pressure (weak relationship)

The problem of model over-specification is less this year because we have 2005 data to rely on, and because we have been more careful with our factor classification decisions. However, even with judicious choice of habitat classification, we are invariably left with a few undefined cases. This year, we have implemented a transition table processing step to make more deliberate and explicit assumptions about undefined cases. We have implemented two alternate scenarios. In a “worst for beetles” (WFB) scenario we assume cases in subject to higher beetle pressure (long or short-distance, given all other factors) should not remain undefined (with 0 probability of starting) given cases subject to less beetle pressure that are defined. The basic assumption is that infestations should be at least as likely to start in high beetle pressure areas as in low pressure areas. To fill in undefined cases we look for defined cases subject to lower pressure (long or short distance). If both long and short-distance options are found, we chose whichever option has the highest start probability. Otherwise, the transition table is left as it is.

In the “best for beetles” (BFB) scenario, we assume that undefined cases are “more like” high probability neighboring cases than low probability neighboring cases. First, we look for defined cases where local pressure or long-distance pressure are one class more intense, or elevation is one class lower. If several of these cases are found, we choose the neighbor with the highest start probability. If no high probability options are found, we look for defined cases in higher elevations, or in lower pressure classes as in the “worst for beetles” case.

We find that this transition table processing step makes the transition table look more convincing and complete, but actually has very little effect on model results.

5 Infestation Progression Model

The addition of 2005 data has added significantly to our understanding of infestation subsidence. In general, we find the following relationships between various model factors and infestation progress:

- The probability of an infestation continuing once started is highest at intermediate elevations (800-1400 m). Elevation has a stronger effect on infestation starting than infestation progress.
- Probability of progress increases with increasing percent pine.
- Stand age has a negligible effect on infestation progress.
- Progress probability increases with increasing percent kill until 40-60% of pine is killed. Progress probability declines as cumulative kill increases even further.
- Progress probability is highest when infestation severity is moderate.
- Progress probability increases with increasing long distance dispersal pressure (strong effect).
- Progress probability increases with increasing local dispersal pressure (weaker effect).

To make assumptions about undefined cases clear and explicit, we edit the progress transition table by the same method that we edit the start table. Again, we find that this editing step makes the transition table look more complete, but has little effect on model results.

This year, we intended to include Allan Carrol’s climate classification as a factor in BCMPB. However, we found climate to be either unformative or a counter-intuitive predictor of the progress of the outbreak. Basically, this outbreak has been worse in places where climate is not apparently ideal for beetles. So far, this effect seems to hold even when we account for beetle pressure and habitat quality (to the extent that we can account for these factors at this time). We wonder whether the striking success of beetles at their northern range in BC is an example of a more general phenomenon (i.e. Beetles respond fundamentally to weather, not climate, and the biggest outbreaks might be expected in newly suitable, climatically marginal habitat?). In light of questions about changing climate, the topic deserves further attention in our opinion. In the meantime, we have not included climate as a predictive factor in this version of BCMPB.

Appendix 2 BCMPB Shelf-Life Model version 3

The following model is based on the information in Lewis and Hartley 2005 (MPBI Working Paper 2005-14 Rate of deterioration, degrade and fall of trees killed by mountain pine beetle: A synthesis of the literature and experiential knowledge. 2005. Lewis, K.J.; Hartley, I. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Initiative Working Paper 2005-14. 21 p.) and extensive discussions with operational foresters.

The model is based on the assumption that no volume “leaves” the site. However, the percentage of the volume that can be recovered for dimensioned lumber and “chip” based products decreases over time. The rate, and to some extent the percentages, differ depending on the climatic moisture regime (i.e. wet versus dry subzones).

This model does not include and consideration of the degradation of value that results from blue stain. Blue staining occurs within the first year, it affects all trees but does not affect the volume recovery.

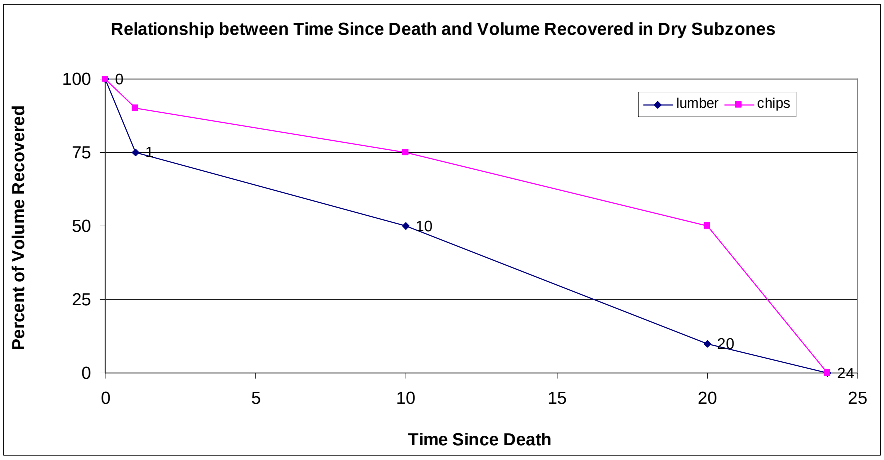
The conceptual model is as follows:

- Within a short period of time (1 to 2 years in dry and 3 years in wet subzones) a pressure check will develop in most trees that will affect the bole from the pith to the surface. These checks will be less serious, with respect to lumber recovery (i.e. straighter) in wet subzones.
- Over the next 5 years in wet subzones and 9 years in dry subzones the lumber recovery will slowly decline to about 50% of the original volume because of the degradation of the surface (checking and bark loss) and, later in the time period, tree fall.
- Finally, continued tree fall will reduce lumber recovery. Once the trees are on the ground lumber recovery will be 0 very quickly because of rot.
- The volume of chips that could be recovered will decline along with the volume of lumber but at a slower rate. The volume of chips that can be recovered will decline principally because of breakage during harvesting and increased chip fines as the wood deteriorates.

The following tables and graphs present initial estimates of the parameters for a shelf-life model based on the above concepts. Note that in the application of the BCMPB model shelf-life parameters for moist subzones will be interpolated between the 2 sets of graphs shown below.

Dry Subzones

	% of Volume Recovered	
TSD	lumber	chips
0	100	100
1	75	90
10	50	75
20	10	50
24	0	0



Wet Subzones

	% of Volume Recovered	
TSD	lumber	Chips
0	100	100
2	80	90
7	50	70
15	10	50
18	0	0