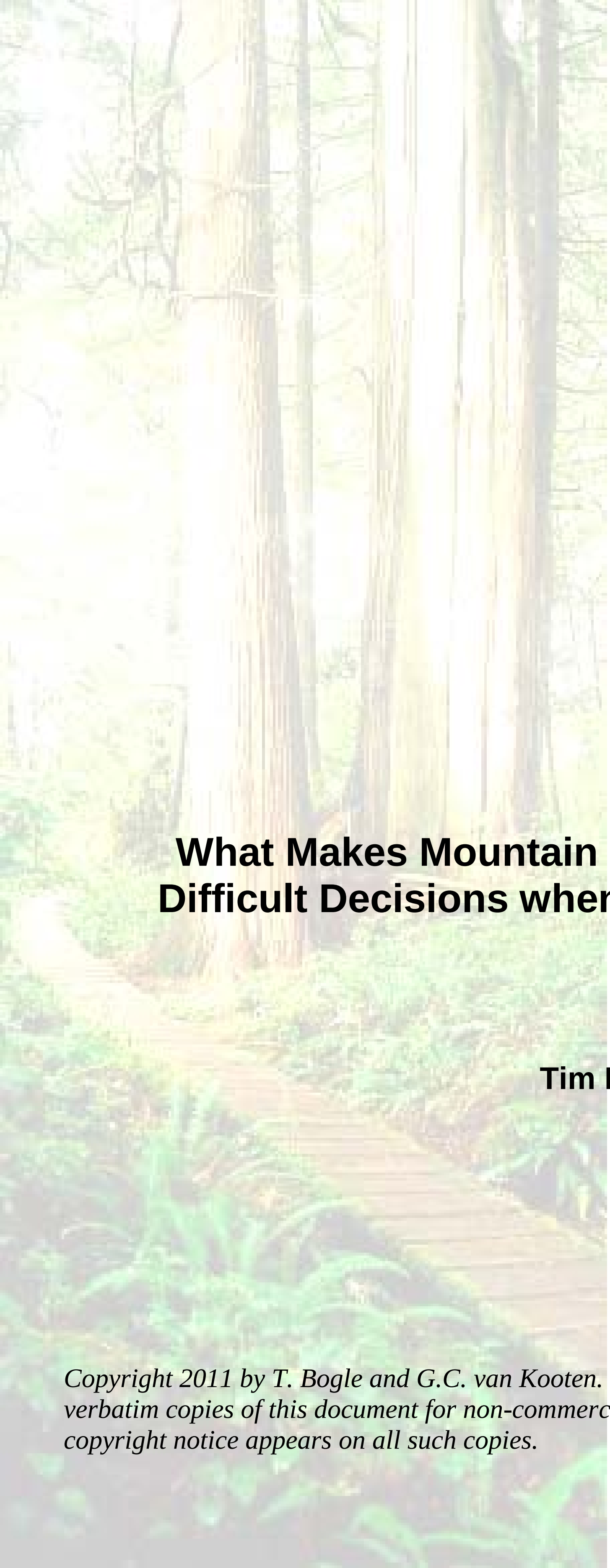

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# What Makes Mountain Pine Beetle a Tricky Pest? Difficult Decisions when Facing Beetle Attack in a Mixed Species Forest

**Tim Bogle and G. Cornelis van Kooten**

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# What Makes Mountain Pine Beetle a Tricky Pest?

## *Difficult Decisions when Facing Beetle Attack in a Mixed Species Forest*

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**Abstract:**

The pine forest of British Columbia is undergoing its largest recorded pest epidemic. The damage caused by native mountain pine beetle creates difficulties for the public owner of the resource, which is interested in protecting future timber supply while salvaging dead and dying pine. This paper addresses two problems that have often been over-looked: the variability and timing of beetle attack, and the variability of pine inventory in each stand. Management controls are limited to the annual rate of harvest and timber product outputs are based on shelf life – the length of time infested timber can still be used to produce lumber. Using mathematical programming to schedule harvest, we introduce a novel objective function based on the maximization of the net returns of the timber portfolio at the end of the 20 year time horizon under harvest and product flow constraints implemented by the public landowner to insure stability in the forest sector, and especially a stable supply of feedstock (bushchips) for bio-energy production, while recovering value from stands that would otherwise become uneconomical to harvest.

The optimal short-run response is to increase harvests over the baseline harvest without beetle. The use of future net returns as the optimization objective ensures that harvest during the 20 year time horizon occurs in stands that would otherwise be economically unharvestable and also the harvest is generally above 70% pine in aggregate. Net returns do not exceed those of the baseline harvest without beetle, regardless of the scenario, as the harvest of low value bushchips must be subsidized by the harvest of timber that can be converted into lumber. Shelflife provides significant changes in NPV as more timber can be converted to lumber if shelflife is longer.

The government has a difficult fiscal management problem. Employing an evenflow of total harvest can yield higher net gains but at the risk of relying more heavily on the harvest of damaged timber and reduced future harvests of quality timber for dimensional lumber. This strategy would produce a “feast” of short term revenue followed by a “famine” when bushchip harvest is subsidized by the harvest of better quality timber. Alternatively, managing the individual forest products could yield some minimum government revenues but this strategy could also lead to the need to deplete reserves that could be reserved for future timber supply. Regardless of the strategy, to optimize for future timber supply potential means that a large percentage (25% in this study) of the damaged pine should only be harvested in the future and will not be of a quality to produce lumber.

***Key words****:* optimal timber supply, catastrophic disturbance, shelf life of damaged trees

## Introduction

The mountain pine beetle (*Dendroctonus ponderosae Hopk.* [*Coleoptera: Scolytidae*]) is a bark beetle that attacks and kills pine trees by burrowing under the bark and laying egg galleries (SAFRANYIK AND CARROLL 2006). The burrowing beetle also inoculates the sapwood of the attacked tree with a blue-stain fungus that interrupts the nutrient flow between the roots and the crown of the tree, causing the tree to die (WARING AND PITMAN 1985). The trees begin to dry out in the first couple of years after death, resulting in checks or cracks along the tree bole, which cause the greatest initial loss in commercial value as the orientation of the checks can limit opportunities for creating dimensional lumber (ORBAY AND GOUDIE 2006). With many management units in the interior of British Columbia possessing pine volumes in excess of 50% of the timber inventory, timber supply expectations need to be altered because fiber that was assumed to be available over a long time horizon must now be harvested quite quickly. Yet, it is anticipated that damaged timber will not be harvested soon enough to be converted into lumber, the primary and most valuable product of the forest industry.

The provincial government, which owns 96% of the province's timberlands, is contemplating bio-energy as an alternative use of the damaged timber (GOVERNMENT OF BRITISH COLUMBIA, 2007). However, studies examining the use of damaged timber for bio-energy have raised issues concerning the high costs of hauling fiber located at increasing distances from bio-energy facilities (NIQUIDET ET. AL. 2008; KUMAR ET. AL. 2008; STENNES AND MCBEATH 2006). The length of time between initial attack and the time a tree is no longer usable for dimensional lumber is known as the shelf life; once the shelf life is surpassed, timber can be used only as bushchips for bio-energy. Bushchips result from on-site chipping of timber deemed unusable for lumber and are used for bio-energy purposes; other chips are residual to sawmilling but are allocated to existing secondary processing facilities such as pulp and paper mills. A rising pine beetle infestation at the stand level and the shelf life combine to diminish a stand's value. The decision maker must balance diminishing timber value against increasing marginal harvesting cost in the search for successful strategies for maintaining timber supply.

Studies such as those cited above have examined the economic consequences of mountain pine beetle (MPB) attack at the aggregate level, while neglecting the more difficult features of the MPB epidemic that occur at the stand level. In this regard, two particular issues are examined in the current study:

1. The forest is not homogeneous. Pure pine stands can be found in certain locations, but pine usually co-exists with other species. If traditional clear-cut practices are implemented in an effort to harvest all dead pine, this results in an estimated average 'by-harvest' of 1.3 cubic metres ($m^3$) for every cubic metre of pine harvested (ENG ET. AL. 2005). Minimizing the by-harvest is necessary to maintain future timber supply.

2. The beetle does not, in a given year, completely attack each stand or kill every pine tree in a stand. This is a confounding issue because, while some trees remain alive and retain a high value, others in the same stand become marginal or useless by the time harvesting occurs.

We examine the intersection of the two problems in order to understand the tradeoffs required to make good strategic decisions. To explore the tradeoffs, three questions will guide the analysis: What are the product supply implications of the beetle attack? Is the province's current policy to increase short-term harvests a reasonable approach? How does the 'shelf life' of MPB-infected timber affect outcomes?

Further, rather than use the common objectives of minimizing costs or maximizing net returns over some time horizon, we choose a novel approach, to maximize the value of the standing timber at the end of the time horizon. This is done to address the public owner's primary conundrum, namely, to salvage as much damaged forest withhout impacting the ability of the forests in the region to continue to provide employment and a stable rural economy in the future. Salvage harvesting will reduce short run timber values but the reduced supply in the future will increase the value of the remaining timber (PRESTEMON AND HOLMES 2000) so retaining as much of an economical supply of timber in the future could be the key to sustaining the local economy after the salvage period. Additional constraints related to fiber flows are implemented to ensure a smooth transition period.

## *Methods*

A canonical forest estate similar in characteristics to management units in the interior of British Columbia is simulated. We assume a forest is made up of five watersheds, each containing ten stands of equal area, age and site productivity. Forest and stand sizes are unimportant for the analysis, so we simply assume each stand is one hectare (and upscale results for a 10,000 ha forest). Each stand is randomly assigned a pine proportion ranging from 0% to 100% in such a way that it produces a forest with roughly 50% pine and 50% non-pine on average. Each stand is assigned an initial standing inventory of 200 $m^3$, representative of the study region, and a unique beetle attack pathway to mimic the rate and time of pine death in each stand. The possible beetle pathways replicate the general distribution of pine death at the forest level as an epidemic grows and then collapses. The cumulative annual forest-level attack is shown in Figure 1. Pine death occurs between years 1 and 8 and eventually sums to 100% of the pine in the stand. The model employs a 20-year time horizon.

*Figure 1: Annual volume of pine killed by mountain pine beetle*

A number of fixed parameters used in this study are provided in Table 1. Each of these parameters exerts an important influence on the economics of timber supply. We do not examine other values of the parameters or their potential variability, leaving this to future research.

Choice of an appropriate objective function is also difficult. While the government of BC has chosen to increase short-term harvest levels significantly to capture value from the damaged timber, it is also concerned about the stability of forest-dependent communities and ensuring a stable supply of timber in the future. With respect to the latter, there is concern to protect non-pine timber, which is best done by avoiding the harvest of sites with high proportions of non-pine timber. As a starting point, therefore, we choose to maximize the value of the standing timber at the end of the 20-year time horizon, while providing a minimum stable economic supply of timber harvest (the pre-beetle sustainable harvest) over the planning horizon.

One purpose of the investigation is to examine how shelf life and the government's harvest flow policy interact to create an optimal strategy. The ‘even-flow’ (non-declining) harvest policy is either applied to the total harvest or to an individual wood product – lumber or wood chips and residue for bio-energy (even flow is required as a biomass electrical generating facility requires a stable input of fiber). The harvest flow for bushchips is assumed to begin two years after the shelf life is surpassed; this ensures that an adequate bushchip supply exists for power production and avoids poor or infeasible solutions. The investment required to create a bio-energy facility also demands the certainty of supply, likely in excess of 10 years.

**Table 1: Model parameters**

| Parameter | Value | Description |
|---|---|---|
| $T$ | 20 years | Length of the planning horizon |
| $t$ | Annual | Time step |
| $p_1$ | $\$150/\text{m}^3$ | Price of lumber |
| $p_2$ | $\$75/\text{m}^3$ | Chip price obtained as a by-product of lumber manufacture |
| $p_3$ | $\$55/\text{m}^3$ | Cost adjusted price of bushchips (assumed $\$20/\text{m}^3$ cost of roadside chipping in the forest) |
| $v$ | $200\ \text{m}^3/\text{ha}$ | Volume per hectare in each stand |
| $h$ | $\$70/\text{m}^3$ | Variable logging cost as a function of volume per ha |
| $c$ | $\$10/\text{ha}$ | Fixed administration cost per harvested hectare |
| $r$ | $\$1200/\text{ha}$ | Fixed planting cost per harvested hectare |
| $\beta$ | $=1/(1+\delta)$ | Discount factor (assume discount rate of 2.5%, so $\delta = 0.025$) |
| $\varepsilon_1$ | 0.50 | Proportion of merchantable volume of pine and non pine converted to lumber |
| $\varepsilon_2$ | $0.30/\varepsilon_1$ | Proportion of merchantable volume converted to pulp chips |
| $\varepsilon_3$ | 1.00 | Proportion of MPB damaged timber beyond shelf life converted to bushchips |

The constrained optimization problem can be formulated as a linear programming model. The objective is:

$$(1)\qquad \text{Maximize TV} = \sum_{k=1}^{P}\sum_{i=1}^{W}\sum_{j=1}^{S}\left\{p_k v_{i,j,T}\varepsilon_k z_{k,i,j,T} - hv_{i,j,T} - c - r)\right\}(1-a_{i,j,T}),$$

where TV is the value of the standing timber inventory at the end of the time horizon ($T$); $P$ refers to the number of products (=3), $W$ to watersheds (=5) and $S$ to stands (=10) in each watershed; ($1–a_{i,j,T}$) is the proportion of stand $j$ in watershed $i$ remaining unharvested at time $T$; $v_{i,j,T}$ is the volume of standing timber on stand $j$ in watershed $i$ at terminal time $T$; $z_{k,i,j,T}$ represents the proportion of product $k$ from stand $j$ in watershed $i$ at terminal time $T$; and the remaining parameters are described in Table 1.

The model constraints are as follows:

| | |
|---|---|
| (2) $\sum_{t=1}^{T} a_{i,j,t} = 1,\ \forall i, j$ | Each stand can only be harvested in its entirety once |
| (3) $\sum_{i=1}^{W}\sum_{j=1}^{S} v_{i,j,t+1} a_{i,j,t+1} \geq \sum_{i=1}^{W}\sum_{j=1}^{S} v_{i,j,t} a_{i,j,t}\,,\ t = 1,...,T-1$ | Even flow of total timber volume |
| (4) $\sum_{i=1}^{W}\sum_{j=1}^{S} \varepsilon_k z_{k,i,j} a_{i,j,t+1} \geq \sum_{i=1}^{W}\sum_{j=1}^{S} \varepsilon_k z_{k,i,j} a_{i,j,t},\ t = 1,...,T\text{ -1 }\ \forall k = \{\text{lumber, bushchips}\}$ | Even flow of product volume |
| (5) $\sum_{k=1}^{P}\sum_{i=1}^{W}\sum_{j=1}^{S} \left[ p_k v_{i,j,t} \varepsilon_k z_{k,i,j,T} - h v_{i,j,t} - c - r) \right] a_{i,j,t} \geq 0,\ t = 1,...,T$ | Non-negative annual net return |
| (6) $a_{i,j,t} \geq 0,\ \forall\ i, j, t$ | Non-negativity |

Constraints (3) and (4) are modified, or lagged, in some scenarios to account for shelf life and an adequate supply of bushchips to avoid infeasility or sub-optimal harvest levels; if the shelf life is zero, the even-flow constraint for bushchips would begin in the second year. In a particular model run, only one harvest flow objective, either constraint (3) or constraint (4) is employed.

## Results

Scenarios are described by harvest control and shelf life assumptions and are summarized in

Table 2. For each scenario, we provide the discounted net financial returns, total production of lumber, chips and bushchips, area harvested, the remaining inventory by species, and the value of the end-period timber portfolio (TV). For the baseline scenario without beetle infestation, the forest landscape would produce about 283,333 m$^3$ of lumber and 170,000 m$^3$ of chips with a net present value of $35.5 million (which includes the value of the terminal timber portfolio), and result in the annual harvest of 167 hectares for a total harvest of 3,333 hectares (Table 2). Without price differentiation between species, the total harvest is composed of 48% pine. As indicated in Figure 2, the total inventory begins with 886,380 m$^3$ of pine and 813,620 m$^3$ of other species. By the end of 20 years, the growing stock is expected to decline to 535,783 m$^3$ of non-pine and 625,883 m$^3$ of pine. The terminal timber portfolio value is $34.6 million. In the baseline scenario, there are no bushchips as only lumber and the additional chip by-product are produced.

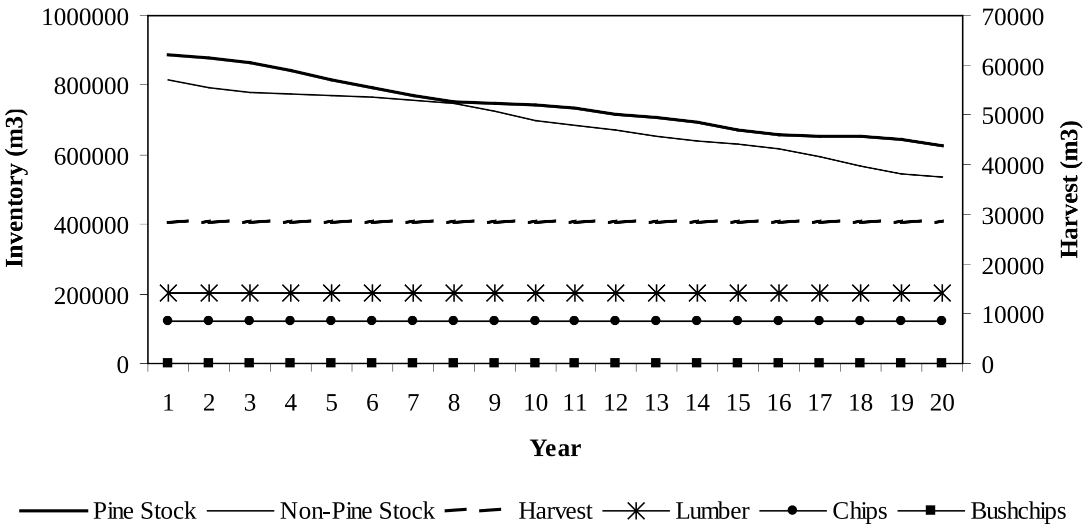

*Figure 2: Scenario 1, Baseline harvest without beetle infestation*

Given the need to sustain harvests, the minimum annual harvest in most scenarios is set to the baseline harvest of 28,333 m$^3$ of timber to ensure the model adequately reduces boom and bust outcomes. To ensure the timber harvest is also economically viable, net annual returns are constrained to be greater than or equal to zero. As a reference, the maximum terminal condition was found for three scenarios, each with a different shelf life (Scenarios 2 through 4). The model had no minimum harvest, but harvests were constrained to be even over each of the four pentads in the 20-year planning horizon. The TV for each of these scenarios is $13.47 million and yields identical ending states for pine (225,420 $m^3$) and non-pine (625,580 $m^3$) inventories. Thus, with little harvest restriction, the best solution relegates one quarter of the pine inventory to bushchips to minimize the by-harvest and maintain future timber supply; 50% of the forest is harvested over one five-year period to achieve this. The resulting TV is only 40% of the no-beetle baseline. Clearly, the distribution of pine in the forest and the use of clear-cutting creates a lasting implication for future timber supply.

While scenarios 2 through 4 provide an indication of the best possible terminal condition, the stated objective for this forest was a continued economic supply of timber. Scenarios 5 through 7 examine the even flow of total timber harvest for three shelf life conditions and are graphed in Figure 3. The dashed lines represent total harvest and the solid lines represent bushchip harvest.

As shelf life increases, there is a steady decline in total harvest and bushchip harvest, as well as a delay in when bushchips become available. If shelf life is longer, maintaining a lower harvest is desirable as less area will be harvested, resulting in higher non-pine inventory and a higher TV. Despite a higher harvest level when shelf life is short (i.e., zero years), net present value is quite low with net returns in most years equal to zero as a result of reduced lumber production. As shelf life increases, more lumber is created than the baseline scenario without beetle.

**Table 2: Scenario description and results**

| Scenario | Net present value ($ ×10$^6$) | Pine as a proportion of the harvest | Total lumber (‘000 m³) | Pulp chips (‘000 m³) | Bushchips (‘000 m³) | Total harvest area (ha) | Pine inventory (‘000 m³) | Non-pine inventory (‘000 m³) | Portfolio value in year 20 ($ ×10$^6$) | Sum of annual net returns ($ ×10$^6$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1) Baseline scenario (no mountain pine beetle) | 35.5 | 0.48 | 283.3 | 170.0 | 0 | 3333 | 625.9 | 535.8 | 34.6 | 11.6 |
| 2) Maximum harvest, no minimum & shelf life = 0 yrs | 22.4 | 0.78 | 320.1 | 192.1 | 246.8 | 5000 | 225.4 | 624.6 | 13.47 | 10.4 |
| 3) Maximum harvest, no minimum & shelf life = 5yrs | 33.1 | 0.78 | 425.0 | 255.0 | 0.01 | 5000 | 225.4 | 624.6 | 13.47 | 17.3 |
| 4) Maximum harvest, no minimum & shelf life = 10 yrs | 18.5 | 0.78 | 308.8 | 185.3 | 273.5 | 5000 | 225.4 | 624.6 | 13.47 | 9.7 |
| 5) Even flow of total harvest, shelf life = 0 yrs | 8.5 | 0.72 | 232.4 | 139.5 | 681.8 | 6143 | 165.1 | 542.7 | 12.69 | 2.3 |
| 6) Even flow of total harvest, shelf life = 5 yrs | 16.8 | 0.76 | 281.3 | 168.8 | 402.8 | 5324 | 224.6 | 615.6 | 13.4 | 7.2 |
| 7) Even flow of total harvest, shelf life = 10 yrs | 22.6 | 0.78 | 336.5 | 201.9 | 208.3 | 5000 | 252.1 | 640.4 | 13.47 | 11.5 |
| 8) Even flow of product harvest, shelf life = 0 yrs | 7.1 | 0.68 | 262.6 | 157.6 | 768.5 | 6932 | 120.7 | 462.3 | 11.17 | 2.6 |
| 9) Even flow of product harvest, shelf life = 5 yrs | 12.6 | 0.72 | 283.3 | 170.0 | 587.2 | 6269 | 161.5 | 538.8 | 12.52 | 5.4 |
| 10) Even flow of product harvest, shelf life = 10 yrs | 17.4 | 0.75 | 304.6 | 182.8 | 400.3 | 5585 | 214.7 | 606.4 | 13.28 | 8.2 |

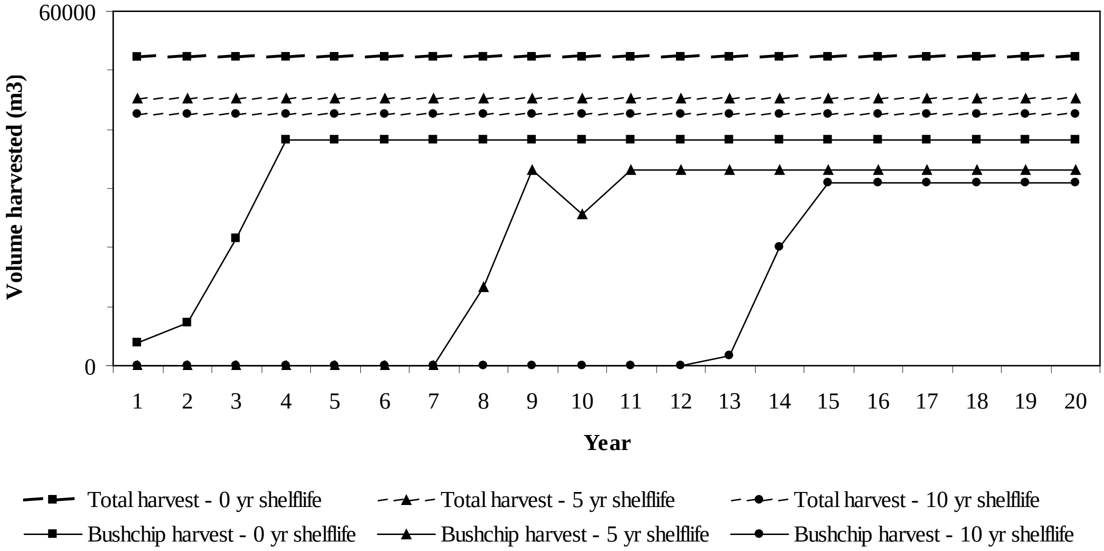

*Figure 3: Even flow of total and bushchip harvest with different shelf life values for damaged timber (Scenarios 5 – 7)*

Now consider what happens if government focuses on the flow of outputs, particularly ensuring that enough bushchips will be available to provide feedstock for a bio-energy facility, while also sustaining an even flow of lumber. Figure 4 summarizes some of the results for Scenarios 8-10, the even flow of lumber and bushchips with different shelf life values. In this case, as shelf life increases, the model increases the supply of lumber and bushchips simultaneously. The strategy of managing product recovery does have negative implications as can be seen by comparing Scenarios 5-7 with 8-10 in Table 2. For identical shelf lives, management for even flow of output yields lower NPV, lower TV and requires more area to be harvested than management for even flow of total harvest. Due to the even flow constraints, harvest levels do not increase significantly over the reference harvest level until bushchip harvests begin.

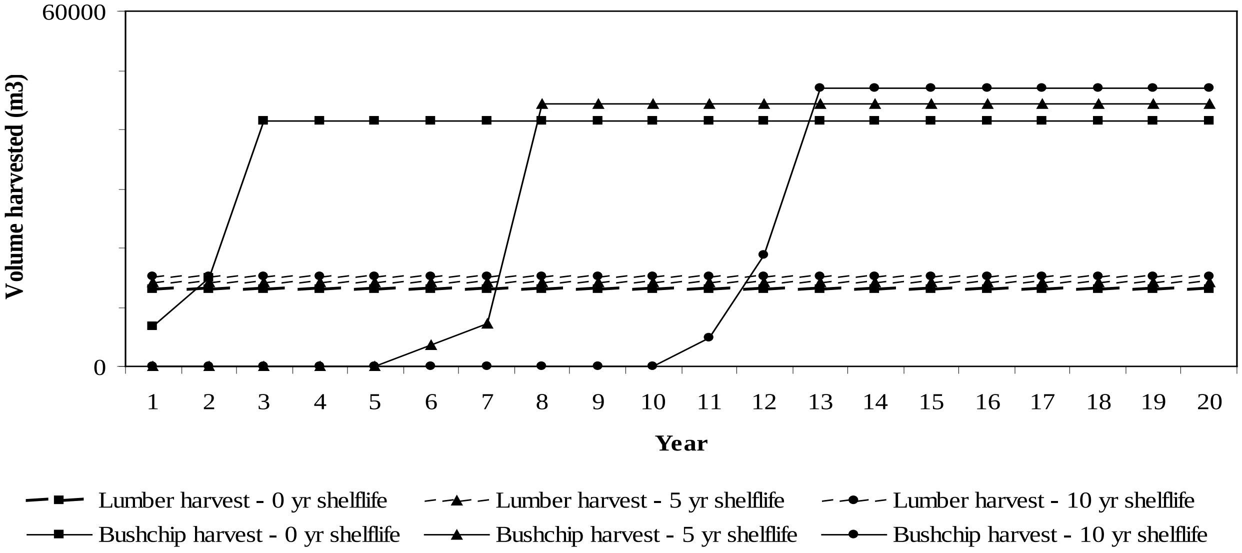

*Figure 4: Even flow of lumber and bushchips with different shelf life values for damaged timber (Scenarios 8 – 10)*

Based on a number of criteria, sustaining total harvest over 20 years yields a more attractive outcome than attempting to sustain product harvests. However, government revenues are generally projected annually and fiscal planning has traditionally been predicated on a continued annual revenue stream to offset the provision of public services. Figure 5 shows the annual net returns by harvest flow strategy for each shelf life value. The even flow of total harvest produces a windfall of short-term revenue, as net returns are extremely high while elevated harvests are focussed on converting pine trees into lumber. As the lumber component declines and the bushchip component increases, net returns go to zero. Conversely, by fixing the amount of output produced over the time horizon, a minimum net return can be achieved regardless of the shelf life. It can be seen that under the economic conditions modelled, the lumber value is subsidizing the harvest of bushchips as all of the stands with significant pine components would possess a negative terminal value if left unharvested.

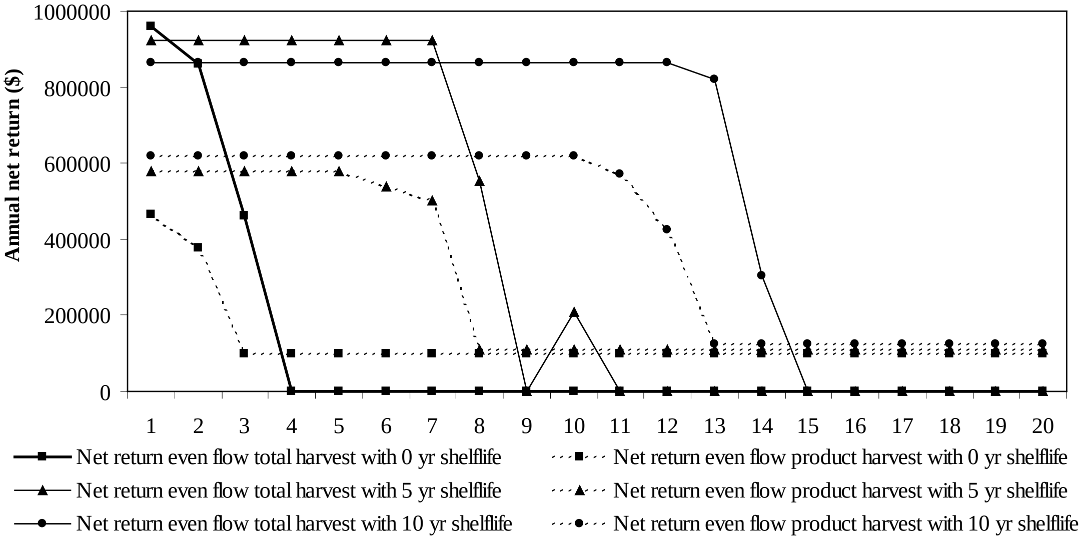

*Figure 5: Annual net returns by evenflow type for different shelflife values.*

## Discussion and Conclusions

The traditional economic objective of maximizing NPV is not conducive to maintaining future timber supply. Therefore, in this study, we maximized the terminal value of standing timber at the end of the time horizon which is consistent with the government desire to protect future timber supply. To focus the policy concerns, three questions were asked: What are the product supply implications of the beetle attack? Is the province’s current policy to increase short term harvests a reasonable approach? How does the ‘shelf life’ of MPB-infected timber affect outcomes?

In response to the first question, the analysis has shown that forcing product objectives may not produce the most economically efficient solution. Indeed, by not considering an adequate product threshold, the forest resources needed to sustain future timber supply will be needlessly depleted. This has implications for bio-energy: subsidizing biomass electricity generation may not be a good policy. The analysis also showed that at least a quarter of the pine resource could be harvested after twenty years, when non-pine trees would be harvested.

Thus, if traditional clear cutting is practiced, this limits harvests of damaged pine in the short run.

In the scenarios examined here, harvests were consistently elevated above the no beetle reference case. This is consistent with BC government policy to increase harvest of beetle-damaged timber. However, depending on the shelf life of damaged trees and the harvest flow policy, the timing of the harvest uplift could vary from immediate to almost a decade into the future. This results in a key communication challenge in determining when to implement such an uplift. An immediate increase in harvests communicates the sense that beetle-damaged pine has a short shelf life and little economic value once it is attacked, and this might ensure production of a much lower level of lumber in the future.

The variability of the pine resource and the shelf-life of standing timber for lumber production define the economic access to the timber resource. We find throughout the analysis that lumber production subsidizes harvesting of bushchips for bio-energy. This subsidy is over and above any explicit subsidies to encourage bio-energy, particularly biomass burning for electricity production. If insufficient lumber is recoverable from the pine or non-pine species in a stand, the stand will be left in the timber portfolio as it has little economic value. Because the time horizon is short, we do not consider the growth of non-pine once the pine has been denuded by the mountain pine beetle. However, the non-pine could become valuable enough some time after the end of our time horizon to justify not harvesting beetle-damaged timber, but leaving it to decay and allow non-pine species to flourish (NIGH ET. AL. 2008).

There remains uncertainty about the shelf life of standing MPB-affected timber. It is likely that shelf life is affected by the biogeoclimatic zone in which the pine is found. We developed the model with five zones to explore the implications of variable transportation costs and shelf life as a function of location in future research. This could affect the conclusions significantly and thus policy related to the pine beetle. For example, it raises issues related to government tenure arrangements: the feedstock available for bio-energy will decline as shelf life increases if contracts to supply products recognize the principle of maintaining the highest and best use for as long as possible. If this requirement is removed, society could lose valuable forest rents to which it is entitled.

Clearly, we have greatly simplified reality. Perfect knowledge about when pine trees are affected by mountain pine beetle and the extent to which stands are infested are clear benefits, as is perfect knowledge about shelf life. In terms of policy, the BC government is faced with only a few key options: (i) ensure more or less continuous revenues by mandating the harvest of specific products from the forest; (ii) use the more flexible approach of simply managing total harvest, while letting companies decide what outputs to produce; or (iii) do nothing to speedup harvests of damaged pine and simply accommodate the damages through reduced harvest levels when the economic supply declines. The second approach may provide significantly larger short-term gains in government revenue during the years of ‘feast’ when damaged pine can still be used for lumber, but will require prudent fiscal management to distribute those gains into the future when expected net returns could decline substantially if harvests continue in the province’s interior pine-dominated zone. The government must also pay attention to the delicate economic balance between lumber and bushchips as companies are engaged in harvesting. Under current economic parameters, it is lumber recovered from damaged pine and non-pine species that enables the harvest of large amounts of bushchips. If the net returns from lumber turn out to be inadequate at some future time then harvest levels must be reduced, making biomass electricity, for example, too costly to generate and requiring electricity from other sources as a replacement.

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