

## Predicting Light Interception in Decaying MPB Stands

Dave Huggard, Sept. 2008 (for Doug Lewis, Min. Environment, Kamloops)

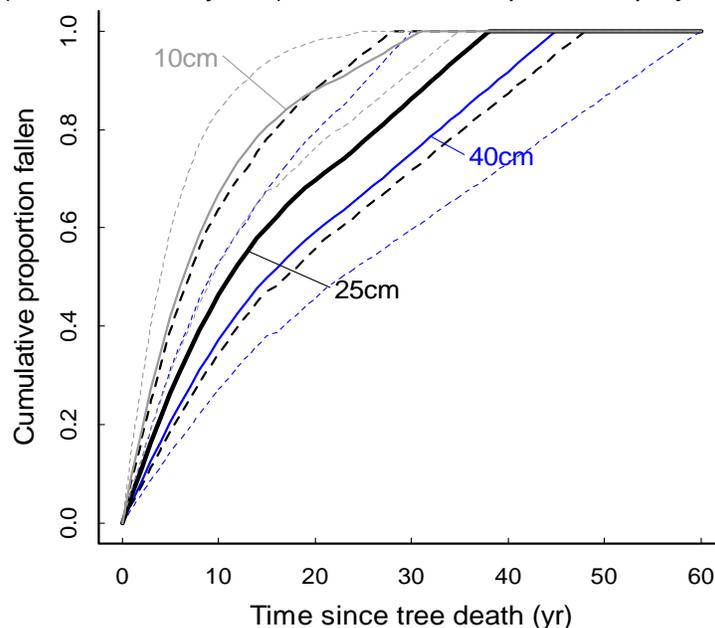
### *Purpose*

To predict interception of light by lodgepole pine trees killed by mountain pine beetles (MPB), as these dead trees decay and fall. The analysis combines information on fall and breakage of snags (from many sources), and loss of shading by branches and dead foliage (mainly from work by Coates and Hall 2005<sup>1</sup>), along with estimates of the uncertainty of these parameters.

### *Approach*

The analysis examines the dead pine component of the stands. Issues with incorporating live overstory trees and understory are discussed at the end.

Fall rates of dead lodgepole pine: Published fall rates of dead lodgepole pine as a function of time since tree death were synthesized in a previous analysis<sup>2</sup>. These results, and their confidence intervals, are used here<sup>3</sup>. Empirical data on lodgepole snag fall extended only 24 years after tree death, when 36% of 40-cm dbh snags were still predicted to be standing. I assumed that these remaining snags would fall by 45 years after tree death (95% CI: 30-60 years), based on a simple linear projection of the upper



**Figure 1. Cumulative fall of lodgepole pine snags of 10cm, 25cm and 40cm dbh versus time since tree death, based on synthesis of published empirical studies. Dotted lines are 95% confidence intervals for each curve.**

<sup>1</sup> Coates, K.D. and E.C. Hall. 2005. Implications of alternate silvicultural strategies in mountain pine beetle damaged stands. Tech. rep. For. Sci. Program Project Y051161.

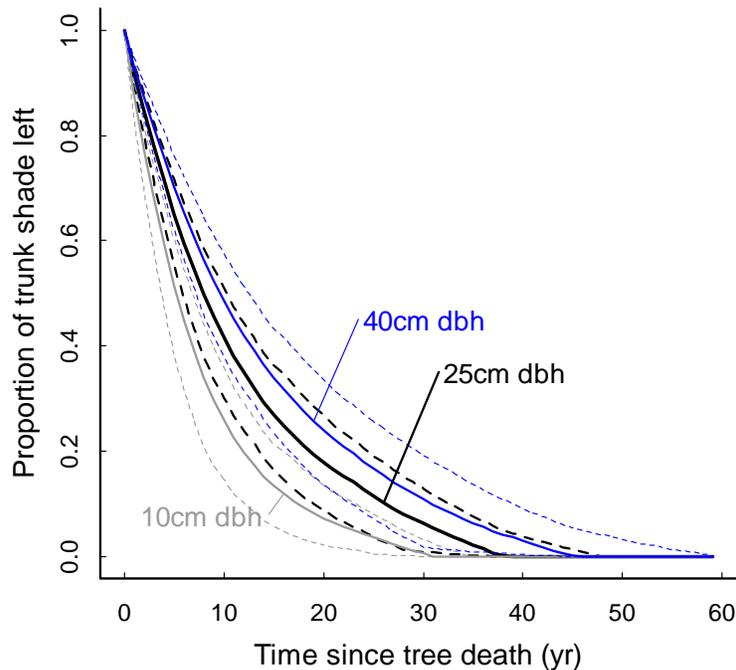
<sup>2</sup> Huggard, D.J. and L.L. Kremsater. 2007. Quantitative synthesis of rates for projecting deadwood in BC forests: Technical report. Unpub. report to BC Forest Sciences Project.

<sup>3</sup> An earlier analysis of hydrological ECA effects of MPB attack combined results for lodgepole and other pines, but the more recent deadwood synthesis suggested that lodgepole has a lower fall rate than ponderosa and other southern pines. The lodgepole-only results used here have moderately slower snag fall, mainly for older snags.

end of the empirical relationship. The deadwood synthesis also showed that snag fall rate decreases as  $dbh^{0.6}$ . This relationship was used to generate snag fall curves and their confidence intervals for 10cm, 25cm and 40cm dbh snags (Figure 1).

Snag breakage

The synthesis of deadwood studies showed a range of reported rates for snag breakage, with no consistent patterns by species, snag size, or mortality source. The current analysis assumed that 5% of snags break each year (95% CI: 3-10%/yr), based on the average of the published studies. The break height was assumed to be randomly located from 0m to the height of the snag (or the remaining height if it had been previously broken). With this assumption, the average height after 1 break is 0.5 the total height, 0.25 after 2 breaks, 0.125 after 3, etc. However, the distribution of break height, which starts out uniform after 1 break, becomes increasingly skewed with multiple breaks. Additionally, with the (assumed) triangular shape of an unbroken snag, the proportion of shading that is removed at each break is not equal to the loss of snag height – the thicker bottom of the snag clearly contributes more shade area than the tapering top that breaks off. With the skewed distribution of break heights, converting average height remaining after  $n$  breaks to average shade remaining is not a simple geometric calculation. Instead, numerical modeling was used: 0.6667 of the shade from the trunk remains after 1 break, 0.3877 after 2 breaks, and 0.2124, 0.1118, 0.0577, 0.0293, 0.0148 and 0.0075 after 3 to 8 breaks, respectively<sup>4</sup>. The distribution of the number of breaks per snag after 1-60 years was calculated based on a binomial distribution (allowing a maximum of 1 break per year). The distribution of number of breaks for each year since tree death was then multiplied by the proportion of shade



**Figure 2. Proportion of shading from the trunk only remaining over time for individual snags of 10, 25 and 40cm dbh. This combines the effects of snag fall and breakage, along with the triangular profile shape of the trunk. Dotted lines are 95% confidence intervals.**

<sup>4</sup> The shading area of the trunk remaining after 8 breaks is clearly negligible, and the chances of a snag breaking this many times before falling is equally negligible.

from the trunk for each number of breaks to calculate the average proportion of shade remaining for non-fallen snags at each year since tree death. This was done for the median and 95% CI values of the snag breakage rate.

#### Combining snag fall and breakage

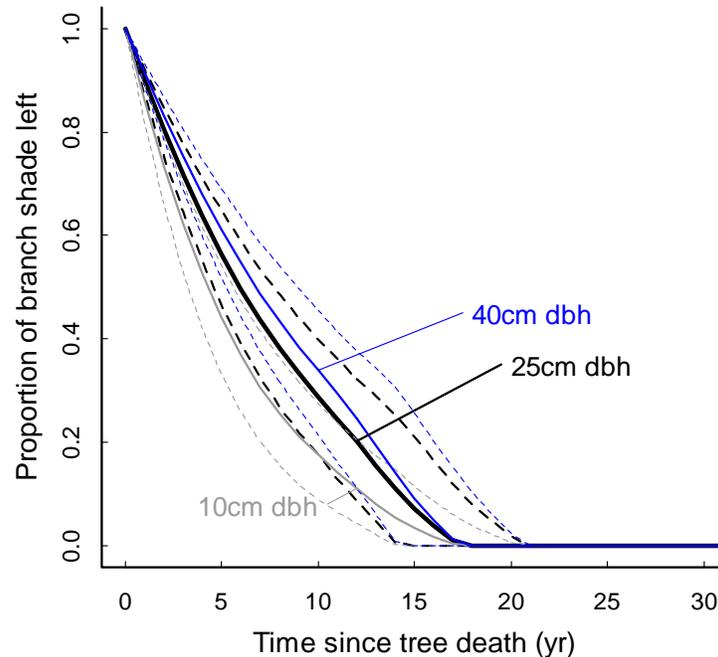
The remaining proportion of shade from the snags' trunks over time was calculated by multiplying the proportion of snags still standing by the proportion of shading area left on standing snags. Monte Carlo simulation was used to estimate the confidence intervals on this product, given the confidence intervals on each component.

#### Loss of foliage and branches

Light interception and age of 3 classes of pine snags from Coates and Hall (2005) were used to directly estimate the reduction in shade from foliage and branches over time. Class 1 snags were aged 0-7 years and had 37.6% light transmission; class 2 snags were 8-17 years with 61.4% transmission; class 3 was >17 years, with 87.8% transmission. The class 1 and 2 results were assumed to represent the mid-range ages of the class: 3.5 years and 12.5 years, respectively. Based on these numbers, transmission at year 0 (tree death) was projected back to 28.3%. The class 3 results were assumed to represent just the shading from the trunk, after any substantial branch shading had been lost, at 18 years. Proportional light interception by foliage and branches scaled from 1, maximum interception, at year 0 when light transmission was 28.3%, to 0 at year 18 when the interception transmission was 87.8%. The change in interception was assumed to be linear between 0 and 12.5 years, and between 12.5 and 18 years.

Approximate confidence intervals on Coates and Hall's (2005) results were used:  $\pm 10\%$  for light transmission for each snag class (e.g.  $\pm 3.76$  for the 37.6% transmission in class 1), and  $\pm 20\%$  for the mid-range age of each class (e.g.  $\pm 0.70$  years for the mid-range age of 3.5 years for class 1). Monte Carlo simulation was used to show how this uncertainty in the input parameters generated uncertainty in the trajectory of foliage and branch shading over time. The error in the ages of each snag class were assumed to be correlated, so that if the mid-range age of class 1 was at the lower end of the confidence intervals in a Monte Carlo run, the mid-range age of class 2 and the age of transition to class 3 were also assumed to be at the lower ends for that run.

The shading due to foliage and branches at any time was reduced by the proportion of snags that had fallen by that time. For example, if 50% of maximum branch shading was left at year 8 and 30% of snags had fallen by then, then total branch shading was 35% of its maximum (= 50% minus 30% of 50%). The rate of proportional loss of foliage and branches was assumed to be the same for all sizes of snags, but higher rates of snag fall for small snags leads to somewhat more rapid total loss of branches and foliage for small snags.

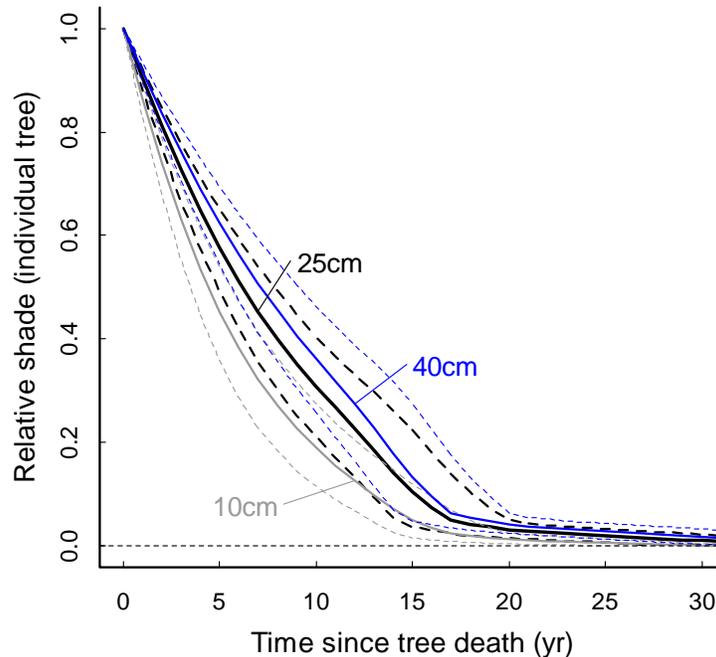


**Figure 3. Proportion of shading *from the foliage and branches only* remaining over time for an individual snags of 10, 25 and 40cm dbh. The curves for different sizes of snags only differ because they include the effects of snag fall on reducing the amount of foliage and branch shade. Dotted lines are 95% confidence intervals.**

#### Combining shading from foliage and branches, and from trunks

Coates and Hall's (2005) results for shading from class 3 snags (trunk only) compared to snags at year 0 suggest that the trunk is responsible for 17% of the light interception of intact recent snags. This is based on the fact that class 3 snags have a light interception of 12.2%, compared to 71.7% for snags projected back to year 0 ( $12.2/71.7 = 17\%$ ). Foliage and branches are responsible for the other 83%. These numbers were used to combine the separate trajectories for shading due to foliage+branch and trunk components. Different weightings for the 2 components could be used for stands with different tree structures. Dense uniform stands with high crowns, for example, may have a lesser relative contribution from foliage and branches.

The resulting curve for shading by an individual snag is shown in Figure 4. The main decline to about year 17 is due to loss of branches and foliage (including branches and foliage lost as snags fall), which provide 83% of the initial shading. The long, low tail after year 17 is due to the remaining shade from the trunks that have not fallen and broken by that time. Smaller snags fall faster and so lose shading more quickly.



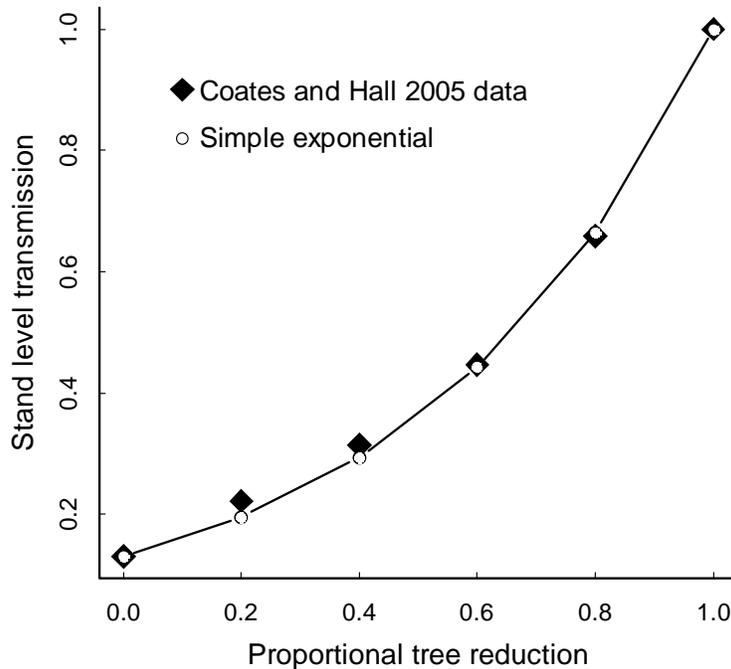
**Figure 4. Proportion of shade remaining over time for individual snags of 10, 25 and 40cm dbh, combining foliage+branch shade (83% of initial shading) and trunk shade (17% of initial). Dotted lines are 95% confidence intervals.**

#### Conversion from shading by individual stems to shading in stands

The above calculations estimate how shading by individual snags changes over time. In a stand, however, shade from different trees overlaps. Increased transmission by each tree does not necessarily have a 1:1 effect on transmission through the stand, particularly in a dense (e.g., newly dead) stand – some of the extra light passing through one decaying snag will be absorbed by another snag. As a simple example, if there were two discrete layers of snags, and each one independently changed from blocking all light to blocking only half the light, the total light transmission would only go up to 25%, not 50%.

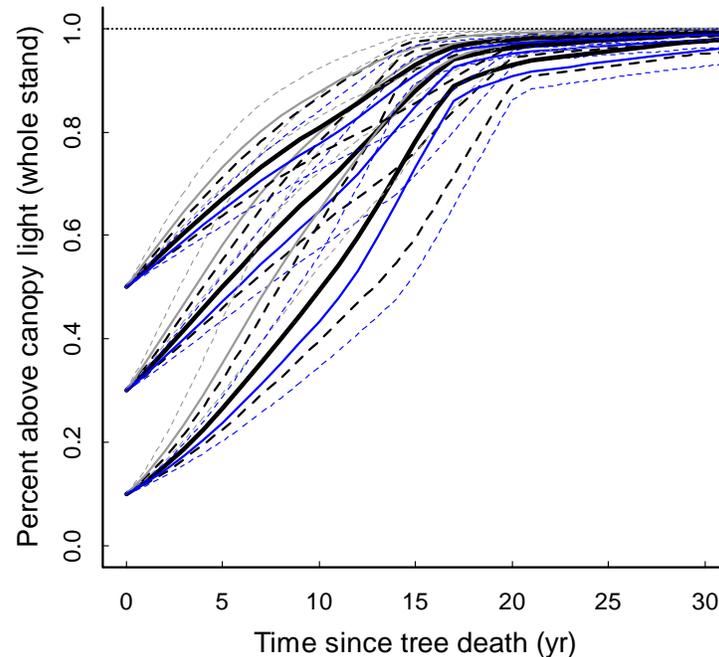
Rather than doing detailed modeling of stand structure, I simply assumed that the increased light transmission over time in a stand happened at a uniform, fine scale. In this case, the cumulative transmission in the stand is given by  $T_0^{1-T_i}$ , where  $T_0$  is transmission in the green stand and  $T_i$  is the relative transmission of the individual snag (on a relative scale, from 1 at year 0 to 0 when the snag is fallen or completely decayed). For example, if light transmission in the green stand ( $T_0$ ) was 0.3 (30%), and interception by individual snags ( $T_i$ ) at year 10 was 50% of their maximum, the stand-level transmission would be 0.547 (54.7%, =  $0.3^{1-0.5}$ ).

Although the assumption of fine-scale, uniform light interception is simplistic, the results of using the resulting formula for stand-level interception closely match the results of Coates and Hall's (2005) detailed simulations of light interception by partial green stands after the loss of dead pine (Figure 4). This supports using the simple formula to calculate stand-level interception from individual-snag interception, when pine mortality and decay is fairly uniform.



**Figure 5. Comparison of a simple exponential model of overlap of shading from individual trees in a stand with the results of detailed simulations of stands with different proportions of green trees after MPB losses from Coates and Hall (2005). The close concordance of the results supports using the simple approximating formula for stand-level roll-ups of shading by individual snags.**

The exponential formula was used to estimate stand-level light changes over time in dense, moderate and more open stands – 10%, 30% and 50% light transmission in the green stand (Figure 6). For stands averaging 25cm dbh, light transmission increases approximately linearly from the green-stand conditions to >~90% at year 17 ( $\pm 5$  years). This reflects the dominance of foliage and branch loss in determining shading levels. Stands with 10cm dbh trees become brighter more quickly, due to the higher fall rates of these small snags. Stands with large diameter snags (40cm dbh) are not very different from stands averaging 25cm dbh, because branch loss from standing snags is the dominant process in the initial years in these large stands. The long tail of residual shading after ~17 years, due to remaining trunks, would probably have little effect on regeneration.



**Figure 6. Stand-level light transmission starting from stands with transmission of 10% (dense), 30% (moderate) and 50% (open), for stands averaging 25cm dbh (thick black lines), 10cm (thin grey lines) and 40cm (thin blue lines). Dotted lines are 95% confidence intervals.**

#### Considerations for live tree components

The above results are for stands composed entirely of lodgepole pine that is killed by MPB. For stands with a live non-pine component of the overstory, the shading from those trees could be assumed to remain constant. The curves in Figure 6 could simply be scaled down so that they asymptoted  $x\%$  lower, where  $x$  is the percentage of non-pine overstory. This ignores any overlapping of shade from the non-pine live trees and the decaying pine. Alternatively, the curves in Figure 4 could be shifted up by the non-pine percentage, then the exponential transformation used to generate stand-level curves, as in Figure 6. This more complicated approach would assume that the live non-pine trees are finely interspersed with the decaying pine.

Two additional issues with incorporating the effects of live non-pine overstory are: i) Different species likely have different amounts of light interception. For example, a 30% live Douglas-fir component in a MPB pine stand might actually be responsible for 50% of light interception (if the fir are bigger than the pines, or bigger- and deeper-crowned). ii) The non-pine overstory would likely respond to increased light levels as the pine die and decay. The non-pine overstory would therefore have increasing light interception over time, which would require more detailed stand modeling.

Seedlings will also be affected by shade from understory trees. Again, predicting these effects in any detail will require stand modeling, to account for the initial light interception by the understory trees, and how this increases as they release and grow. For young seedlings, shrubs and herbs will also cause shade. It may be most sensible to assume that these issues will be dealt with operationally, by site preparation and/or choice of planting sites, rather than trying to explicitly model shade from competing vegetation.

Caveats

This simple approach to predicting shading over time in MPB-affected stands is intended as an approximation to allow general projections of values such as hydrological Equivalent Clearcut Area in different stand types under different MPB management scenarios. More complex, explicit stand modeling is providing better information for silvicultural decisions, such as which stands to underplant and when. None of the modeling can substitute for direct experimental comparisons of light levels and seedling responses under MPB-affected canopies.

The predicted shading trajectories are stand averages. In reality, patchiness would produce variability in light (including in the green stand), which probably matters for seedling survival and growth. Selective planting in more open conditions would be a simple operational way to mitigate some of the concern about shading.

The confidence intervals used are fairly weak guesses, and only represent uncertainty in the average parameters, not the extent of true variability from stand to stand. Because light interception by foliage and branches is so dominant in the shading trajectories, this would be the most important component for collecting additional data. That should include variability in both the transmission of each snag class, and the ages of the snags in the classes.