Forests for Tomorrow Adaptive Management Initiative

Synthesis of Information on Selected Topics & Clarification of Key Uncertainties

EXCERPT:
Overstory Release in Response to Light

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Overstory Release in Response to Light

The Forests for Tomorrow (FFT) program was established by the BC Government in 2005 in response to the devastating impact of major fires and the mountain pine beetle (MPB) epidemic on the forest land base of the Province. The program is aimed at improving the future timber supply and protecting other forest values through the re-establishment of young forests on lands that would otherwise remain underproductive.

The mountain pine beetle epidemic had affected over 10 million hectares of forest land by 2008 and is expected to expand further. This loss in forest cover is unprecedented in both scale and complexity. Many forest types have been affected across a range of ecological conditions from the dry Chilcotin to moist sub-boreal and high elevation zones. These twin factors of scale and complexity have, in turn, created numerous uncertainties for forest managers. Adaptive management strategies have been proposed as one approach for dealing with these uncertainties.

An adaptive management workshop held on June 26, 2008 under the FFT program for key staff engaged in restoring forest cover to the mountain pine beetle area raised a range of uncertainties or questions from participants. This is one of the topics for which our team was asked to review and summarize information in the existing literature.

Executive Summary

When stands are attacked by mountain pine beetle, some overstory trees survive. Many of these surviving trees will ‘release’ to expand in crown size, diameter and height. This release may shade seedlings, but may also increase stand volumes and provide crop trees earlier than expected.

Overstory trees release in response to decreased competition for light, water, nutrients and space from neighbouring trees. Increased light to existing foliage allows rapid build-up of new foliage, and increased root space increases moisture and nutrient availability.

The degree of release depends on the attributes of the particular species, the length of time trees have been ‘suppressed’, and local site conditions. Usually the increase in diameter is more than the response of height. Some trees do not response to release. Either they are already in a dominant position, or have a poor root system and low live crown ratio that make it impossible to respond. Sometimes thinning shock (increased light to trees accustomed to shade) will retard release, prevent it altogether, or kill the tree. Generally tolerant species have quicker, more striking responses than intolerant species.

Thinning of trees can improve growing conditions for remaining trees. In effect, the volume of the stand is redistributed to the remaining trees. However, this is not always the case on all sites or species, and thinned volumes are often never recovered.

In stands killed by mountain pine beetle the overstory trees that remain alive may be pine, but could more likely by Douglas-fir or Engelmann spruce. Subalpine fir is more likely an understory species.

For lodgepole pine, Brockley (2007) reported that effects of post-thinning density on tree diameter at breast height (DBH) were strongly linear at both their study sites, with the largest increases in diameter being measured at the lowest stand density. An extreme case is noted by Mason (1915 in Daniel et al. 1979) where a lodgepole pine tree increased from 134 rings per inch to 8 rings per inch over a 4 year period after release. The Canadian Forest Service (2001) examined overstory growth after commercial thinning of lodgepole pine (done in an attempt to beetle proof stand). In the first 5 years after harvest, radial growth rate increased in spaced stands by about 40%, but declined in unspaced stands (by about 18%). In Sullivan et al.’s (2006) overall analysis of tree growth across the three regional replicates, lodgepole pine grew significantly faster in mean diameter in the low-density than in either of the medium- or high-

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density stands. The Forest Practices Board studied stands attacked by mountain pine beetle during 1979 in Sub-Boreal Pine Spruce biogeoclimatic units. Survival rates of mature pine ranged from 10 to 50% for the areas sampled. Most overstory trees that survived the infestation grew in diameter significantly faster after the epidemic than before it. The range of response varied from 1.0 to 3.0 times the radial growth during the last 25 years when compared to the previous 25 years. The average increase was approximately 44% greater than the pre-infestation growth rate. Height response to thinning is much less than diameter response, supporting the contention that a limited degree of crowding is required to maximize the height growth of lodgepole pine. Responses of Douglas-fir and Engelmann spruce to increased light are likely more dramatic than for lodgepole pine because the more shade tolerant species often respond better to release (see the section on "Response of BC Conifers to Light Regimes Created by Overstory Removal", beginning on p.32).

Summary: A qualitative assessment of the few studies we found suggests that lodgepole pine and interior Douglas-fir may increase in crown size by 30 to 40% over 5 years in post beetle attacked stands. Similar increases in stem diameter will occur, increases in height are likely not significant. We expect shading may be increased as much as 10% to 20% near live trees over 5 years as a result of those expanding crowns. At the same time, light levels are increasing due to dying twigs and branches, so the net light levels are not simple to estimate. The proportion of live trees in the stands will determine the net changes in light levels. Empirical studies to assess changes in light and crown closure over time for various combinations of proportion of live and dead stems in a stand would be informative.

The Issue

When stands are attacked by mountain pine beetle, usually some overstory trees survive. It is likely that these surviving trees will 'release' to expand in crown size, diameter and height. This release may shade seedlings, but may also increase stand volumes and provide crop trees earlier than expected. The amount and timing of the 'release' are of interest.

Basic Biology

Basic silvicultural understanding suggests that overstory trees will release in response to decreased competition for light, water, nutrients and space from neighbouring trees. Increased light to existing foliage allows rapid build-up of new foliage, and increased root space increases moisture and nutrient availability, fostering enhanced growth. The degree of release depends on the attributes of the particular species, the length of time trees have been 'suppressed', and local site conditions. Usually the increase in diameter is more than the response of height. An extreme case is noted by Mason (1915, cited in Daniel et al. 1979) where a lodgepole pine tree increased from 134 rings per inch to 8 rings per inch over a 4 year period after release (tree age unknown). Some trees do not readily respond to release. Either they are already in a dominant position, or they have a poor root system and low live crown ratio that make it difficult to respond in a timely manner. "Thinning shock" may occur when increased thermal and solar loading and high evaporative demand on needles accustomed to shade reduces needle function and net photosynthesis. Sometimes "thinning shock" will retard release, prevent it altogether, or kill the tree.

It is well known that thinning of trees can improve growing conditions for remaining trees and can result in stands of the same or even greater volume than the pre-thinned stand if it were left unthinned (e.g., Daniel et al.1979). Moderate thinning is often found to be more effective than heavy thinning, but even very heavy thinning can result in the same or better stand volumes than expected from unthinned stands if given enough time. The increase in volume (or even

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recovery of stand volume) does not always occur, depending on species and site conditions. Coates (2008) observed that in some plots in the Flathead, the volume was greater (approximately 20 years after the attack) than at the time of the mountain pine beetle infestation despite losses of lodgepole pine. In effect, increased diameter growth rates after the attack compensated, at least in part, for the volume lost to the attack, but did not bring the stand up to the volume it would have had without the beetle attack.

Species differ in their response to release. Generally shade-tolerant species have quicker and more striking responses than intolerant species. Capacity for release generally decreases with tree age (but ponderosa pine and Douglas-fir have shown accelerated growth in response to release even after 200 years). Thinning while trees are young (pre-commercial thinning, PCT) increases individual stem diameters Sullivan et al. (2006). PCT alone, or in combination with vegetation management treatments creates the conditions that allow for an increase in crown volume or size on the remaining trees and, because crowns are the production factory of a tree, this usually increases vigour and growth. The duration of accelerated growth depends on stand dynamics as the canopy closes and individual tree growth rate declines. Growth naturally declines after various ages (depending on species and site conditions). Usually, stands attacked by mountain pine beetle are older than stands typically pre-commercially thinned, so we are more interested in release of older overstory trees, but some young stands of pine are also attacked so remaining overstory trees cans sometimes be quite young.

In stands killed by mountain pine beetle the overstory trees that remain alive may be pine, but could more likely be Douglas-fir or Engelmann Spruce. Subalpine Fir is more likely an understory species.

Release of Overstory Lodgepole Pine

Lodgepole pine has great potential to respond to various silvicultural practices designed to diversify structural heterogeneity and growth rates of crop trees within stands Sullivan (2006). For lodgepole pine, Brockley (2007) reported that effects of post-thinning density on tree DBH were strongly linear at both their study sites, with the largest increases in diameter being measured at the lowest stand density. These results are consistent with the results reported from other *Pinus* thinning studies (see summary in Johnstone and Cole 1988; Makinen and Isomaki 2004, both in Brockley 2007).

Other studies in British Columbia have documented increased diameter and volume growth of lodgepole pine after release. The Canadian Forest Service (2001) and Whitehead and Russo. (2005) examined overstory growth after commercial thinning of lodgepole pine (done in an attempt to beetle-proof stand). As illustrated in Figure 1, they reported that in the first 5 years after harvest, radial growth rate increased in spaced stands (by about 40%) but declined in unspaced stands (by about 18%). (Fertilization enhanced radial growth in all treatments). They suggested that with growth concentrated on larger stems in spaced units, larger piece size at the final cut should result in higher log values and lower logging costs because the same volume is on fewer pieces so costs associated with handling wood are decreased. There are concerns however over wood quality from more widely spaced stands (see below). As well, market conditions and milling systems affect gains or lack of gains from spacing. Dunsworth (pers. comm.) noted that the expected higher value for larger pieces did not seem to materialize during Weyerhaeuser's Forest Project.

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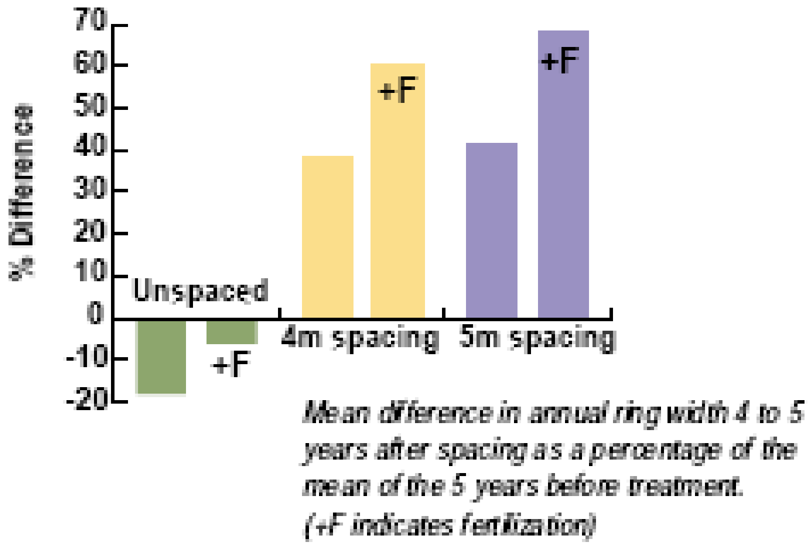

Figure 1. Mean difference in annual ring width 4 to 5 years after spacing (CFS 2001).

Live overstory trees remaining after beetle are not always old because young stands are also attacked. Although stands are rarely attacked at less than 20 or 30 years old, the results from studies below may still be applicable.

Lindgren et al. (2007) showed that thinning of young lodgepole pine (at 12 to 14 years old) resulted in significantly increased DBH and basal area (BA) growth over the 10 year period of their study. As well, 5 years following thinning, crown area, volume and live crown ratio all appeared to be enhanced by PCT and repeated fertilization; however, the differences were not statistically significant. Each study area (located near Summerland, Kelowna and Williams Lake) had nine treatments: four pairs of stands thinned to densities of ~ 250 (very low), ~ 500 (low), ~ 1000 (medium) and ~ 2000 (high) stems ha − 1 , with one stand of each pair fertilized five times at 2-year intervals, and an unthinned stand. The usual prescription (>90 per cent of stands) for PCT of lodgepole pine in BC is 1200 – 2000 stems per ha, with variations from this range tending to be higher rather than lower density. The broad range of densities applied during this study (250 – 2000 stems per ha) was clearly testing extremes beyond standard operational prescriptions and, at the lowest densities, may give some insight to responses in beetle-killed stands. However, these stands are younger than stands typically killed by beetle. Results were consistent with those reported by several studies following PCT and fertilization treatments Lindgren et al. (2007). Height growth was not significantly enhanced by thinning treatments, volumes generally decreased.

Sullivan et al. (2006) designed a study to test the hypotheses that large-scale stand thinning to low densities, at a 15-year period after PCT, would enhance: (i) productivity and structural features (crown volume and dimensions, diameter, and height growth of crop trees (those dominant trees destined for harvest)); and (ii) coniferous stand structure (abundance, species diversity, and structural diversity of coniferous tree layers). There were five lodgepole pine stands located at each of three replicate study areas in south-central British Columbia: Penticton Creek, Kamloops, and Prince George. These areas were selected on the basis of having several thousand hectares of young lodgepole pine forest. Stands within these tracts of young

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forest had relatively uniform tree cover and comparable diameter, height, and density of lodgepole pine trees prior to PCT. Original stands before thinning typically had over 10,000 stems of lodgepole pine, but that varied from site to site. Each replicate had four second-growth lodgepole pine stands (age range of 17–27 years); three of which were PCT to low (~500 stems/ha), medium (~1000 stems/ha) or high (~2000 stems/ha) density. The fourth stand was left unthinned. The second-growth stands had very few remnant trees and snags remaining from previous stands. There was also an old-growth lodgepole pine stand (age range 160–250 years) as part of the set of treatment stands at each study area.

In Sullivan et al.'s (2006) overall analysis of tree growth across the three regional replicates, lodgepole pine grew significantly faster in mean diameter in the low-density than in either of the medium- or high-density stands. However, there was no difference in mean height growth among stand densities over the15-year period since PCT. The pattern of faster diameter growth in the low-density stands was also reflected in the significantly higher tree volume increment for lodgepole pine in the low than high-density stands across the regional replicates. Mean tree volume increments were different between the low- and high-density stands (but medium density stands were similar to both).

In Sullivan et al.'s (2006) study, trees in the low-density (52.8 m^3) stands had a similar crown volume to the medium-density (42.9 m^3) stands, but a greater volume than those in the high-density (27.8 m^3), unthinned (11.7 m^3), or pine component (30.9 m^3) in the old-growth stands. Mean crown volume was also significantly lower in the unthinned than in each of the medium-density, old-growth, and high-density stands. This same analysis was conducted with crown volumes of all conifer species included as an overall mean value for the old-growth stands. Again, mean crown volume was significantly different among stands, with the low-density, medium-density, and old-growth stands all having greater crown volumes than those in the unthinned and high-density stands. Mean crown diameter at the widest point was also significantly different for lodgepole pine in these stands. The pattern of differences among stands essentially followed that of crown volume. Measurement of mean crown height indicated that there was a significant difference among stands with the low-density, medium-density, and old-growth stands having the greatest crown heights among stands. When total conifers were considered in the analysis, trees in the old-growth stands had the highest crown heights of all stands. Mean crown ratio (crown length/total height) of trees was also significantly different among treatment stands. Crown ratios were similar in the low-density (0.77), medium-density (0.72), and high-density (0.62) stands, and both the low- and medium-density stands had higher mean crown ratios than those in the unthinned (0.52) and pine component of the old-growth (0.40) stands. The mean crown ratio for overall conifers in the old-growth stands (0.57) was similar to the high-density and unthinned stands, but was lower than those in the low- and medium-density stands. In addition, mean crown volume was similar in the two heavily thinned stands and the overall conifer crown volume in the old-growth stands. Thus, even at an age of 32–42 years, these young stands have comparable crown volumes to those in the old-growth.

Sullivan et al.'s (2006) results at 15 years after treatment followed the same trajectory reported at 5-year and 10-year measurements in these same stands. Heavy thinning from dense stand (usually over 10,000 stems/ha) to 500 stems/ha (low-density) has consistently maintained faster diameter growth than in the medium- and high-density stands. A similar relationship was reported for western larch (Schmidt and Seidel 1988 in Sullivan et al. 2006) and for dominant and co-dominant trees in thinned 20–50-year-old stands (Long 1983, Bailey 1996, both in Sullivan et al. 2006). Height growth continued to be variable but was reasonably uniform at 5.5–6 m when the adjusted mean height increments were analyzed across the regional replicates. The less dramatic effects of thinning on height than diameter growth support the contention that

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some limited degree of crowding is required to maximize the height growth of lodgepole pine. These growth patterns match those reported earlier from much smaller (<1 ha) research-scale installations (Sullivan et al. 2006) and from operational-scale installations.

Pre-commercial thinning of lodgepole pine stands is controversial because the treatment does not necessarily achieve the intended yield objectives and negatively affects wood quality. These concerns are related to heavy thinning which reduces the total volume of wood and the ratio of juvenile to mature wood, thereby affecting the structural integrity (load-bearing) of the final lumber products. However, at least in Sullivan et al.'s (2006) study, at 15 years post-thinning in stands 32–42 years of age, mean stand volume (ranging from 108.53 to 132.51 m^3/ha) was similar in the medium and high thinning densities, albeit higher that that (72.88 m^3/ha) in the low-density thinning. Density management regimes typically represent a compromise between maximization of volume production (m^3/ha for a specified time interval) and maximization of individual tree growth and size. Usually, when stands are heavily thinned, the gains in individual tree size do not outweigh the loss of stand volume due to thinning.

The Forest Practices Board studied stands attacked by mountain pine beetle during 1979 in the Wentworth landscape unit, Quesnel forest district. These stands are much older than the ones studied by Sullivan et al, above. The area sampled was in the Sub-Boreal Pine Spruce biogeoclimatic units (SBPSxc, SBPSmk and SBPSdc). They reported mortality, "secondary structure" (seedlings, saplings and sub-canopy trees that survived the pine beetle attack), growth following release, and new regeneration for stands attacked by mountain pine beetle 26 years ago. Survival rates of mature pine ranged from 10 to 50% for the areas sampled. Most overstory trees that survived the infestation grew in diameter significantly faster after the epidemic than before it. Ten of the 14 sampled trees showed a significant growth response. The range of response varied from 1.0 to 3.0 times the radial growth during the last 25 years when compared to the previous 25 years (see Figure 2). The average increase was approximately 44% greater than the pre-infestation growth rate. A photo shows radial growth of approximately 70mm for the last 25 years compared to 40mm for the previous 25 years.

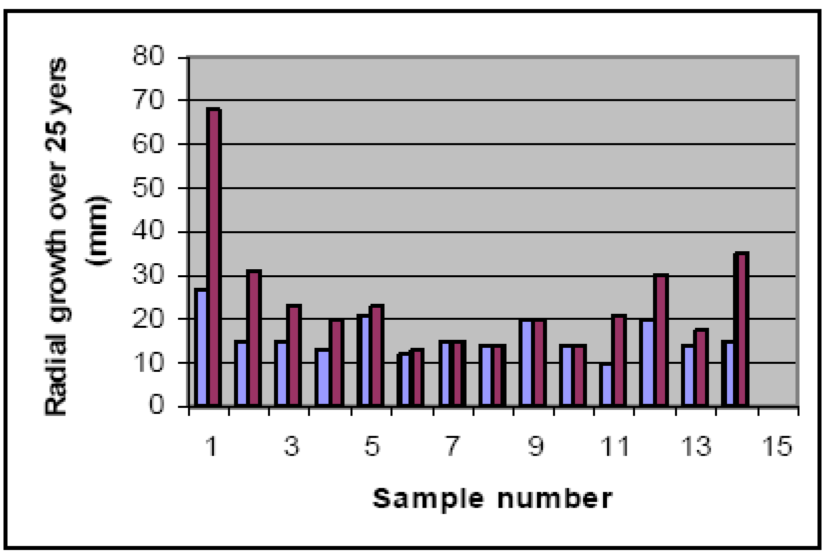

Figure 2. Release of surviving overstory pine trees following 1979 beetle attack over 25 years pre beetle (blue) and post attack (red).

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Release of Other Overstory Species

Coates (2008) studied tree response after a 25-30 year old MPB attack in the Flathead region of south eastern BC. His study indicated that growth release of surviving overstory trees varied with species and size following high pine mortality (50-100%). Surviving lodgepole pine trees often exhibited a strong positive response after the attack. Western larch, interior spruce and Douglas-fir showed a similar responses but response in subalpine fir was weak. These results are supported by studies from other areas (Daniels et al 1979).

Douglas-fir will respond to release by increasing diameter growth. Pre-release tree variables that help predict post-release diameter growth include diameter growth rate, diameter, and height. Pre-release height and diameter growth rate are important indicators determining whether advance Douglas-fir should be retained. Trees with greater pre-release height and diameter growth respond more than slower growing trees. Slower growing trees may also respond, but over a longer period of time. Three factors found to be important in predicting post-release height growth are pre-release height growth rate, live crown ratio at time of release, and whether the 5-year pre-release annual height growth was decelerating, constant or accelerating.

Interior Douglas-fir may release in a similar fashion to coastal Douglas-fir. Chan et al. (2006) reported that in Douglas-fir in western Oregon, thinning increased overstory stem growth, crown expansion, and retained crown length. Thinning treatments ranged from light (from 550 original trees thinned to ~250 trees/ha), moderate (~150 trees/ha), and heavy (~75 trees/ha) thinning. Thinned overstory canopies began to close rapidly the third year after thinning, decreasing % skylight by approximately 2%/year, whereas % skylight in unthinned stands increased slightly.

Wood Quality after Release

There is a concern that wood quality will be compromised in open grown trees. More knots and wider rings lead to less desirable wood products. Wood density is often considered to be the most important indicator of clear-wood quality, with high-density wood being preferred to low density wood. Thinning and fertilization treatments are often associated with decreased wood density, primarily because of the disproportionately large increase in low-density earlywood production compared with high-density latewood. Juvenile wood is produced within and near the live crown and has several undesirable wood properties, including lower density, higher fibril angle and shorter cells compared with mature wood, which is produced along the branch-free portion of the lower stem. Because thinning and fertilization treatments tend to increase the size of crowns where juvenile wood is laid down, it follows that these silvicultural treatments would increase the juvenile to latewood ratio throughout the lower stem.

Pruning may mitigate some of the negative stem form and wood quality attributes associated with fast-growing trees without adversely affecting stem growth. However costs of pruning are high and the technique is rarely used on an operational basis in the interior or the coast.

Summary

For overstory lodgepole pine and Interior Douglas-fir we can expect crowns of trees surviving mountain pine beetle infestation to increase in size by 30 to 40% over 5 years in post beetle attacked stands. Similar increases in stem diameter will occur, while increases in height are likely to not be significant. Shading may be increased as much as 10% to 20% near live trees over 5 years as a result of those expanding crowns. At the same time, light levels are increasing due to dying twigs and branches, so the net light levels are difficult to estimate. The proportion of live trees in the stands will determine the net changes in light levels. Empirical studies to

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assess changes in light and crown closure over time, as well as stem diameter, height and volume, for various combination of proportion of live and dead in a stand would be informative.

Key Uncertainties

There is sufficient current information on overstory release to suggest that live trees will increase in size substantially after their neighbours die. This information can be used to predict general light levels underneath canopies of different levels of live stems.

Additional information can be gained in the longer term to increase the accuracy of the responses. Proposed experiments for Forests for Tomorrow will measure overstory plots including rates of crown expansion, height and diameter growth.

Short-Term Learning

The information gained through the experiments will add information over the long term (5 to 10 years and longer). These experiments will not help decisions over the next few years. We suggest that sufficient information exists to give a reasonable sense to responses of live stems after remaining stems have been killed by beetle attack.

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