POST MORTALITY RATE OF WOOD DEGRADATION AND TREE FALL IN LODGEPOLE PINE TREES KILLED BY MOUNTAIN PINE BEETLE IN THE FOOTHILLS AND ROCKY MOUNTAIN REGIONS OF ALBERTA

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1.0 EXECUTIVE SUMMARY

The purpose of this study was to determine the initial rate of decay and deterioration of pine killed by mountain pine beetle, in order to make comparisons with longer-term studies in BC. Ten sites were sampled in the Foothills region, and six in the Central Mixedwood region. A total of 155 trees were destructively sampled and year of death was determined by tree ring analysis. Several response variables were measured, including moisture content, number and depth of checks, and depth of saprot, at four different locations along each tree. These response variables were examined, primarily qualitatively, for their relationship to the predictor variables years-since-death and diameter at breast height. Most of the trees sampled had died one to two years prior to sampling; the sample size for 3 or more years-since-death was very small. The sapwood moisture content declined very quickly to fibre saturation point, within the first year post-mortality, especially in samples from the Mixedwood region. Foothills trees were slightly slower in drying rate, although drying was faster than what was observed in central BC, and the basal disc retained higher moisture content for all post-mortality years sampled. The number and especially depth of checks was greater in samples from the Mixedwood region, presumably due to the faster rate of drying and greater shrinkage stress. By year 3 post-mortality, essentially all of the Mixedwood trees showed one or more checks at any of the 4 sample discs, whereas this point was not reached in Foothills samples until 7 years post-mortality. Saprot was more prevalent in the Mixedwood samples and almost non-existent in the Foothills samples except in the basal disc (closest to the ground) in trees that had been dead for 5 years. Damage caused by woodborers was insignificant. Saprot and woodborers are the agents most important in weakening the base of the tree to where it eventually falls over. The lack of activity of these two agents in the short time period post-mortality that we were able to sample, explains the very few trees that were observed to have fallen in any of the sample sites. The trends indicated in the first two years post-mortality for trees sampled in Alberta are similar to that observed in BC except that the Alberta trees appeared to dry down faster and develop more checks within the first two years post-mortality. This is particularly true for the Mixedwood region; trees from the Foothill region are slower to develop checks and the checks are not as deep, at least for the first few years following death.

2.0 Introduction

The mountain pine beetle (MPB, *Dendroctonus ponderosae*) is endemic to lodgepole pine (*Pinus contorta* var. *latifolia)* forests of western Canada. The province of British Columbia has experienced the most extensive outbreak of the insect ever recorded in North America (Taylor and Carroll 2004). In 2006 the beetle extended its range into the neighbouring province of Alberta and has been shown to successfully attack and reproduce in jack pine (*P. banksiana*) (Cullingham et al. 2011) and the hybrids formed between lodgepole and jack pines.

The MPB can have profound economic and ecological implications for industry and the reforestation of infested forests. Given that multiple perspectives on natural resource management issues are common, management strategies have to be carefully planned and make the best use of the resources at risk. One of the main factors to be considered is the "shelf Life" of standing dead pine as it relates to the proper sequencing of harvesting affected stands to ensure maximum benefit of the wood fibre at risk. Timber supply analyses and resource management plans also have to recognize other ecological variables such as water flow, habitat types and reforestation possibilities, all of which can be affected by mortality of trees due to MPB, and changes in stand dynamics as dead trees age and begin to fall over. Considerable work has been done in BC to examine the changes to wood quality and quantity following mortality of lodgepole pine trees by MPB.

The purpose of this study was to replicate the research done in BC, in the Foothill region of Alberta. This study complements sampling that was already done in the Boreal Mixedwood region of Alberta as part of a separately funded project. Specific objectives were to:

1. Quantify the relationship between time since death, wood moisture content, and other measures of wood quality and quantity.
2. Determine the influence of region or subregion on the rate of change in wood properties.
3. Quantify the effect of site factors (e.g. soil moisture) on the rate of change in wood properties.
4. Determine the rate of tree fall across subregions.

The infestation in Alberta is relatively recent, and was aggressively managed by harvesting of attacked trees. As a result, the availability of trees for sampling that had been dead for longer than 2-3 years was very low. Therefore, a substantial review of the literature from studies in BC and elsewhere is provided. Most of this review was extracted from Lewis, 2012 (available from: www.unbc.ca\lewis). The results and discussion sections of this report compare the Alberta samples to what is known from BC.

3.0 BACKGROUND INFORMATION

3.1 Definition of "Shelf-life"

The term "shelf-life" is often used as a colloquial expression to describe how long wood from dead trees can be manufactured into products. However the "shelf-life" of dead trees is more complex than the notion of the "shelf-life" of a product such as milk. In the latter case, there is an obvious point at which milk becomes unsuitable for consumption and the variables that affect this point are relatively few and simple, such as storage temperature. In the case of dead wood, there are many factors that play a role in the suitability of dead wood for wood products. Biophysical changes that take place in the wood after a tree dies, such as drying and decay, are one group of factors. Another factor is the type of wood product desired. Characteristics of dead wood suitable for veneer are much different than the characteristics of dead wood suitable for wood pellets. A third factor is the technology used to manufacture the product (e.g., different methods of creating flakes or chips for composite boards). Finally, economic factors play a significant role in suitability of dead wood for wood products. These include cost of raw material, hauling distance, and market prices for the product. Our study was limited to the biophysical factors of wood degradation – the change in characteristics of wood as it ages post-mortality.

3.2 Literature Review

3.2.1 Bluestain

The only means by which wood fibre is actually lost from trees, not just altered in its properties, is when a tree is burned, attacked by decay fungi, or the wood is consumed by wood boring insects. Blue stain in wood from trees killed by MPB is caused by a specific group of pigmented fungi that are carried into the tree by the beetle itself. Invasion by blue stain fungi is rapid, initially colonizing the sapwood ray parenchyma cells, then penetrating sapwood tracheids (Ballard et al. 1984). Colonization of the rays and the tracheids results in reduced defensive capability and water stress, and may contribute to tree decline and mortality. In a study that followed the advance of blue stain fungi, total colonization of the sapwood was found to occur within 7 weeks of initial attack (Solheim 1995). Other studies have shown that the penetration by blue stain fungi was so rapid (9-10 months following attack, over 50% of total volume and almost 100% of sapwood volume was stained) that salvage harvesting of mountain pine beetle killed lodgepole pine prior to severe staining would be very difficult (Harvey 1979 and that blue stained wood volume reached maximum levels within the first year post-mortality (Chow and Obermajer 2007, Lewis and Thompson 2011). The amount of blue stain in a log is dependent on the proportion of sapwood, which depends on a number of factors, such as crown volume. Growth rate also influences the proportion of sapwood, with more vigourous trees generally having a greater proportion of sapwood. The relationship between growth rate and penetration depth by blue stain was confirmed in the study by Lewis and Thompson (2011) who found depth of blue stain to be significantly related to the growth of trees in the 20 years prior to attack, and the size of the tree at the beginning of that 20-year period.

Other than the significant reduction in aesthetic value of blue stained wood, especially for the Japan export market (Solheim 1995), there is little effect of blue stain fungi associated with mountain pine beetle on strength properties of lodgepole pine wood. Lum et al. (2006) tested 270 samples each of blue-stained and non-stained 2 x 4, kiln-dried lumber selected from mills in the interior of BC for several mechanical properties. All samples were brought to the same moisture content by conditioning in an environmental chamber, then tested for density, toughness, modulus of elasticity (MOE). The study concluded that blue stain did not have a negative effect on the mechanical properties of the wood tested.

One property that does appear to be significantly different in blue-stained wood compared to non-stained wood is permeability. Blue-stained wood subjected to wetting-drying cycles was found to have a greater permeability to water and was more dimensionally stable (less twisting), than non-stained wood. Further, uptake of chromated copper arsenate preservative following a 24 hour dip or a pressure treatment cycle, was greater in stained than in non-stained wood. The difference extended only to the sapwood and was not evident in the heartwood (McFarling and Byrne 2003). The same study showed that stained sapwood subjected to wetting and drying cycles checked less than non-stained sapwood, and that in stained sapwood stresses induced by drying were relieved by the production of many “micro-checks” (defined as barely visible fine checks) in comparison to non-stained sapwood which produced fewer and larger checks.

3.2.2 Moisture Content

Moisture content is an important driver of other processes that determine how wood quality and quantity changes over time following mortality from mountain pine beetle. The change in moisture content is responsible for the development and extent of checks (Haygreen and Bowyer 1996) and for the rate of development of decay fungi.

The rate of change of moisture in beetle-killed trees and in wood cut from trees at various stages post-attack has been relatively well studied. Lumber produced from dead lodgepole pine trees killed by mountain pine beetle (an uncertain number of years ago) in Idaho had a moisture content of about half that from live trees and there was only a slight moisture gradient from sapwood to heartwood. Both moisture meter measurements and the oven-dry method found moisture contents consistently less than 30% (Lowery and Hearst 1978).

In a BC study, beetle-killed lodgepole pine trees were sampled one year after attack. In comparison to green trees which had a sapwood moisture content of 85-165%, trees attacked in July had a sapwood moisture content of 40% by the end of August, and by the end of the year, moisture contents were at fibre saturation point (Reid 1961). In the same study, trees attacked earlier in the season (July) fell below fibre saturation point before trees that were attacked later in the season (August).

In another study, 120 lodgepole pine trees were sampled from 4 locations in southern BC. The sample included an equal distribution of green, red and grey attack stages. Mean sapwood moisture contents of red stage trees ranged from 19.8% to 26.9% among locations, and was between 40 and 80% in the green stage, which included trees attacked from one-month ago to one year ago (Kim et al. 2005).

Lewis and Thompson (2011) found that the sapwood moisture content (oven dry method) of the sapwood of trees sampled in central BC dropped to approximately 25% within the first 2 years post-mortality, measured at locations 1/3 and 2/3 of the merchantable tree height. Samples taken from 0.3m and 1.3m up the stem remained above 80% and 40% respectively, for several years due to absorption of moisture from the ground. Heartwood moisture content showed a similar pattern but with a lower starting point of 35-40%. In that study, years-since-death was accurately determined using cross-dating. Similarly, a study of green, red and grey attack lodgepole pine found that unattacked trees had an average sapwood moisture content of 140% which declined to 28-40% for all three attack stages (Chow and Obermajer 2007). In that study the moisture content shows a different pattern from the bottom to the top of the tree, which changes depending on stage of attack, however it is not clear what the stump height was, and whether or not heartwood was included in the results. That study also included measurement of moisture content of lumber produced from logs at the three stages of attack. In comparison with lumber from unattacked trees which averages around 55%, the moisture content of lumber from green, red and grey stages was 29.5%, 26.6% and 22.8% respectively.

3.2.3 Checking

The development of cracks or checks in trees killed by mountain pine beetle is a function of the change in moisture content as the wood, especially the sapwood, changes from over 100% moisture content, to less than 20% moisture content. As described above, this happens relatively quickly with sapwood moisture content dropping significantly even within the year of attack. As wood dries, it first loses free water (water in the lumen, or hollow of the tracheid cells), then once it reaches fibre saturation point, the wood begins to lose bound water; water that is bound to the cellulose molecules in the cell walls by hydrogen bonds. As water is drawn from the cell walls, the cell wall shrinks, and it is the shrinking process that causes cracks or checks to develop in the wood. The amount of shrinking, and therefore cracking, is proportional to the amount of water removed from the wood. Shrinking is a reversible process, with swelling following the addition of water to the cell walls (Haygreen and Bowyer 1996). The tangential dimension shrinks more than the radial dimension which adds to the formation of cracks that appear first in the outer sapwood, and then continue to deepen. The development of small surface checks over time most likely results from the re-adsorption of water by the wood cell walls during wetting cycles, and the loss of water from the cell walls and consequent shrinkage during drying cycles.

Lewis and Thompson (2011) found that the number of trees with detectable checks (measured in the field on rough-cut cookies, at only one location on the tree) increased with years-since-death (YSD) although the data were highly variable due in part to variability in sample size. Within the first two years post-mortality, the number of trees without checks (at 1.3m) declined to around 60% and remained steady for several years. Even after 7 years post-mortality, 20% of trees sampled showed no evidence of checking at a cookie taken from breast height. However the middle section of trees showed a faster rate of development of checks, and a small increase in the number of checks with YSD suggesting that this section is more likely to develop checks with time. For all sections combined, the percent of trees with checks increased from near 0 in current attack years, to around 70% by the second year after death (Lewis and Thompson 2009). In other words, trees had a 70% chance of developing one or more checks by the 2nd year after death. Check depth was found to increase with YSD, and this relationship was particularly noticeable for the basal (0.3m) disc.

Variables that influence the development of checks and check depth were tested for significance using data taken at 1.3m because this location and that of disc 3 (1/3 of tree height) showed the greatest check depth. Variables tested included YSD, soil moisture regime, diameter at breast height, average stand density, diameter growth during the last 10, 20 and 50 years, percent change in diameter relative to estimated diameter 10, 20 and 50 years ago, and specific gravity of sapwood and heartwood. The most significant predictor variables for both number and depth of checks were YSD and diameter at breast height with both predictor variables positively related to the response variables.

There have been other studies that examined checking in lodgepole pine killed by mountain pine beetle. In one mill study that employed scanning technology to optimize lumber recovery, a sample of 40 logs, which ranged in attack category from green to early grey, but which lacked severely checked logs (due to what was available in the log yard at the time) were scanned at the ends and along the debarked outer surface for checks. A check severity index was developed that included the number, depth and length of checks. The check severity index of the sample logs ranged from 0.06 to 0.740. The number of checks per log ranged from 1-5, the average check depth ranged from 29.4% to 99.3% of the radius, and the average check length ranged from 9% to 100% of the log length (Orbay and Goudie, 2006). The study found a significant relationship between value as a percent of a “healthy” (without the observed check defects) and check severity index.

In another study, conducted in 2006, with a similar sample design to Lewis and Thompson (2011), 360 lodgepole pine trees from 45 sites in north central BC were sampled (Magnussen and Harrison, 2008). Year of attack was estimated using tree ring analysis and local knowledge, although the actual methods used, and the proportion of trees accurately dated by cross-dating, is not described. However the authors state that their determination of year of attack was inexact, and thus they treated the year of attack as a categorical variable in their analyses. Similar to findings from other studies, this study found that the number of checks increased significantly with tree size, and that the proportion of trees with no checks dropped sharply off in year 3 post-mortality. They found that the distribution of checks per tree became increasingly right-skewed (more checks) with earlier attack years. The number of checks per tree was not significantly related to soil moisture regime, again in agreement with findings from Lewis and Thompson (2011), but there was a positive relationship between the number of checks per tree and the presence of spiral grain. Spiral grain was the most important factor determining the number of checks, and trees with spiral grain had just under twice the number of checks as trees without spiral grain. Spiral grain was recorded in the field as a percentage in the first 2.5m log above stump height, but was incorporated in the model as a binary variable (presence, absence) and it is not clear what the % spiral threshold was to record a tree as having spiral grain for the model. Check depth in this study varied with year of attack, spiral grain and soil moisture regime. In trees that have spiral grain, the checks will follow the spiral, thus making it even more difficult to cut boards from logs as the check spirals around the circumference of the tree. Trees on drier sites had wider and deeper checks than trees from wet sites. Check length in the basal 2.5m log was significantly greater on dry sites compared to mesic and wet sites. Checks in trees in year of attack categories greater than 2 were significantly greater than those in trees in categories 2 or less.

3.2.4. Decay, wood borers and loss of wood volume and strength

It is only through the actions of decay fungi and wood borers that fibre is lost or weakened. The action of drying and checking, while affecting the ability to saw lumber and make other products, does not affect the quantity or strength of unchecked wood fibre. However, at the whole log or lumber scale, the development of checks makes the entire log or piece of lumber more likely to break during felling or as wood in use, and therefore does affect strength properties at this larger scale.

Tree mortality can result in development of saprot (decay of the outer sapwood) as the sapwood loses its defense capability upon mortality. Mortality does not lead to the development of heartrot in a tree which usually only occurs in living trees that have either been wounded, or infected by a special group of fungi that gain access to trees through branch or twig scars.

Published information on the rate of decay (saprot) in lodgepole pine with YSD is limited. Interviews with mill operators in the area where dead lodgepole pine was salvaged following an outbreak in the 1980s (interior plateau of BC), suggested that decay was not a factor in utilization of the trees until they fell over and then decay progressed rapidly. A study from Oregon (Harvey, 1986) found that of 226m^3 sampled, less than 1% of the volume was lost to decay 11 years after tree death, and decay was observed in only 13.7% of sampled trees. Another Oregon study targeted at the use of beetle-killed lodgepole pine for power poles found that 70% of the trees that had been dead for 5 or more years were suitable for power poles, although some required long-butting (bucking off the bottom portion of the log) due to decay. Trees dead for less than 5 years had a 94% rate of suitability (Tegethoff et al. 1977).

In BC, there have been 2 main studies that examined decay in beetle-killed lodgepole pine. In Lewis and Thompson (2006, 2011), decay was measured in cross-sections of felled trees at numerous locations up the stem. Within the first year of mortality, the percentage of trees with saprot detected was negligible, but the percentage increased substantially by the end of the first year post-mortality, especially in discs above the basal disc. With increasing YSD, the percent of trees with saprot continued to increase and it was the lowest disc that showed the greatest rate of increase, with the upper discs showing negligible change in saprot. By year 9 post mortality, the percent of trees without saprot at the base had declined to almost zero.

In the study by Magnussen and Harrison (2008), where YSD was estimated and treated as a categorical variable, 28% of 101 sampled trees had some form of decay, which was concentrated in 6% of their sample discs and most of these were in the first 2.5m of the stem.

Saprot formed 45% of the decay observations, with “incipient decay” (not defined) and heartrot caused by *Phellinus pini* equally making up the remainder of the decay observations. Analyses in this study combined all rot types and all sample heights, and found an increasing amount of saprot with years since attack. The observations that only 6% of the sampled discs had almost all of the decay observations, and that the first 2.5m log contained most of the decay, suggests that the increase in decay was primarily in the basal portion of the tree, which concurs with findings in Lewis and Thompson (2011).

Overall, evidence strongly suggests that while saprot is established along the length of the tree within a year or two of mortality, progression of decay essentially stops as the sapwood moisture content drops to or below fibre saturation point. The exception to this, and the explanation for increasing decay amounts and proportion of trees showing decay reported in several studies, occurs at the base of the tree, where moisture is absorbed from the ground which enables the survival of saprot fungi and continuation of decay. The absorption effect was demonstrated in the Lewis and Thompson (2011) study, where discs sampled at 0.3m had significantly greater moisture contents than discs sampled from greater heights. The effect diminishes by 1.3m and appears to disappear in upper discs.

Wood borers are insects that bore into wood, with some feeding on the wood itself (e.g., termites) and for others using the wood for breeding or nesting sites (e.g. carpenter ants). Ambrosia beetles are a wood-boring insect that will infest dead trees. In the case of dead lodgepole pine, ambrosia beetles are known to infest trees within 2 years of mortality as long as a population of ambrosia beetles is nearby. These beetles bore into the sapwood and inoculate the galleries with a fungus, which is used as a food source. The fungus is black and collectively the beetle and the fungus cause narrow, black galleries in the sapwood of infested trees, and the pin-sized holes can result in a reduction in aesthetic quality of the wood.

Other wood borers in BC, such as carpenter ants, may play a role in tree fall, but this has been poorly studied. Lewis and Thompson (2011) quantified the damage caused by wood borers in lodgepole pine killed by mountain pine beetle. A greater percentage of trees showed some damage by woodborers with YSD, and while ambrosia beetle galleries were identified at numerous locations on the stem, activity by wood borers was only at the base of the tree. By 10 years post mortality, 80-90% of trees showed evidence of wood borers at the base of the tree. While damage from wood borers can be removed by long-butting, activity by these insects will most likely contribute to fall down of dead trees, similar to the effect of saprot.

3.3 Summary of Literature and Research from BC

Following successful attack of a lodgepole pine tree by mountain pine beetle and its associated blue-stain fungi, translocation of water, photosynthesis and other metabolic functions slow down and ultimately stop within a month or two of attack. As this cessation of metabolic activity coincides with the normal onset of dormancy, the tree remains green in appearance until the following year when needles become red.

Lack of transpiration results in a reduction in moisture content from over 100% in green live trees, to 40-80% within the first two months following attack, to approximately 25% or less following the first year of attack. The reduction in transpiration is due in part to the rapid colonization of the sapwood by blue-stain fungi which plug up the wood elements responsible for transporting water. Within 2 months of attack, the sapwood of affected trees has been almost completely colonized by blue-stain fungi. These fungi do not break down wood constituents for their nutrition, and there is no impact of blue-stain on wood mechanical properties. Blue-stained wood has been shown to take up preservatives and water more efficiently than non-stained wood.

As a result of the change in moisture content, checks develop in the wood. By two years since attack (and death), 50-70% of trees have developed one or more checks that are large enough to be detected in the field on rough-cut cross-sections. The number of checks per tree increases during the main drying-down period (2 years after attack) and then tends to stabilize at one to five checks per log (3m to 6m long). The two most important variables that explain the number of checks that develop are years-since-death (YSD) and tree diameter with both having a positive relationship with number of checks. The depth of checks increases with YSD and is also greater in larger diameter trees.

Saprot develops in areas of the dead tree that are moist enough for the decay fungi to function. Saprot may become established in a tree within months of death, but in all locations except the base of the tree, which remains moist due to contact with the ground, saprot activity ceases. Saprot continues to develop at the base, extending approximately 1-1.5m up the tree. Wood borers, particularly carpenter ants, are also active at the base of the tree and the degree of damage is positively related to YSD. Collectively, the activity of saprot and woodborers result in failure of the tree.

Tree fall as a result of mortality by mountain pine beetle is negligible for the first 5-6 YSD, but then increases to 30-50% tree fall within 9 years post-mortality and over 80% by 15-20 years post-mortality. There is considerable variation around the rate of tree fall which is suspected to be due to variability in soil moisture, wind speed, topography and other factors that affect root integrity and force on the tree.

Other than the initial and rapid down-grade of wood quality (aesthetic only) due to blue-stain, there is little change in the mechanical properties of lumber produced from beetle-killed trees. However, the ability to produce lumber, and the options available to the sawyer for producing larger dimensions, are significantly affected over time due to the development of cracks. More trees develop checks with increasing YSD, and the depth of the checks increases with YSD.

4.0 METHODS

4.1 Site Selection

Sampling took place in summer and early fall of 2011, in the Upper and Lower Foothills subregions. These samples augmented data collected in 2010 from the Boreal Mixedwood subregions. Candidate sites were selected following discussion with members of the Foothills Research Institute, industry and government representatives, and made use of previously located permanent sample plots. Candidate stands for sampling were walk-through surveyed to confirm the presence of dead trees and for an approximate estimate of years since death based on external indicators (foliage colour and retention, bark condition). In 2011, five sites in each of the Upper and Lower Foothills subregions were selected for sampling and in some cases included the area adjacent to an existing permanent sample plot (plus a > 100m buffer). In 2010, five sites were located in the Central Mixedwood region. Figure 1 shows a map of the sites sampled in both 2011 and 2010.

4.2 Site and Tree Sampling

At least 3 tree species composition and stand structure plots were established at each sample site. The species, condition (dead or alive) and position (standing or fallen) were recorded for each plot. Soil moisture regime was determined using slope position, plant indicators and soil texture. At least 10 trees were selected for destructive sampling at each site, targeting recently dead and older dead where possible.

Trees were sampled using procedures adapted from Lewis and Thompson (2011), and included measurement of the following variables at 4 points along the stem (stump height, breast height, 1/3 merchantable tree height, 2/3 merchantable tree height): sapwood and heartwood moisture content, penetration depth of stain fungi, number and depth of checks, penetration depth of saprot, wood borer damage. Years since death was determined using tree ring analysis and cross-dating (Stokes and Smiley 1968). Tree dbh and total height were also measured.

In addition to the above sampling, a nested sub-sample of 2-3 trees per site for the 2011 samples were sampled in more detail in order to measure check length. This was done by painting a line along the length of the tree, then bucking the tree into small sections to track the check length.

A walkthrough reconnaissance for downed trees was also done at each site. Very few down trees were observed therefore further sampling of these to determine year of tree fall was abandoned.

4.3 Data Analysis

Very few trees were found that died more than 2 years before the year of sampling (Figure 2), therefore most of the data analysis was qualitative. Based on previous results from studies in BC, the most important variables that influence factors that affect wood quality and quantity (e.g. moisture content, checks, saprot) were expected to be years-since-death, and tree diameter. Therefore moisture content of the sapwood and heartwood were plotted against YSD, and the number and depth of checks were plotted against YSD and DBH.

Percentage of trees with no measurable damage caused by checking at breast height, and by saprot and woodborer, were plotted against YSD, and the percent of trees with any check observed at any of the four sample discs was plotted against YSD. The total number of checks observed at the four discs was regressed on tree diameter.

The number and length of checks in the subsampled trees were also plotted and regressed on YSD. DBH was tested for significant effects on check length.

5.0 RESULTS

The distribution of tree species by diameter class for the Foothills (upper and lower) and the Mixedwood stands are shown in Figure 2, and Table 1 provides additional detail on the sample sites within the two different ecoregions. Pine was much more common in the Foothills stands compared to the Mixedwood stands which had more spruce species and hardwoods. Live pine trees in the Mixedwood stands were only found in smaller diameter classes whereas in the Foothills stands, there remained a significant amount of pine among all diameter classes that had not yet been killed by mountain pine beetle.

Table 1 Description of stands sampled

Ecoregion	Years since death	Number of plots	Stems per hectare	Percent pine	Percent down
Mixedwood	0-4	17	840-2867	4-65	0-4
Foothills	1-7	30	252-500	75 upper* 69 lower	<1

* Upper and lower Foothills subregions

Figure 3 shows plots of years since death versus tree diameter at breast height for the Foothills and Mixedwood samples. Most of the trees died one to two years prior to sampling, with only a few trees that died 3 or more years prior to sampling. The longest dead trees tended to be of smaller diameter. The lack of samples that had died more than 2 years prior to sampling limited our ability to statistically analyze the data.

Figure 4 shows the moisture content of sapwood and heartwood separately for the Foothills and Mixedwood samples. Sapwood moisture content averaged around 30% within one year after sampling for all but the lowest sampling point (disc 1) for the Foothills samples. Moisture content of these samples remained at just over 60% for the first 2 years post mortality, then declined to around 50% (although sample sizes were small). The Foothills samples appeared to reach relatively steady moisture content by the first year post mortality. Mixedwood sites did not show the same pattern of greater moisture content in the lowest disc, and these samples showed a slight decline in moisture content over time at most disc locations, in both the sapwood and the heartwood, and the heartwood samples had a higher moisture content than the sapwood in the first and second years post mortality. Moisture content of the Mixedwood samples was lower in the first two years post-mortality than in the Foothills samples.

Checks occur as wood dries and given that the Mixedwood trees showed lower percent moisture content, it is not surprising that the number of checks observed at each sample disc was greater in the first two years post mortality in the Mixedwood trees compared to the Foothills trees (Figure 5). For most of the trees, the greatest number of checks was observed at disc 2 and 3 regardless of ecoregion. Although sample size makes it difficult to interpret apparent trends, it appears that the number of checks increased at all disc locations for the Mixedwood samples, and at all but the disc sampled at breast height for the Foothills samples. Looking only at the breast height disc, the percent trees with no checking at disc 2 declined very quickly during the first year post mortality to about 55% at the Mixedwood sites and 65% at the Foothills sites. The percent of trees that developed checks seen at the breast height disc continued to increase at the Mixedwood sites, but remained somewhat steady at the Foothills sites (Figure 6). The percentage of trees that show one or more checks at any sample disc is shown in Figure 7. Mixedwood sites developed checks more quickly than Foothills sites. By the third year post-mortality most of the Mixedwood trees had one or more checks, whereas at the 3rd year post mortality approximately 55% of the Foothills trees showed one or more checks at any sample location.

Check depth (Figure 8) showed a similar pattern, with the average check depth at each disc location being significantly deeper in samples from the Mixedwood ecoregion compared to the Foothills. Checks were between 3 and 4 cm deep within the first year post mortality in the Mixedwood samples, and remained about the same depth with increasing YSD. The Foothills samples developed shallower checks within the first few years post mortality (between one and two cm) but appeared to become deeper over time, although sample size in these later years post mortality was very small. Similar to the number of checks, the deepest checks normally occurred at discs two and three.

To determine if there was any relationship between the number and depth of checks and diameter, the number and depth of checks were plotted against disc diameter for each disc location (Figure 9). The figure does not show any particular patterns of increasing check numbers or depth with diameter. A linear regression of the total number of checks against DBH was not significant for both the Mixedwood and the Foothills samples (P= .121 and P=.985 respectively).

A total of 18 trees were subsampled in the Foothills ecoregion to measure check length. Figure 10 shows plots of the length of each check by YSD and by DBH, and then the mean check length per tree plotted against DBH. There is no apparent influence of YSD or DBH on check length, and linear regressions were not significant (P>0.05).

The percent of trees that had no saprot at the basal disc declined to approximately 30% by year four or five post mortality for samples from the Mixedwood and Foothills ecoregions (Figure 6). The Foothills samples at year 7 post mortality show no saprot at the base but there were only two trees in this category. The mean depth of saprot for trees in each YSD category is shown in Figure 11. Despite drier sapwood, the Mixedwood samples showed more saprot development than the Foothills samples although in both cases the saprot was less than one cm deep. Saprot did not seem to be affected by disc location for Mixedwood samples, but for Foothills samples, saprot was more developed at the base of the tree, and by year five post mortality (only three trees), saprot was evident only at the base of the tree.

Very few trees in the Mixedwood ecoregion had damage by woodborers whereas woodborer damage was more common in the Foothills samples (Figure 6). Most of the woodborer damage was caused by ambrosia beetles.

6.0 DISCUSSION

Interpretation of the results from this study is limited by a very low sample size for trees that died more than two years prior to sampling. However the data are more than sufficient to examine trends that can be compared with results from BC studies for longer term estimates of deterioration rates. Trees that had died more than five years prior to sampling were small diameter, which is consistent with observations by Lewis and Thompson (2009). Most likely these trees were killed when beetle populations were at endemic or incipient-epidemic levels, before the beetle population was large enough to mass attack large, healthy trees (Amman and Schmitz 1988).

Results from this study were similar to previous results from BC. Moisture content of the sapwood declined very quickly for samples from both ecoregions, and in general was similar to that observed in BC. Samples from the Mixedwood region dried down more quickly than the Foothills region and did not show the same elevation of moisture content at the basal disc compared to other locations on the tree that was observed in the Foothills samples and the trees from BC.

As described above, it is the process of drying, especially in the sapwood, which leads to the development of checks, which explains the greater rate of development of checks in the Mixedwood samples compared to the Foothills samples. However both ecoregions appeared to have more checks in the first two years post mortality, compared to results from BC (Lewis and Thompson 2011). Similar to BC results, the greatest number of checks occurred in discs two and three. Check development in disc one was delayed in the Foothills region samples due to the elevated moisture content in the basal disc resulting from passive absorption from the ground. The number of checks on average in the Mixedwood samples at the basal disc was higher and not different from the number of checks observed at higher locations on the tree. This is most likely due to the reduced moisture content of the basal disc at Mixedwood sites compared to Foothills and BC. The Foothills ecoregion has the greatest annual precipitation of any other ecoregion in Alberta (approximately 600mm/year) and it is milder than most other regions (mean annual temperature approx. 1.5C). The Mixedwood ecoregion has an annual precipitation of 470 mm and a meant annual temperature of 0.2 C. Winters in the Mixedwood ecoregion are colder than those in the Foothills (Downing and Pettapiece, 2006). The lower total precipitation and cold winters of the Mixedwood ecoregion may explain why the sapwood moisture content dropped more quickly and did not show a higher level at the basal disc compared to the Foothills region where soils would be wetter for a longer portion of the year.

The proportion of trees that had developed one or more checks at any of the disc locations was similar to BC results in that by year two post-mortality, over 60% of the Mixedwood trees and close to 60% of the Foothills trees had developed one or more checks, compared to approximately 70% in BC. Trees in the sampled area of Alberta appear to have a slightly lower rate of check development (percent trees checked), but more checks per tree than trees in BC, within the first two years post-mortality. There was a lack of correlation between check numbers and depth, and tree size (DBH) in Alberta, unlike in the BC samples where DBH was a significant determinant of check numbers and depth. On average, trees from Foothills were larger than trees sampled in BC, whereas Mixedwood trees were smaller. Collectively this suggests that tree size is not an important driver of check development in Alberta. It is more likely that the drier conditions in Alberta result in faster drying of the sapwood and greater strain imposed on the wood resulting in more checks. However, once trees have been dead for three or more years in the Mixedwood region, and five to seven years in the Foothills region, all of them will have one or more checks. In the Mixedwood region, there will be on average more than one check at any point sampled along the tree by year three post-mortality. To reach this stage for the Foothills trees may take five or more years. However it is important to note that checks were observed in the field immediately after felling on a rough-cut (chainsaw) surface. It is possible that small or narrow checks were missed during these field observations, and it is possible that checks may develop or deepen during the skidding, loading and hauling stages.

Checks in trees from the Mixedwood region were very deep compared to checks in trees from the Foothills region, and were even deeper than trees from BC when compared within the same year post-mortality. Checks appear to deepen more slowly in the Foothills region compared to the Mixedwood region and central BC. It may be that drying in winter due to cold temperatures is at least partly responsible for the deep checking observed in the Mixedwood region.

Saprot fungi require moisture for growth so it was surprising that samples from the Mixedwood region showed more saprot both in terms of penetration depth and in location up the tree. In central BC, saprot was really only prevalent at the base of the tree, where moisture content was higher and the fungi could develop. A similar pattern was observed in the Foothills samples, which showed very little saprot except at the very base of the tree and at five years post mortality.

In summary, as observed in other studies, most of the major changes in wood quality occur during the first one to two years post mortality as the wood moisture content changes significantly, especially in the sapwood, as a result of tree death. This change in moisture content results in checks, which are the main defect in beetle-killed trees. The rate of check development in individual trees, and the proportion of trees that have checks, is greater for the Mixedwood region of Alberta compared to the Foothills region. The volume of wood does not change as a result of checking, but the wood becomes dry. Saprots and woodborers do cause wood volume loss as both agents use wood for nutrition. Very little saprot was observed in the Foothills samples and the very low rate of tree fall observed in both regions, reflects the lack of time that saprots have had to deteriorate the base of the tree to the point where it falls over. Based on just a few samples, we suspect that tree fall rates will be higher in the Foothills region, due to more extensive development of saprot at the base of the trees which is supported by higher sapwood moisture content at this location. The time it will take for trees to fall as a result of saprot at the base is unknown for the Alberta region, but given similar rates of development of saprot in trees in BC, it is estimated that fall down won’t occur at significant levels until 8-10 years post mortality in the Foothills region, and possibly longer in the Mixedwood region. It is only at this point that actual wood volume is lost due to greater rates of decay for trees that are in contact with the ground.

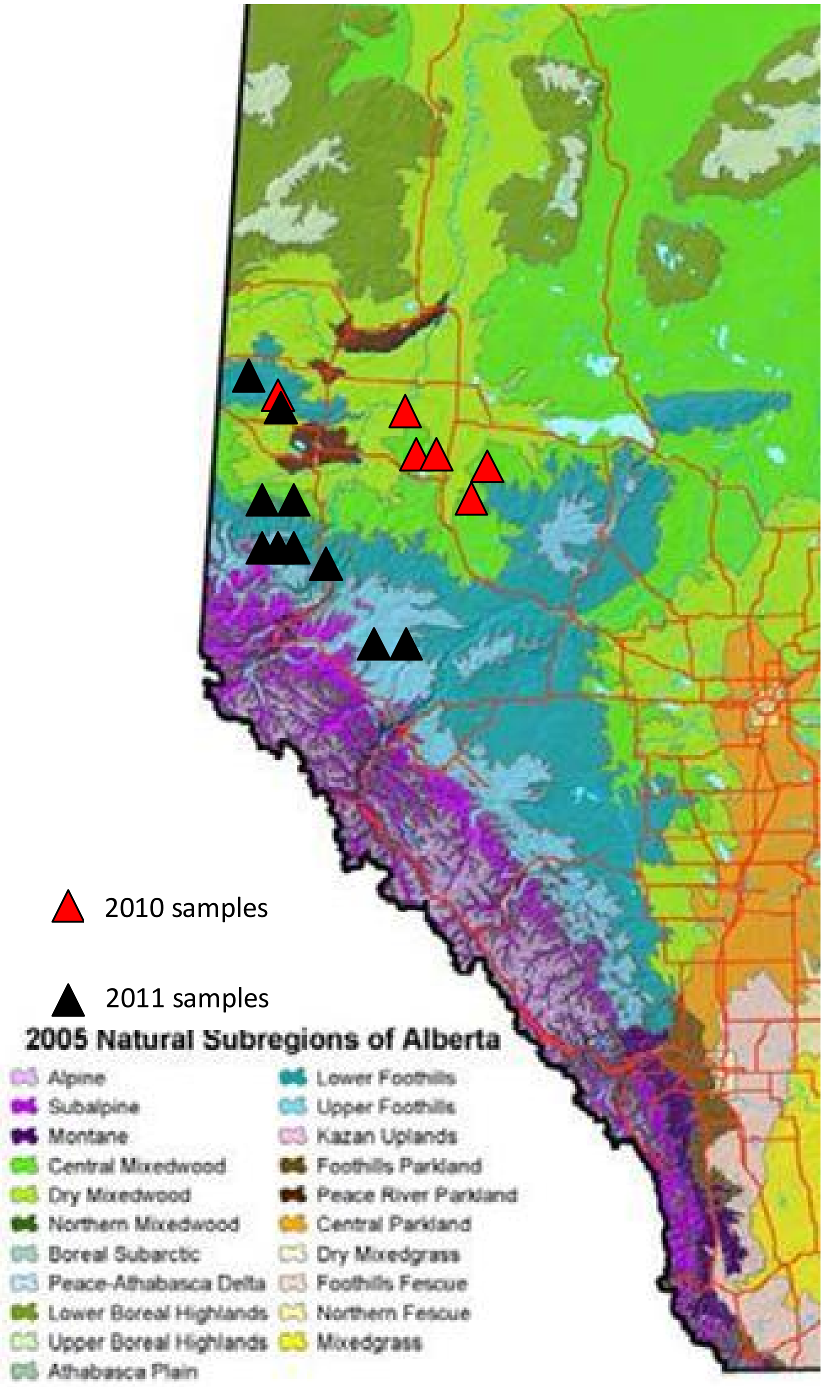


Figure 1. Map of Alberta showing sample locations for 2010 (Central Mixedwood) and 2011 (Foothills) sampling periods.

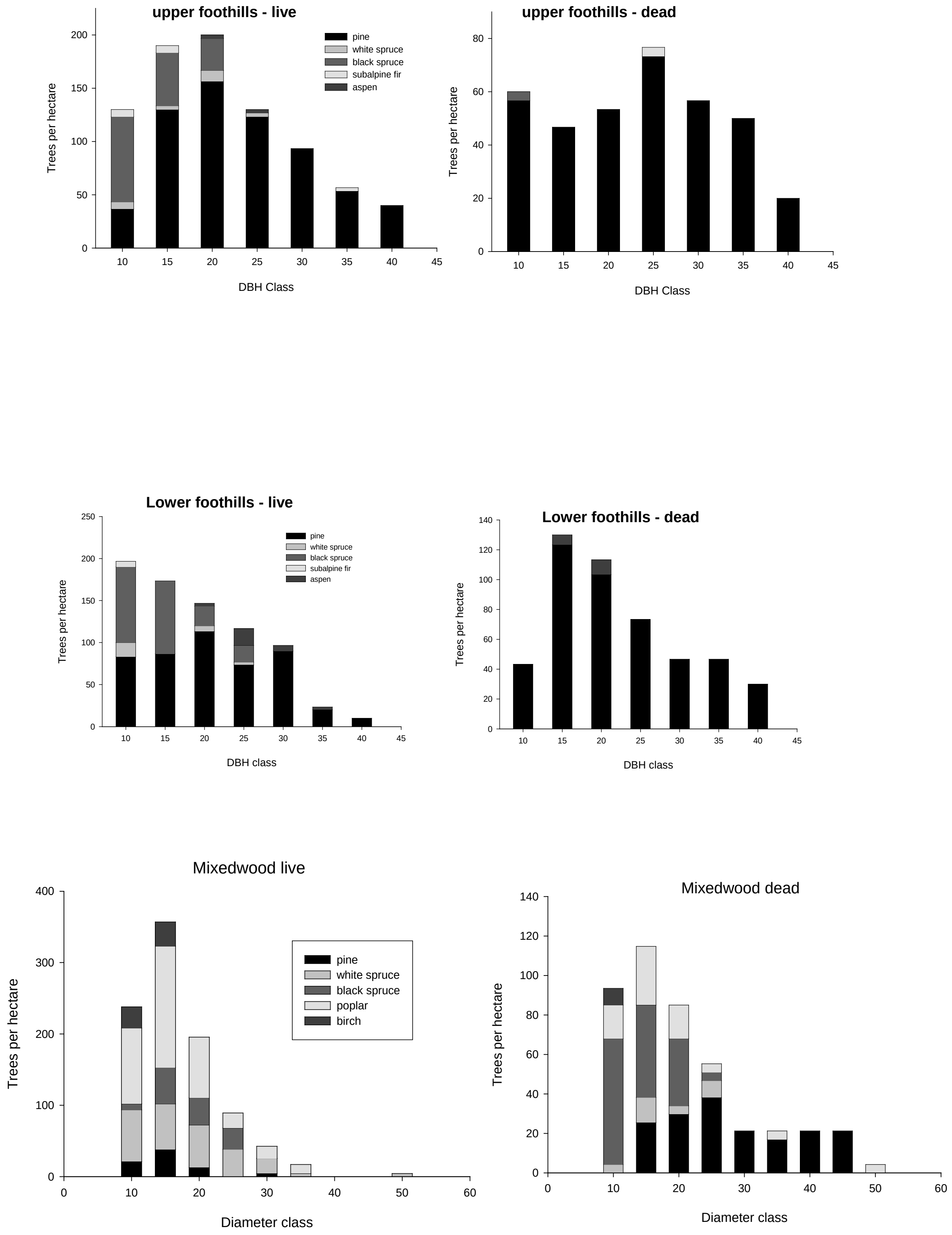


Figure 2. Distribution of trees by diameter class, species and live or dead, in the Upper Foothills, Lower Foothills and Central Mixedwood regions.

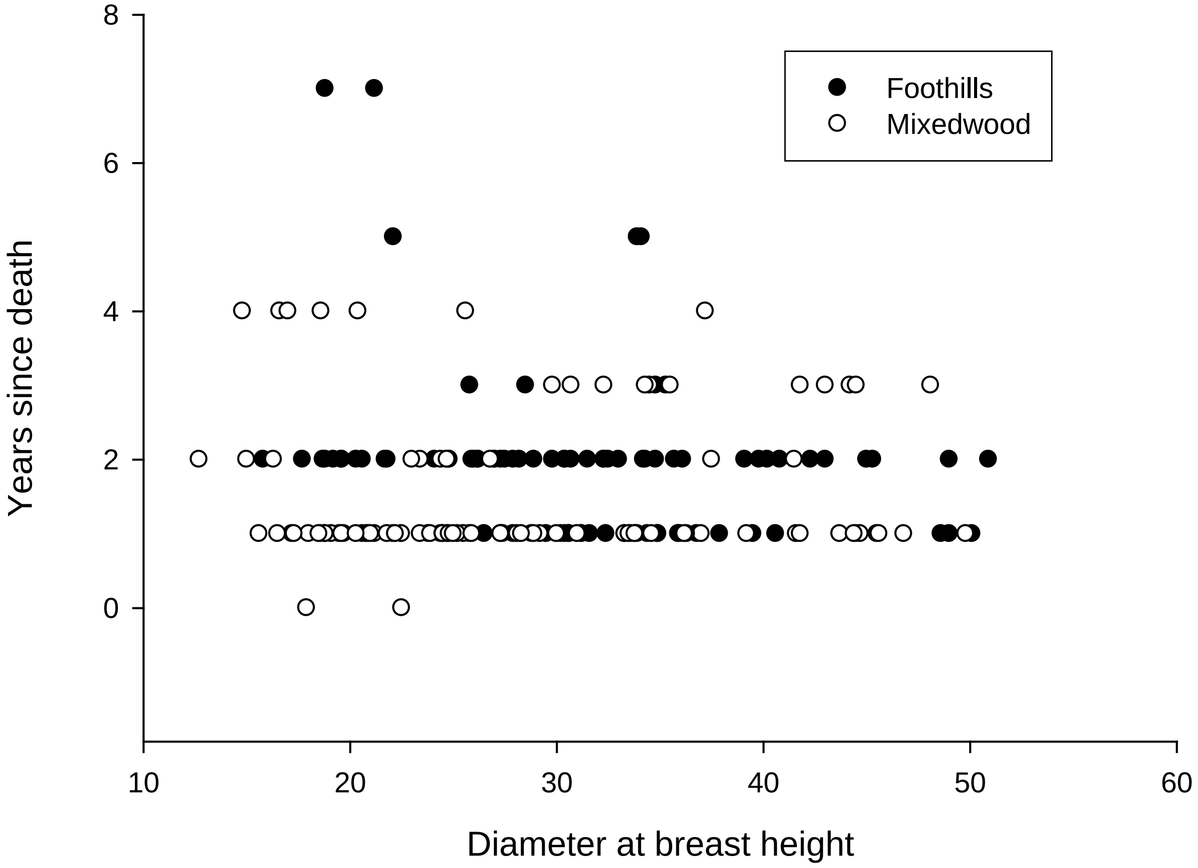


Figure 3. Years-since-death by diameter at breast height, for the Foothills and Mixedwood regions

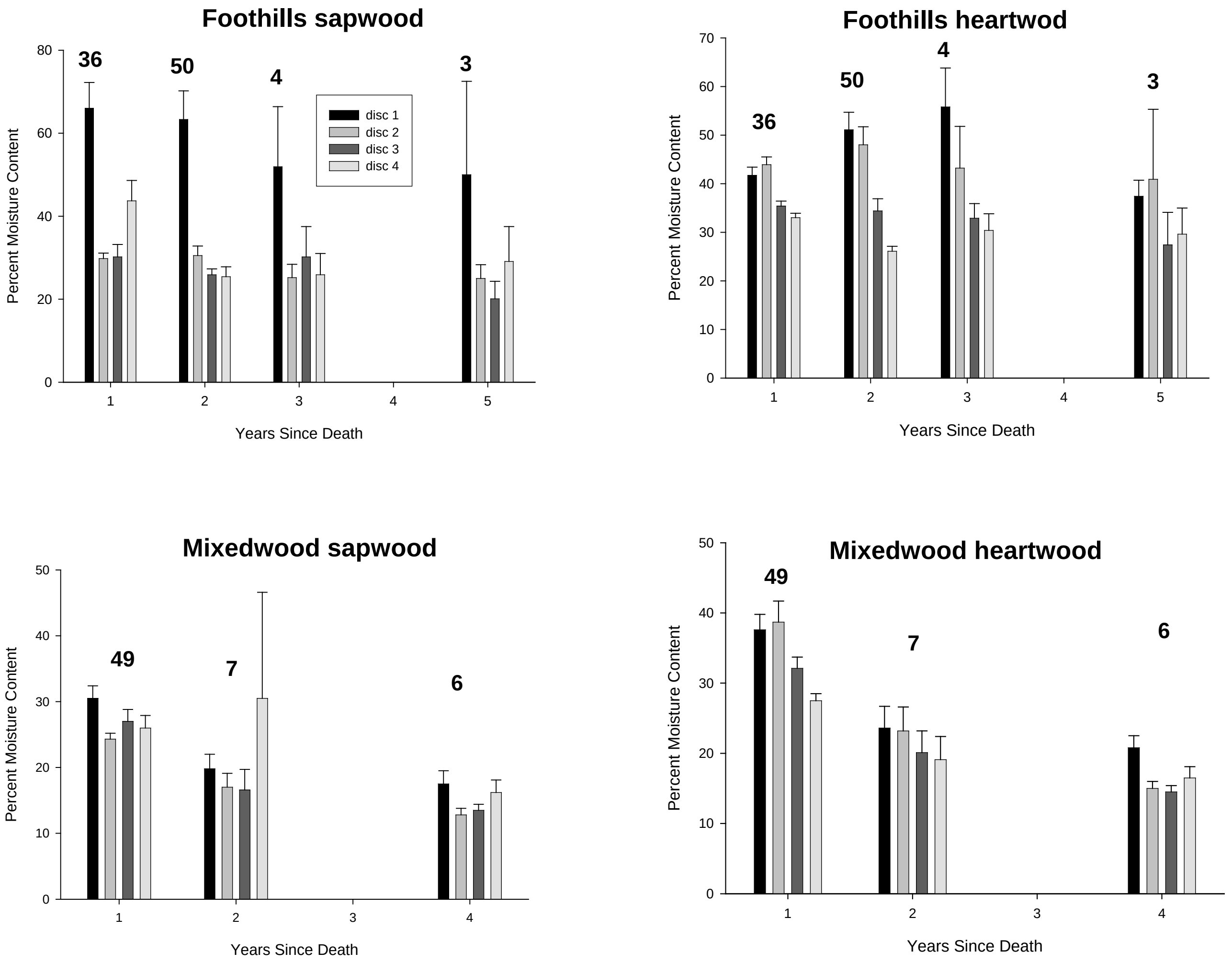
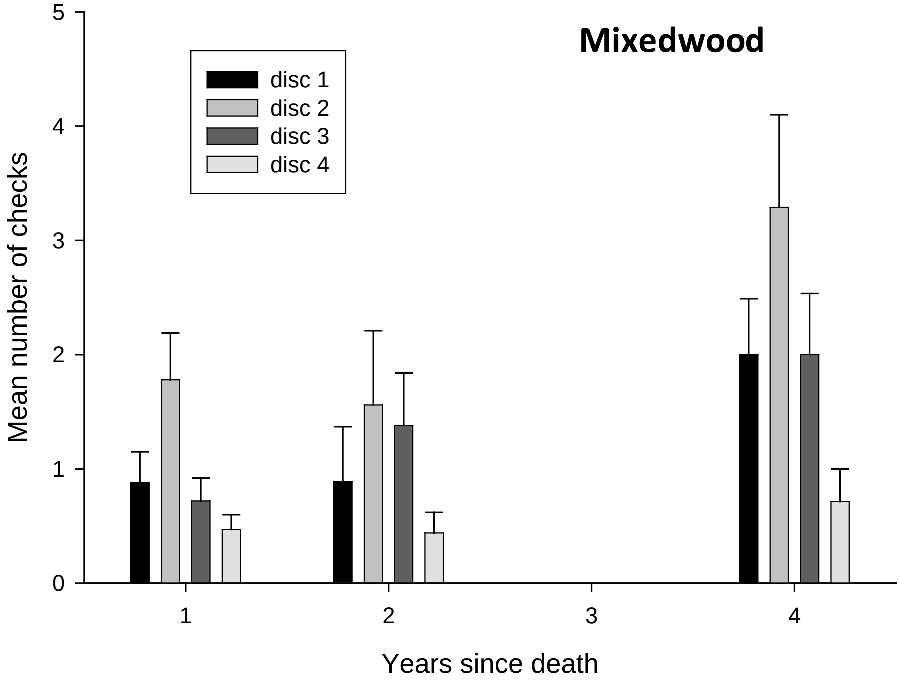


Figure 4. Percent moisture content in the sapwood and heartwood of trees from the Foothills and Mixedwood regions.



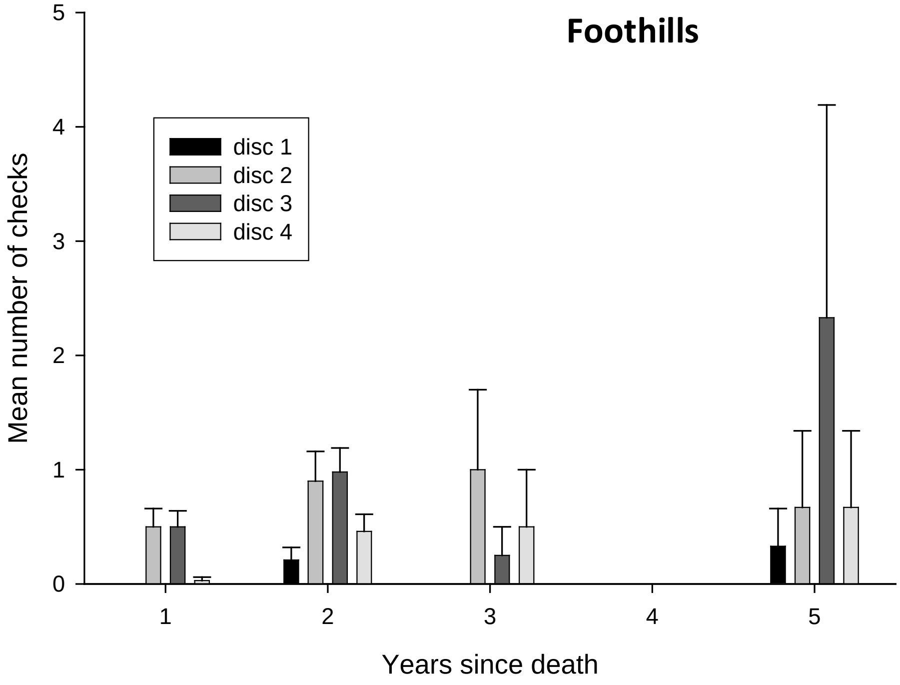


Figure 5. Mean number of checks at each disc location (1 = 0.3m, 2=1.3m, 3=1/3 of merchantable height, 4=2/3 of merchantable height). Lines with Ts represent standard error.

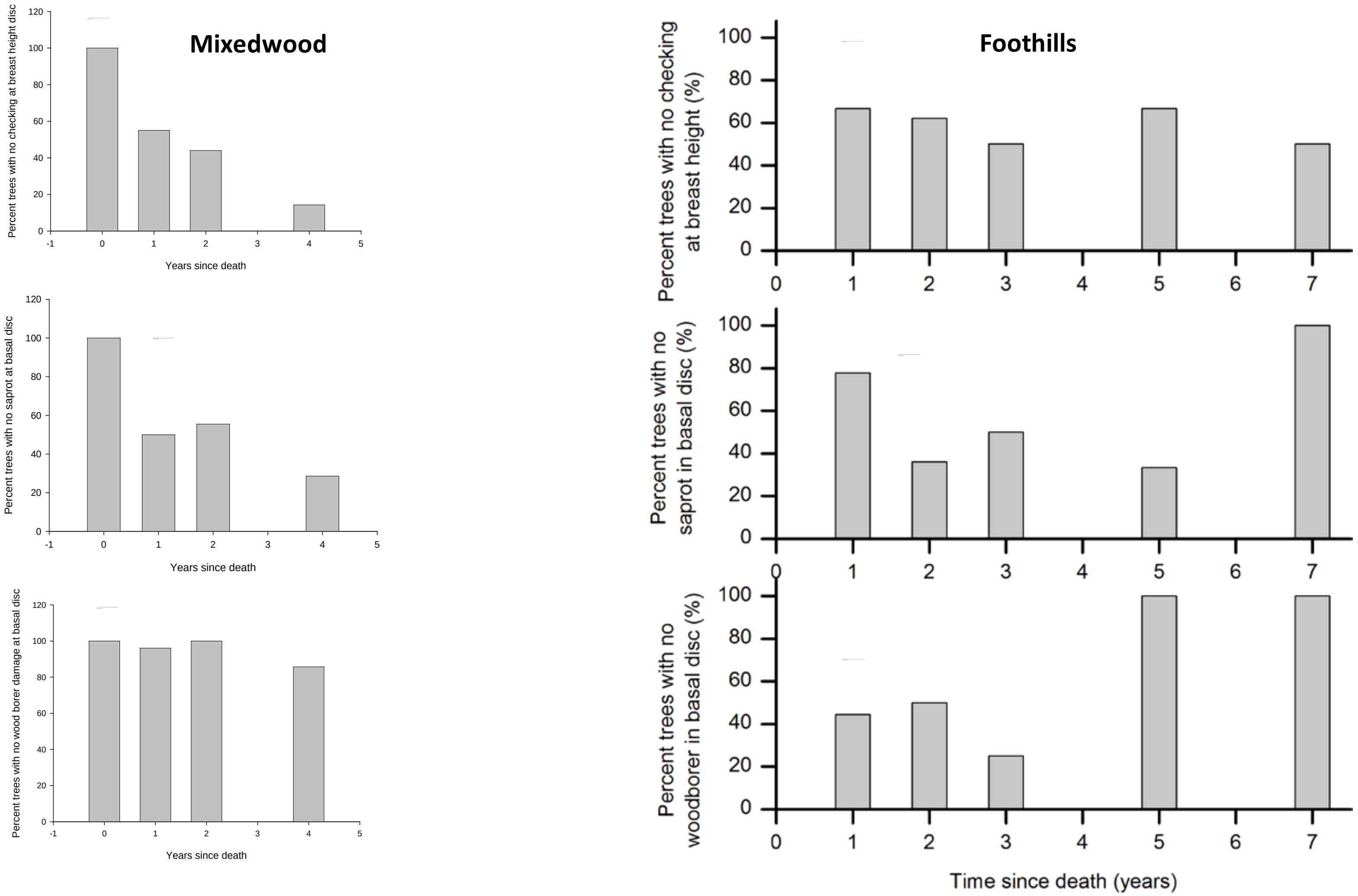


Figure 6. Percent of trees with A) no checking at the breast height disc (disc 2), B) no saprot at basal disc (disc 1), and C) no woodborer at basal disc for the Foothills and Mixedwood regions. Sample sizes for greater than 2 years post-mortality are only a few trees.

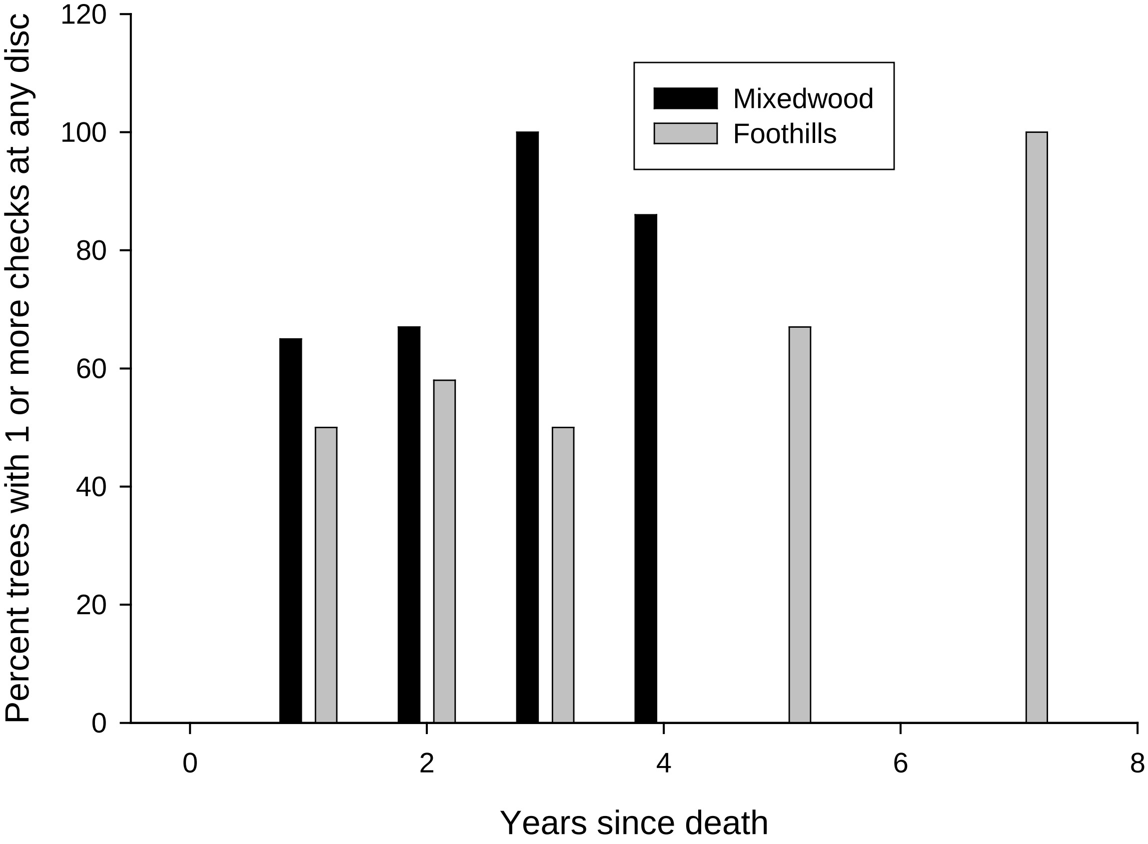
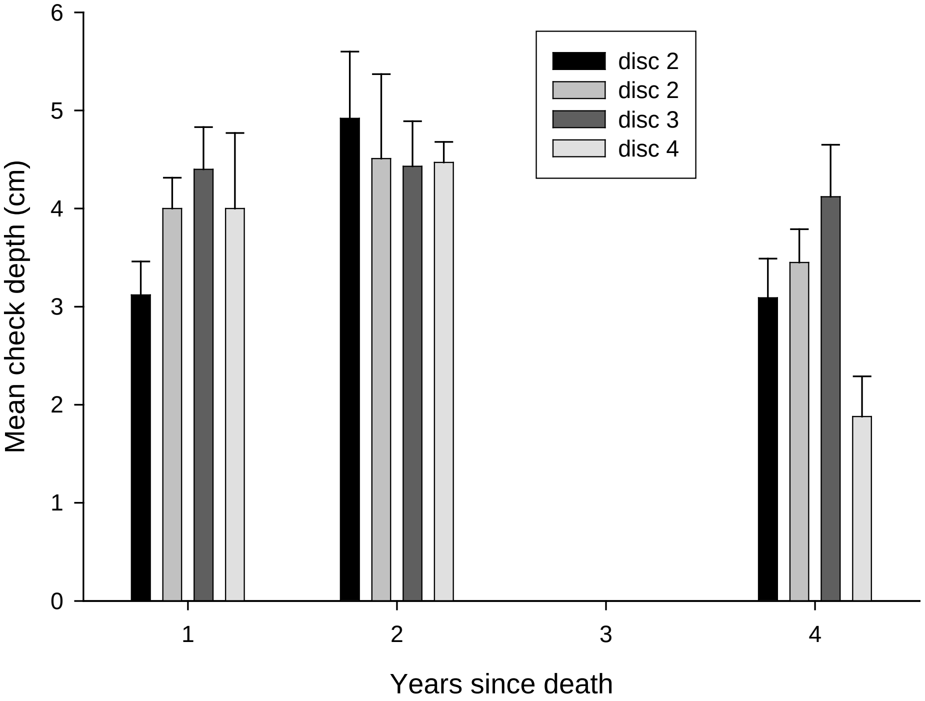


Figure 7. Percent trees with one or more checks at any of the sampling locations (discs 1, 2, 3, 4), for Foothills and Mixedwood regions.



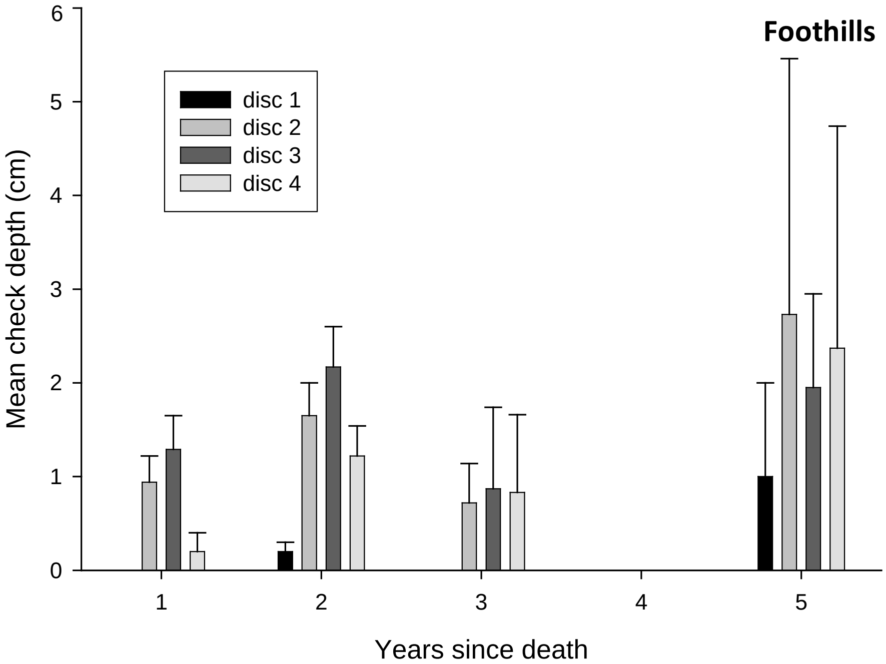
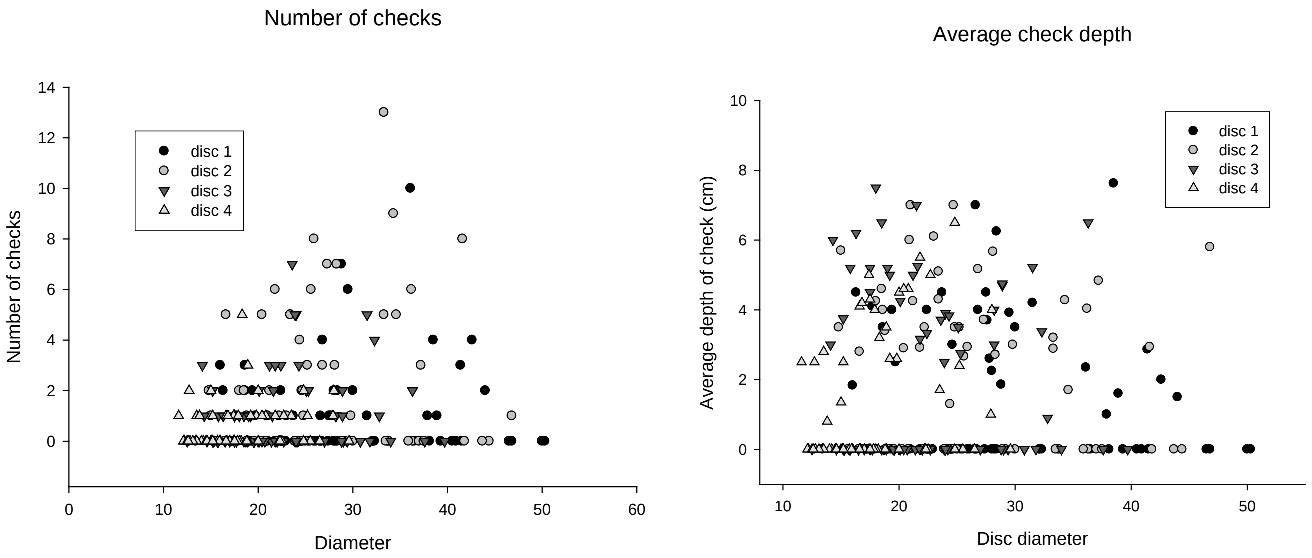


Figure 8. Mean check depth by years-since-death and disc location. Disc 1 = 0.3m, disc 2=1.3m, disc 3= 1/3 merchantable height, disc 4=2/3 merchantable height. Lines with Ts are standard error.

Mixedwood



Foothills

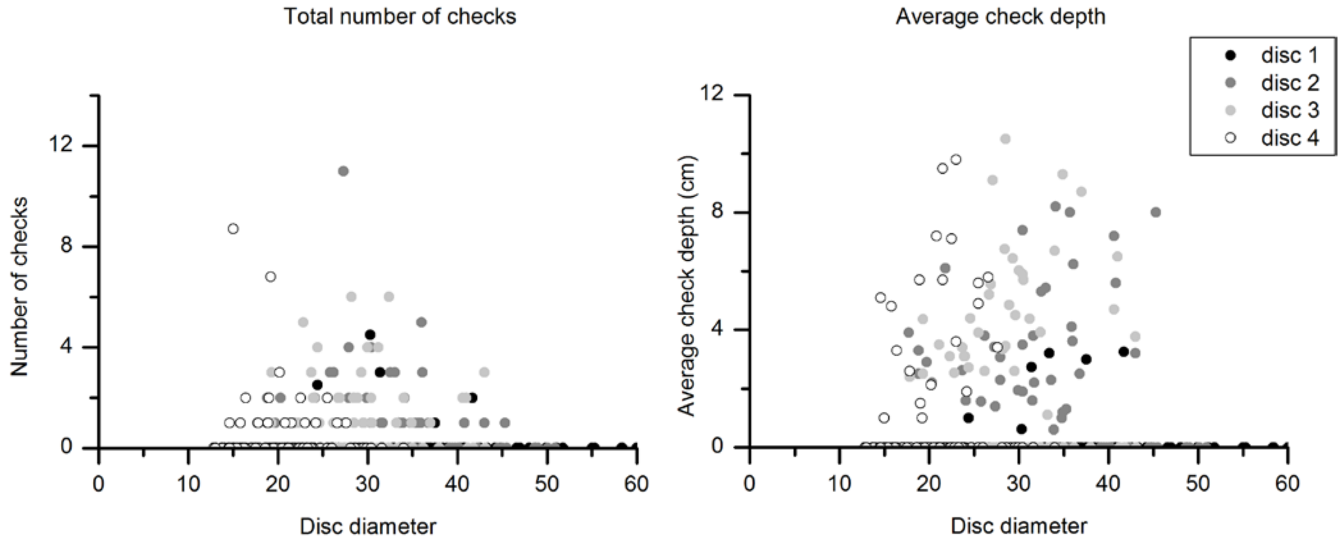


Figure 9. Number and depth of checks (left and right graphs respectively) plotted by disc diameter for the Foothills and Mixedwood regions.

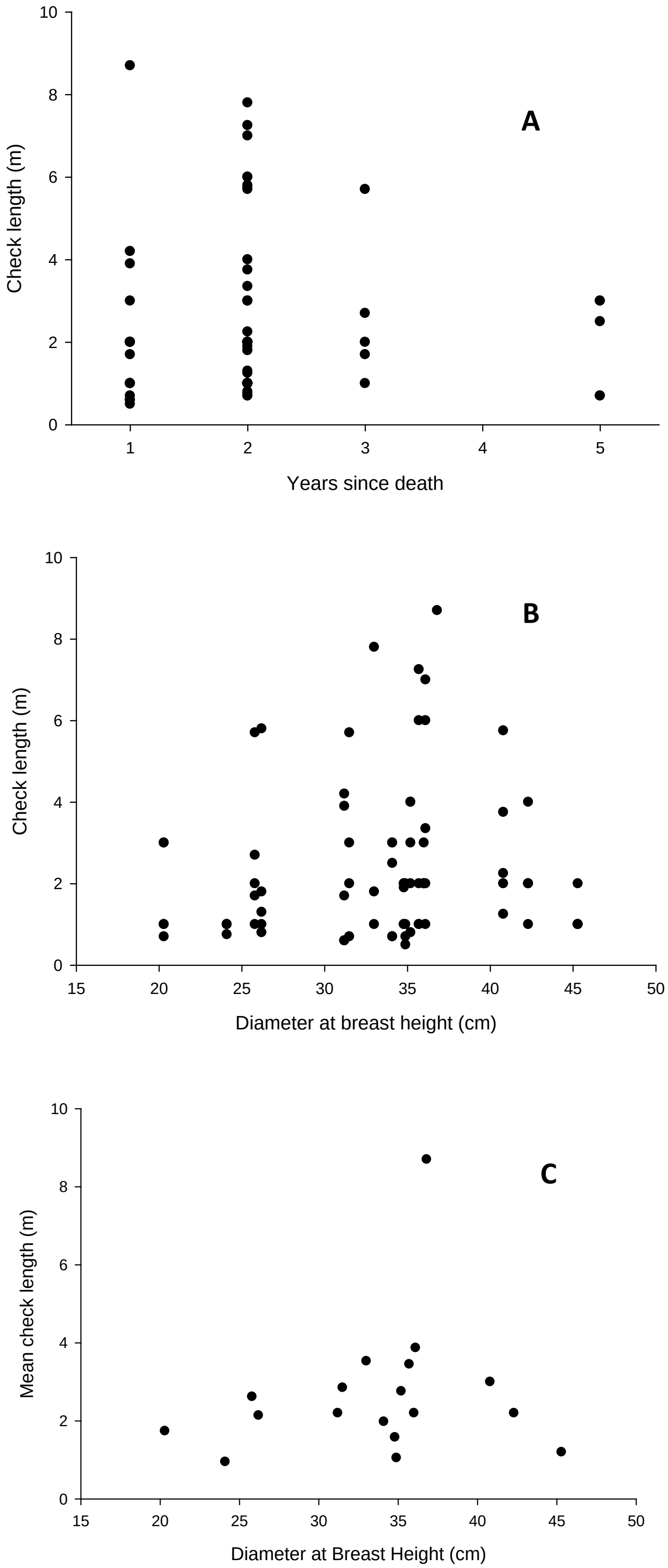


Figure 10. Check length plotted by years since death (A) and diameter at breast height (B), for each individual check measured. Mean check length per tree plotted by diameter at breast height (C).

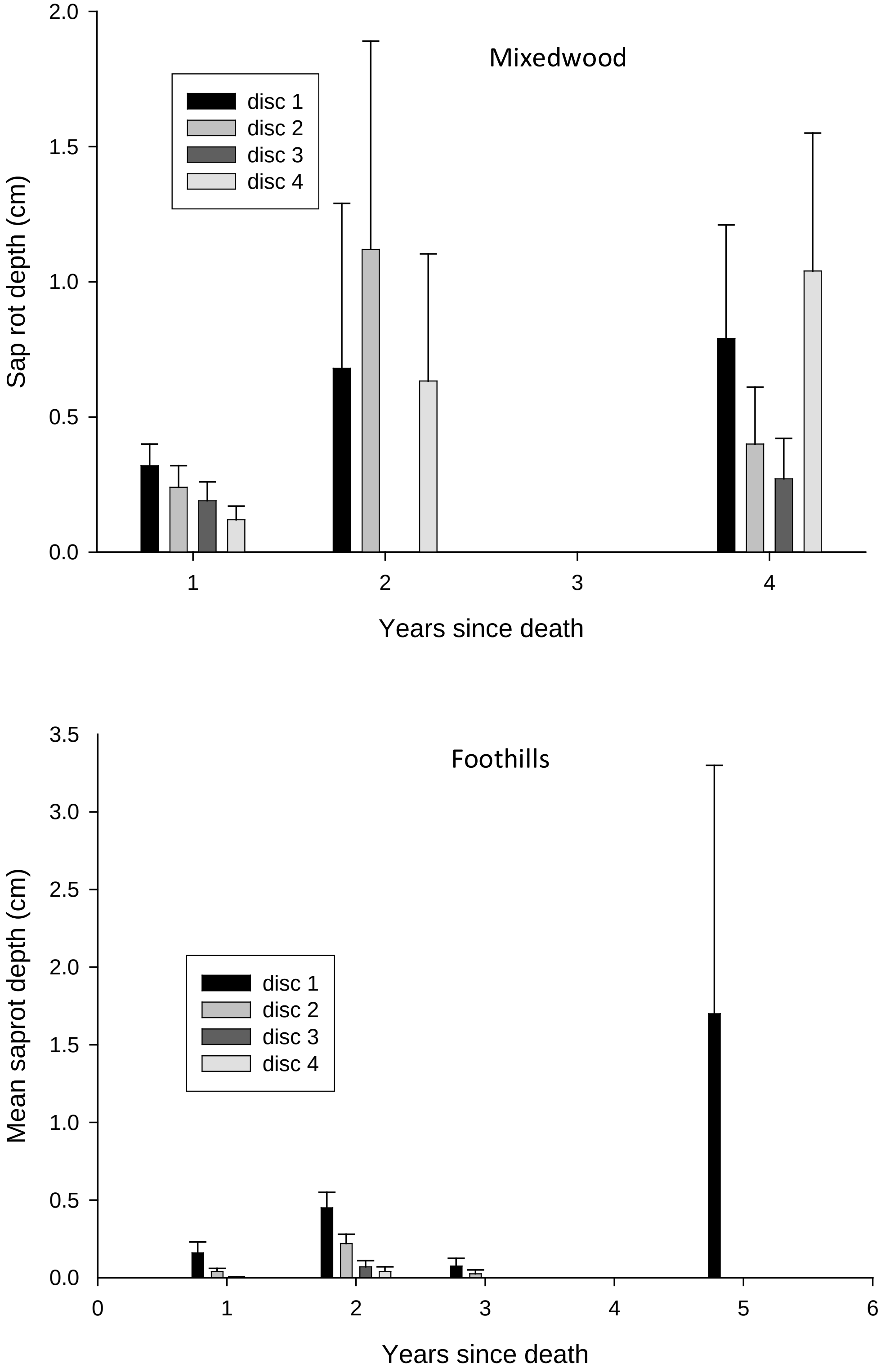


Figure 11. Mean saprot depth plotted by years since death and disc location. Disc 1 = 0.3m, disc 2=1.3m, disc 3= 1/3 merchantable height, disc 4=2/3 merchantable height. Lines with Ts are standard error.

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