Degradation and Loss of Wood Fibre in Spruce Budworm-Killed Timber, and Effects on Utilization

by

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Abstract

Far more investigations of the deterioration and utilization of the stems of trees killed following spruce budworm (Choristoneura fumiferana [Clem.]) defoliation have been, or are being, carried out during the current budworm outbreak in eastern and central North America than in all previous outbreaks combined. Unfortunately the results are dispersed in a wide variety of publications, some of which are relatively obscure and difficult to find. This report is an attempt to assist the forest manager faced with salvage decisions, by reviewing and summarizing current knowledge and by identifying some of the potentially useful literature.

Key Words: Spruce budworm, balsam fir, stem deterioration, sap rot, dead trees, salvage, utilization, pulp quality.

Résumé

La dégradation et l'utilisation des tiges d'arbres tués après avoir été défoliés par la tordeuse des bourgeois de l'épinette (Choristoneura fumiferana [Clem.]) ont été beaucoup plus étudiées au cours de l'infestation actuelle, dans l'est et le centre de l'Amérique du Nord, qu'au cours de toutes les autres infestations antérieures réunies. Malheureusement, les résultats de ces études sont dispersés dans beaucoup de publications, dont certaines sont relativement obscures et inaccessibles. La présente étude bibliographique se propose d'aider l'aménagiste qui doit décider des modalités de récupération, en faisant le point des connaissances actuelles et en indiquant certaines publications utiles.

Mots clés: Tordeuse des bourgeois de l'épinette, sapin baumier, épinette, dégradation des tiges, pourriture de l'aubier, arbres morts, récupération, utilisation, qualité de la pâte.

Introduction

The current spruce budworm (Choristoneura fumiferana [Clem.]) outbreak in eastern and central North America has transformed thousands of square kilometres of forest into grey, dying or dead trees. Forest managers must decide in which of three basic ways they will treat stands containing such trees. The three choices are (1) to bypass the stand, allow the trees to die, breakup and decompose, and wait for the next rotation; (2) to protect the trees that are still alive from further insect defoliation, usually at high cost, so that they can be harvested alive later; or (3) to salvage the stand as soon as possible. As a rule the last choice is preferable, provided that the degradation and loss of stem fibre in the killed trees are not of sufficient magnitude to tip the balance from a profitable to an uneconomical operation (2).

Forest managers are understandably reluctant to harvest stands that contain a high proportion of dead trees. Such stands have several characteristics that adversely affect forest operations. For one thing, they are associated with distinctly greater safety hazards than are healthy stands. In harvesting stands with a high proportion of mortality, tree hangups are more likely because the dead trees weigh less, tops are more likely to break off during felling, eye injuries are more common because the dead twigs are less visible, and the usual presence of dense shrub growth and fallen trees reduces the maneuverability of both men and machines. Salvage operators know they will encounter these problems, and by walking through a stand they can gauge the approximate extent of safety problems that lie ahead.

The other unfavorable characteristics of dead trees are associated mostly with the degradation and loss of wood fibre, and are far more difficult to predict. In fact it is doubtful that a precise, straightforward manual on the rate of deterioration of the stems of budworm-killed trees, and the optimum methods of harvesting, handling, storing and utilizing those trees, will ever be written; there are simply too many variables (4,10).
Stem Deterioration

With respect to the utilization of trees killed following spruce budworm defoliation, three significant changes occur in the stems as trees pass from the moribund to the dead state, viz., they become relatively dry and brittle, they are invaded by wood-consuming insects, and they are invaded by the principal agents of deterioration: fungi. Although the stems of some severely defoliated and weakened trees have been observed drying on one side or along one vertical band of the cambium before the remainder, as a rule the entire cambium of a tree dies more or less simultaneously (3). Until death, regardless of overall tree vigor and degree of defoliation, the stem for all practical purposes remains as suitable for utilization as that of a healthy tree. When tops die two or more years before the rest of the tree, which frequently happens, the insects and fungi that invade and deteriorate those tops seldom descend into the merchantable stem portion (7, 28). There is little evidence that stem decay and butt rot, which may be present in the stem prior to budworm outbreak, are significantly affected by defoliation and death (27, 28).

Insects. Several insects depend on the stems of recently killed trees as feeding and/or breeding sites essential for the completion of their life-cycles. In balsam fir killed by spruce budworm defoliation, five main groups of insects are involved: bark beetles, ambrosia beetles, woodwasps, weevils, and sawyer beetles (wood borers). All groups are strongly adapted to seeking out and attacking trees virtually as soon as the trees die. After two or three successive years of mortality in a stand, some of these insects can become so abundant that severely weakened trees are attacked before they die (8). There is evidence that weevils may even cause some trees to succumb (1). Direct degradation and loss of wood fibre resulting from insect activity in killed balsam fir are limited (5). Bark beetles and weevils do not penetrate the wood to any extent, their activity being confined mostly to the inner bark and outer wood surface. Woodwasps and ambrosia beetles penetrate the xylem, but only to a limited degree. Most of their larval mines are much less than 2.5 cm in depth, and are relatively small in diameter. Wood borers (Monochamus spp.) cause the most damage; their mines, up to 6 mm in diameter, as a rule penetrate to the centre of the bole. At the average density of entrance holes found in budworm-killed balsam fir in eastern North America (22/m²), it has been estimated that 15-cm-diameter logs would only lose approximately 1% of their volume to larval mining (32). The major role of secondary stem insects might well be in their relationship to specific fungi that cause deterioration. This will be discussed in succeeding paragraphs.

Fungi. When a tree dies, its sapwood, until then virtually resistant to fungal attack, loses both the protection afforded by the living bark tissue and its own capacity to generate chemical barriers to infection. The sapwood suddenly becomes very susceptible to fungal invasion. Several different fungi attack the outer stemwood of budworm-killed trees; some are borne by invading stem insects, while others rely on the activity of those insects to enhance their development and spread within the stem. The fungi invade the stems in a more or less regular succession, and this initiates a process of disintegration and decay. It is a more or less continuous process, interrupted only during the six months from November to April when cold temperatures suspend most fungus (and insect) activity. The first sign of fungal deterioration is a reddish-yellow discoloration of the outer sapwood. This wood usually remains firm, and the defect is referred to as sap stain or firm sap rot. Virtually all of this defect is caused by the fungus Stereum chailletii (Pers. ex. Fr.), which is apparently completely dependent upon woodwasps for transmission from dead to recently killed or dying trees (29). Female adult woodwasps deposit both their eggs and spores or fragments of S. chailletii 12 to 20 mm deep beneath the cambium, and they can occur in such numbers that most of the sapwood can be discolored a few months after tree death. Woodwasps that attack balsam fir are generally more abundant in eastern than in central North America, and this is why sap stain has been found to develop more rapidly and extensively in killed trees in the Atlantic provinces of Canada and in Maine than in Minnesota or Ontario (1, 4, 6, 30).

The next stage of deterioration, which generally occurs one year or more after tree death, is a progressive softening of the outer stemwood. As a rule about 95% of this defect, known as advanced sap rot, has an orange, stringy appearance and is caused by the fungus Polyporus abietinus Dicks. ex. Fr. This is a wood-destroying fungus of the "white rot" group that breaks down both cellulose and lignin. The remaining 5% of advanced sap rot is caused by two or three fungi that belong to the "brown rot" group and break down cellulose but not lignin. This wood takes on a pale brown, cubical appearance, and is usually found as patches within the stringy P. abietinus sap rot, most frequently in the lower third of the bole. Wood borers, mainly Monochamus scutellatus Say, have been found in killed trees at much the same population level in all investigations of budworm-killed balsam fir, except in Newfoundland, where they are not as abundant (16). Trees relatively heavily attacked and mined by this insect generally have more extensive sap rot. This appears to be primarily because "ribbons" of P. abietinus sap rot frequently surround the mines and extend into the heartwood. Otherwise P. abietinus invades the central heartwood slowly, if at all. Several investigations of the rate of development of sap rot in balsam fir following death from spruce budworm defoliation have been carried out in eastern and central North America (4, 5, 6, 9, 16, 30). In some investigations, notably in northwestern Ontario, southern Ontario, Maine and Minnesota, P. abietinus sap rot has been found in all trees dead for two years, and occupying much of the sapwood in trees dead three years. On the other hand, studies in northeastern Ontario, New Brunswick and Newfoundland revealed very little sap rot in killed trees until the trees were dead four or more years.

In all of these investigations balsam fir bark beetle (Pityokeites sparsumus Lec.) population levels have been extremely high where P. abietinus sap rot developed rapidly, and very low where sap rot developed slowly. Attempts to isolate P. abietinus from bark beetles have failed, and usually within
individual stands a few dead trees can be found with heavy bark beetle attack and relatively little sap rot, and vice versa. Apparently the beetle plays no direct role in the development of P. abietinus sap rot in killed trees. Rather, it would appear that the conditions that promote or result in heavy bark beetle attack of the stems also favor the relatively rapid establishment and spread of the sap-rotting fungus within killed trees. Thus, bark beetle population levels may serve as a useful indicator of the rate of stem deterioration within killed trees. These can be checked quite easily in trees that have been dead for at least one summer, at which time the beetle has completed its stem activity. The tiny, circular entrance and exit holes in the bark, about 1 mm in diameter, can be seen with the naked eye or with a hand lens. An average of four or more holes per dm$^2$ of bark surface indicates that a heavy population was present shortly after the trees died, and an average of much less than one hole per dm$^2$ indicates a light population at that time.

An even more precise estimate can be obtained by peeling off a section of the bark and noting the presence of bark beetle nuptial chambers. These are irregular depressions in the cambium, about 6 mm across, from which two to four broad galleries radiate in mainly horizontal directions. In a light population nuptial chambers are difficult to find, whereas in a heavy population average counts of two to three per dm$^2$ are common. In trees dead only a few months — generally easy to recognize by their retained foliage of a distinct reddish-brown color — one must be aware that during the spring and early summer the bark beetle has probably not completed its stem activity and therefore population levels may not be fully reflected by the abundance of bark holes and nuptial chambers.

In most stands with budworm mortality, balsam trees die over a four-year period. Consequently, in salvage operations there may be living trees mixed with dead trees in various stages of fungal deterioration. There is a further complication in that, as mortality occurs from year to year, a gradual buildup can be expected in both secondary stem insect population levels and the abundance, or “inoculation potential”, of the deteriorating fungi. Therefore, the last trees to die in a stand will probably deteriorate more rapidly than the first trees killed. There is also evidence that trees dying in the late fall or winter deteriorate more slowly than those dying in the spring or summer. Add to these complexities the broad regional differences in deterioration rates mentioned earlier, and it is clear that predictions of the extent of sap stain and sap rot in salvaged timber prior to harvesting are, at best, educated estimates.

Since balsam fir is the tree species most commonly killed by the spruce budworm, it is not surprising that practically all deterioration studies have been carried out on that species. Some information is available on the deterioration of white spruce (Picea glauca (Moench) Voss) (12) and “eastern spruce” (1) killed by the spruce budworm, and of white spruce killed by other insects (22). All of these studies suggest very similar rates of deterioration of both balsam fir and spruce stems following mortality.

Harvesting

The moisture content of the stems of defoliated trees, particularly the sapwood, drops quite rapidly following tree death (6). This makes the fibres and hence the stems more brittle, and can be a serious problem as stems are liable to break during harvesting, handling and transportation. Manual felling and skidding operations generally result in the least breakage; the most breakage occurs with mechanical harvesting machines that subject stems to a whipping action (23). Manual harvesting operations in killed stands in which virtually no stem breakage occurred have been observed, whereas mechanical harvesting operations have been reported in which 30% of dead stems have been broken. In a study in Maine it was found that yarding was the harshest phase of a budworm salvage operation (9). Logging residue losses have been found to be considerably higher in budworm-damaged than in healthy stands (17). A recent report describes how one company repeatedly modified its logging equipment and techniques to combat problems, mainly breakage problems, associated with salvaging budworm-killed stands in Ontario (31). Transportation costs can be affected in tree-length hauls broken trees can reduce average truck loads by as much as 20%. Problems arise in trucking shortwood because the same volume of dead-tree logs can weigh as much as 35% less than logs cut from living trees. This can be an advantage or a disadvantage, depending largely on whether trucks are paid on a load volume or weight basis, and on any volume or weight limit restrictions.

Storage

In eastern Canada some budworm-damaged regions are being cut at rates that exceed mill demand, and the surplus timber is being stored in roadside piles for four or more years. The rationale for this policy is that stands can be harvested more efficiently if any tree mortality is relatively recent; the fire hazard is reduced, and the stems deteriorate more slowly in storage piles than if dead trees are left on the stump. The first two reasons are irrefutable; however, the third is by no means certain. If the timber is debarked and stored in well ventilated piles it may be true that its deterioration rate will be slower than if the trees had been left standing. However, little is known about the rate of deterioration in storage piles of timber cut from trees that were already dead and in which sap stain and sap rot were already present. Preliminary results from current investigations suggest that the more serious “brown rot” group of deteriorating fungi may be more common in storage piles than in dead standing trees, that longer logs deteriorate faster than short logs (17), and that peeling the logs at the time of storage slows the rate of deterioration (24).

Utilization

Pulp. Fungal deterioration of dead stems can seriously affect the yield and quality of pulp and paper produced from budworm-killed trees. Sap stain, which is usually present in even the more recently killed trees, has little effect on fibre strength or chip quality since the fungi responsible consume little or no cell wall material. However, the darkly pigmented cell walls cause considerable losses in brightness, particularly in stone groundwood. Sap rot, on the other hand, is caused by fungi that metabolize and decompose the cell wall substances and pass from cell to cell through bore holes in the walls which they form by enzyme action. This weakens and softens the wood considerably. The “brown rots” increase the lignin:cellulose ratio and should be avoided by pulp mills whenever possible (18). Fortunately, 95% or more of the sap rot in budworm-killed balsam fir is caused by the “white rot” fungus P. abietinus, where at least the lignin:cellulose ratio is unaltered.

Since it is invariably adjacent to the bark, much of the soft sap rot in dead stems is usually removed by the debarker. Ring debarkers have been reported to have removed roughly 14% of the wood volume in balsam fir dead an estimated three years (9,14), and 23.1% of the volume in balsam fir dead four or more years (13) following insect mortality. This additional waste material can create disposal problems, as well as problems with drum-debarking capacity. As a rule, drum debarkers leave more sap rot adhering to the bolts than do ring debarkers. This is a disadvantage because of the detrimental
effects of sap rot on pulp quality. Consequently, debarking that removes most or all of the sap rot is in reality a crude but helpful method of upgrading dead stem quality.

Any sap rot that does enter the chipper generally increases the amount of powder and the percentages of fines and pin chips, and decreases the percentage of accept chips (13,20). Provided that most of the soft sap rot was removed by the debarker the accept chips produced from dead trees make pulp of only marginally reduced quality in comparison with that produced from living trees. However, the successive losses of fibre volume that can occur in the harvesting, handling, transportation, debarking and chipping processes when budworm-killed stands are being salvaged combine to increase the costs of a given quantity of fibre at the processing point, often substantially (13,15). Since these losses tend to increase with increasing length of time since tree death, the desirability of salvaging budworm-attacked stands before or soon after mortality begins is obvious.

Whenever possible budworm-killed trees should be pulped chemically rather than mechanically; stone groundwood in particular should not be used. Not only does stained wood cause more serious brightness problems in mechanical pulps, but the strength of these pulps is affected by sapwood to a greater degree than that of chemical pulps. As for the various chemical processes, results from different experiments and tests do not always agree. The principal reason for this is probably the lack of uniformity in the methods used, i.e., some tests use all of the stemwood including sap rot out to the cambium, while others use only the inner stemwood that remains after debarking. In general, the yield of sulphite pulp from dead trees is similar to that from living trees; however, the yield of kraft pulp can be reduced noticeably (12,14,20). Sulphite pulp brightness is sometimes reduced when dead, deteriorated trees are used (12,14). Sap rot reduces chemical pulp strength because the fungi and the pulping processes combine to shorten the fibres and make them more flexible — tear strength is the property most seriously affected (9,12). Kraft pulp appears to sustain somewhat greater strength reductions than sulphite pulp (12). The main problems in processing dead, deteriorated trees in a kraft pulp mill have been summarized by the Pulp and Paper Research Institute of Canada as pulp yield loss, quality decrease, increased alkali consumption, non-uniform pulping, and increased recovery-boiler loading (13). When budworm-killed trees are used in any pulping process they should be mixed as uniformly as possible with living trees to minimize problems with cooking, pulp freeness control, and energy consumption.

Lumber. Recently the lumber industry has begun utilizing budworm-killed balsam fir more frequently. In a study on spruce defoliation or killed by the budworm, it was found that about 40% of the lumber volume was downgraded by defects that occurred because of the budworm's activity, and this resulted in a 21% reduction in product value (1). Several studies are in progress dealing with lumber produced from budworm-killed balsam fir. In lumber manufacturing, in contrast to pulp utilization, wood borer (Monochamus) mines are a serious problem, more from an aesthetic than a strength point of view. Other serious degrade problems occur because of sap stain, sap rot, and drying check; and volume losses are incurred, although heavy slabbag and trimming are usually necessary (21). When dead balsam fir trees are used for lumber, trees should be harvested as soon as possible after death, preferably within a year (26).

Waferboard. Recent studies suggest that both spruce and balsam fir timber from budworm-killed trees make waferboard of an acceptable quality (1,25). However, the wafer yield tends to decrease with increasing sap rot content, and therefore trees should be harvested as soon as possible after death.

References