PRELIMINARY REPORT ON THE RATE OF DETERIORATION OF SPRUCE BUDWORM-KILLED BALSAM FIR, AND ITS RELATIONSHIP TO SECONDARY STEM INSECTS

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ABSTRACT

Balsam fir (*Abies balsamea* [L.] Mill.) in three widely separated areas where trees had been dead for 0 to 1 and for 1 to 2 years following spruce budworm defoliation were dissected, and the extent to which stems had been attacked by secondary insects and microorganisms was studied. All trees examined 1 to 2 years after death in a stand heavily attacked by bark beetles had advanced sap rot, while trees in a stand with very little bark beetle activity had no advanced sap rot. These results agree with those of earlier studies in which a close relationship was shown between the incidence of bark beetle attack and sap rot, and in which budworm-killed trees in Ontario were consistently heavily attacked by bark beetles and were found to contain extensive sap rot when dead for longer than 1 year, whereas in Newfoundland, New Brunswick and Quebec bark beetle activity was relatively light and generally 3 to 4 years elapsed after death before appreciable sap rot developed. Current recommendations concerning safe periods in which killed balsam fir remains economically salvageable, 1 year in Ontario and 3 to 4 years in the eastern provinces, should be modified in view of these results. Bark beetle activity and sap rot development were not always related in individual trees; apparently the stand conditions that result in high bark beetle populations are also conducive to a relatively rapid rate of development of sap rot in killed trees.

RÉSUMÉ

Des spécimens de Sapin baumier (*Abies balsamea* [L.] Mill.) morts depuis 0 à 1 et depuis 1 à 2 ans des suites de la défoliation par la Tordeuse des bourgeons de l'Épinette ont été disséqués dans trois régions très distantes l'une de l'autre, et le degré auquel les tiges avaient été attaquées par des insectes et microorganismes secondaires a été étudié. Tous les arbres examinés 1 à 2 ans après leur mort dans un peuplement sévèrement attaqué par des scolytes de l'écorce révélaient un stade avancé de pourriture de l'aubier alors que les arbres d'un peuplement très légèrement infesté ne révélaient que peu de pourriture de l'aubier. Ces résultats s'accordent à ceux d'autres études antérieures ayant révélé un rapport étroit entre l'incidence de l'attaque des scolytes de l'écorce et la pourriture de l'aubier. Conséquemment, les arbres tués en Ontario par la Tordeuse avaient subi les sévères attaques de scolytes de l'écorce et présentaient une pourriture avancée de l'aubier lorsque leur mort remontait à plus d'une année, alors qu'à Terre-Neuve, au Nouveau-Brunswick et au Québec, l'activité des scolytes s'est révélée relativement faible et de façon générale, de 3 à 4 ans s'étaient écoulés depuis la mort, avant que ne se développe significativement la pourriture de l'aubier. D'après ces résultats, il faudrait modifier les recommandations concernant les périodiques sûres durant lesquelles le Sapin baumier mort demeure économiquement récupérable, soit 1 an en Ontario et 3 à 4 ans dans les provinces de l'Est. L'activité des scolytes de l'écorce et le développement de la pourriture de l'aubier n'étaient pas toujours reliés chez les arbres pris isolément; apparemment, les conditions du peuplement qui aboutissent à d'importantes populations de scolytes de l'écorce conduisent aussi rapidement au développement de la pourriture de l'aubier chez les arbres tués.

TABLE OF CONTENTS

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INTRODUCTION

Despite the fact that several studies, including two in Ontario, have been undertaken concerning the rate of deterioration of balsam fir (*Abies balsamea* [L.] Mill.) killed by spruce budworm defoliation, few have involved intensive investigation of the effects of the resulting sap stain and rot on the pulp and paper manufacturing processes. The extent and severity of the current spruce budworm epidemic in eastern Canada, and the limited application of control measures, have resulted in widespread balsam fir mortality which will inevitably increase in the near future. Provincial governments and pulp and paper industries are faced with difficult decisions as to the feasibility of salvage operations in killed stands. They are concerned about the degree of pulp quality and value reduction associated with trees as time passes following mortality. One major problem is uncertainty about the extent of sap rot and sap stain in dead, standing trees. Even when this is known, the salvage operator has little or no data concerning what effect a particular proportion of defective wood will have on the pulping characteristics of the dead, harvested timber. All of these questions must be answered if intelligent decisions are to be made on the feasibility of carrying out salvage operations in budworm-killed stands.

A balsam fir tree at the time of budworm-induced death is usually not much different from a living tree as far as the quality, quantity, and value of its product are concerned. If death occurs after the seasonal period of insect and fungal activity, that is, in November or early winter, there is generally little change other than a decrease in moisture content until activity resumes in the spring. The lower moisture content may in itself have detrimental effects on the pulping process (Lowery et al. 1977). However, much more serious quality losses begin with the advent of warm weather, or when trees succumb during the growing season. The stems are then attacked, often quite rapidly, by secondary insects, the principal ones being the balsam fir bark beetle (*Pityokteines sparsus* [Lec.]), woodwasps (mostly *Sirex* spp.,) and sawyer beetles (*Monochamus scutellatus* Say). Concurrently, or shortly thereafter, the outer stem wood is invaded by bacteria, yeasts, and fungi such as *Stereum chailletii* (Pers. ex Fr.) capable of causing wood discoloration and incipient (firm) rot. From one to several years after tree death the stems are usually invaded by fungi that can metabolize the wood cell wall substances and greatly reduce the hardness and strength of the wood: this condition is called advanced rot. *Polyporus abietinus* Dicks. ex Fr. causes 90% or more of this type of deterioration in budworm-killed balsam fir in eastern Canada.

In the 1950s, two Canadian Forestry Service studies were carried out on the rate of deterioration of spruce budworm-killed balsam fir: one in Ontario (Basham 1951) and one in New Brunswick (Stillwell and Kelly 1964). These were followed in the late 1960s by an inter-regional study, involving the four eastern Canadian Forestry Service research centres, of the comparative rates of deterioration in balsam fir trees girdled to simulate budworm mortality (Basham et al. 1976). These studies indicated a much more rapid and extensive development of sap stain caused by *S. chailletii* in Newfoundland, New Brunswick, and Quebec than in Ontario. However, the far more serious sap rot caused by *P. abietinus* became established much earlier in killed trees in Ontario than in the three eastern provinces, and this suggests that losses would be considerable in operations involving trees dead longer than 1 year in Ontario, whereas salvage would still be economically feasible in trees dead up to 3 or 4 years in the eastern provinces. This was substantiated by a study of the deterioration of balsam fir in Newfoundland killed by the eastern hemlock looper, in which it was estimated that trees dead for 4 years were still suitable for pulpwood (Hudak et al. 1978). Only in this latter study was an attempt made to determine the effects of the deterioration of dead trees on pulping properties (Hiscock et al. 1978). However, because of marked regional differences that have been observed in the average rate of tree and stand deterioration (i.e., Ontario vs Newfoundland), the pulping results presented therein have only limited applicability outside Newfoundland.

Population levels of the different secondary stem insects fluctuate widely over time and from region to region. There is evidence that the rate at which deteriorating fungi affect the outer stem wood depends to a large extent on the presence/absence and abundance of the three principal secondary stem insects. For example, it has been shown that *S. chailletii*, the fungus responsible for sap stain in recently killed trees, is virtually dependent on woodwasps for transmission from dead to recently killed trees (Stillwell 1966), and that higher levels of bark beetle populations appear to be associated with faster rates of development of sap rot caused by *P. abietinus* (Basham et al. 1976). Furthermore, there are indications that, once this sap rot is established, its localized rate of penetration is hastened by the tunneling of sawyer beetles into the heartwood (Basham and Belyea 1960). Therefore, it is not surprising that in the Atlantic provinces, where woodwasps have always been observed on killed balsam fir stems in far larger numbers than in Ontario, sap stain caused primarily by *S. chailletii* develops faster and more extensively than in Ontario. In the earlier studies already mentioned, bark beetles have been consistently far more abundant on killed trees in Ontario than in the Atlantic provinces. It has been suggested that this may explain the much more rapid and extensive development of sap rot caused by *P. abietinus* in budworm-killed trees in Ontario than in those in the eastern provinces (Basham et al. 1976).

In 1979 the "Task Force for the Review of Canadian Forestry Service Research on the Eastern Spruce Budworm" attempted to establish a rationale which would bring research more in line with the needs of forest managers in eastern Canada. Following discussions with managers in the six eastern provinces, 10 research goals were identified. One of these goals was "to determine how, and within what time periods, the use of budworm-killed trees affects the quality, quantity, and value of the product from the mill". Managers in the provinces of Nova Scotia, New Brunswick, Quebec and Ontario placed a very high priority on this particular goal. In anticipation of this need, the Great Lakes Forest Research Centre in 1977 began a 5-year study of the nature and rate of deterioration of balsam fir killed by budworm from the current outbreak in Ontario. Portions of the sample trees were to be thoroughly tested for pulping characteristics. In the mid-1970s personnel of the Forest Insect and Disease Survey Unit determined that trees dying from spruce budworm defoliation in the Chapleau-Timmins region of northeastern Ontario were rarely being attacked by bark beetles and that dead trees appeared to be surprisingly sound (Sippell et al. 1976). Consequently, it was decided that the study would be carried out in different areas, one with light to none, one with moderate, and one with heavy bark beetle populations, in case there was, in fact, a relationship between bark beetle activity and sap rot development in killed balsam fir stems.

At the present time only preliminary pulping-test results carried out on the trees sampled less than 1 year after death are available. Consequently this report deals only with stem insect activity, and the development of sap stain and sap rot (and their associated microorganisms), in the stems of balsam fir sampled 0 to 1 and 1 to 2 years following death caused by spruce budworm defoliation.

MATERIALS AND METHODS

Permanent sample plots were established in three widely separated areas in balsam fir stands severely defoliated by budworm from the current spruce budworm outbreak. One plot was located near Chapleau, Ontario, where very little evidence was found of bark beetle attack on recently killed trees. A second plot was located near Mattawa, Ontario, where the level of bark beetle attack on dead trees was classified as moderate. No stands with recently killed balsam fir subjected to heavy bark beetle attack could be found in Ontario, although such conditions were extremely common in northwestern Ontario in the spruce budworm outbreak of the late 1940s. Hence, the third plot was established near Whyte, Minnesota, where there was heavy bark beetle attack on recently killed trees. This plot is only about 60 km from the Ontario border (See map, Fig. 1).

The plots were established in the fall of 1977. In each, 250 severely defoliated, moribund balsam fir between 10 and 20 cm DBH were tagged and described. In addition, between 40 and 50 dead balsam were tagged in each of the three regions. These trees, on the basis of the retention of many brown-red needles and the absence of sawyer beetle exit holes on the stems, were judged to have died sometime within the past year. At Mattawa the moribund and dead tagged trees were found in the same stand and hence were located in a single sample plot. In the two other regions the dead trees were in stands near, but not within, those containing the moribund tree plots. The moribund trees were re-tallied and described the following spring and fall. By the fall of 1978 sufficient moribund trees had died in each plot to supply the needs of this study. Death was judged to have occurred when no green foliage could be detected, and the removal of small areas of bark on three sides of the stem revealed brown, dry cambium. To reduce as much as possible differences in average tree size in different sampling years, the 24 dead trees in each plot with the fewest abnormalities such as forks, serious stem wounds, etc. were selected and divided into four groups of six trees each with similar size class distributions. One such group was then sampled, and a second group was sampled in the fall of 1979, so that in each region six trees which have been dead between 0 and 1 year and six trees which have been dead for 1 to 2 years have been sampled.

At the time of sampling, the selected trees were felled and dissected, cuts being made at a stump height of 15 cm, at .75 m and from there at 1.5 m intervals until a diameter of roughly 7.6 cm (3 in.) was encountered. At each of these cuts the diameter of the stem, inside bark, was measured and recorded. So, too, were the diameters of clear wood if sap stain or sap rot was present, and of heart rot, although this was rarely encountered. On each of these cross-sectional surfaces the sap stains and sap rots were described, and the percentages of deterioration attributed to sap stain, incipient sap rot, moderate sap rot, and advanced sap rot were estimated. Sap stain was defined as discolored wood with the same hardness as clear wood when prodded with the point of a sharp knife. Incipient sap rot was defined as discolored wood slightly softer than clear wood. Advanced sap rot was defined as very soft, disintegrated wood offering little or no resistance to the knife. Moderate sap rot was defined as intermediate between incipient and advanced sap rot.

All of the measurements, as well as the DBH and total height of each tree, were recorded on logarithmic tree measurement sheets. The sheets were subsequently planimetered and for each tree the total merchantable volume from stump height to a 7.6 cm top, the net volume

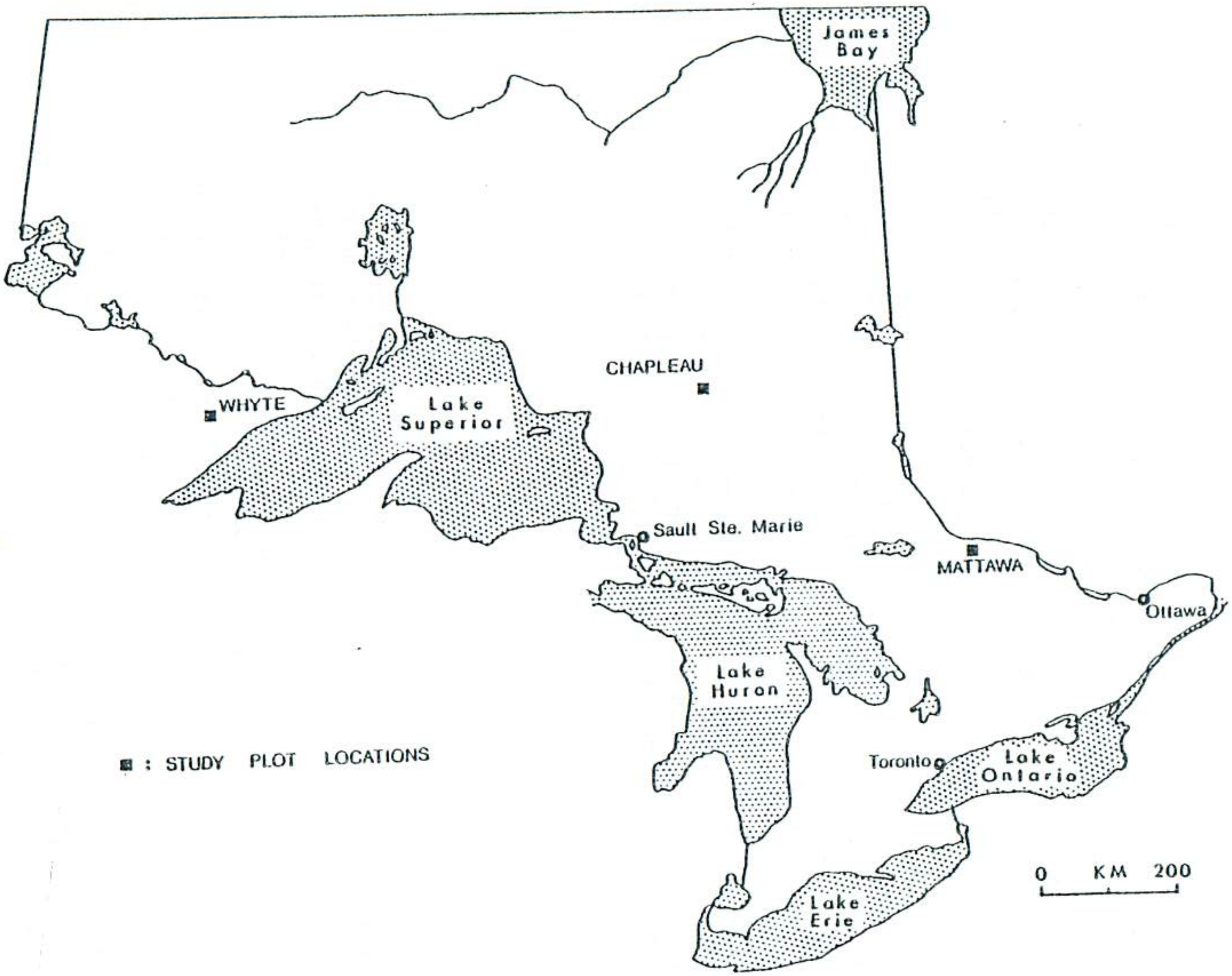

Figure 1. Map of Ontario showing the location of the three study areas.

of clear wood, and the actual volume of deterioration (sap stain and/ or sap rot) within the merchantable stem length were determined.

Stem sections roughly 15 cm in length were obtained at heights of roughly 60 cm and at 3 m intervals thereafter for subsequent dissection and isolation of microorganisms associated with sap stains and sap rots. Stem insect attacks on these sections were assessed, as they were on two additional 30 cm bolts obtained expressly for this purpose from the basal and top stem regions of each tree. Insect activity was assessed by recording the total number of bark beetle holes in the bark, bark beetle nuptial chambers in the cambium, sawyer beetle entrance and exit holes, woodwasp oviposition holes, and woodwasp exit holes. These numbers were expressed for each tree in terms of the number per dm^2 of stem surface area examined.

Three bolts approximately 1.22 m (4 ft) in length were extracted from each sample tree for pulp quality testing. These consisted of one top bolt with the top at the 7.5 cm diameter point of the stem, and two basal bolts 30 cm apart, generally between .75 m and 3.5 m above ground level. These bolts were shipped to Forintek Canada Corporation, Western Forest Products Laboratory, Vancouver, B.C. to be tested for the effects of sap rot and sap stain on debarking losses, chip quality, and the yield and quality of stone groundwood, refiner mechanical, thermomechanical, kraft, and bisulphite pulps.

RESULTS

Stand Descriptions

The three stands chosen for this study had to be accessible, predominantly balsam fir, heavily defoliated by spruce budworm so that a large proportion of the trees were in a moribund state, and they had to vary markedly in balsam fir bark beetle population levels, namely, light to none, moderate, and heavy. These parameters made it impossible to select three stands similar in all respects. The proportion of balsam fir in all stands was about 90%. The balsam stands at Chapleau and Mattawa were roughly 52 years old, those at Whyte were about 64 years old. The trees in the Chapleau and Mattawa stands had approximately the same diameter class distribution; however, those at Whyte were, on the whole, somewhat smaller. The average height of the balsam fir sampled at Chapleau was 11.0 m, at Mattawa 12.8 m, and at Whyte 11.9 m. The sites of the three stands were quite different, ranging from well drained in Chapleau to relatively poorly drained at Whyte. Stand densities also varied markedly; the stand at Whyte was the least dense, whereas the Chapleau stand was relatively dense. Despite all of these differences, it was encouraging to encounter markedly similar mortality patterns in all three. Of the 250 moribund balsam fir tagged in each region in 1977, 27 had died at Chapleau, 32 at Mattawa, and 30 at Whyte, by the fall of 1978.

Secondary Stem Insects

The three major secondary stem insects, bark beetles, woodwasps and sawyer beetles, attack balsam fir either just before, or during a short period following, tree death (Belyea 1952). Bark beetles and woodwasps generally complete their activity in dead stems, and die or depart in approximately one year, whereas sawyer beetles take almost two years to complete their life cycle and depart (Belyea 1952). Hence, sawyer beetle exit holes are the only visible sign of activity by any of these insects that one would expect to increase significantly between trees dead 0-1 year and those dead 1-2 years. Secondary stem insect activity recorded for the 18 sample trees dead 0-1 year and the 18 trees dead 1-2 years is presented in Table 1. Little difference was found in the incidence of woodwasp or sawyer beetle activity. Somewhat less woodwasp activity was observed in the sample trees at Whyte than in those at Chapleau and Mattawa, and slightly less sawyer beetle activity was evident in the trees sampled at Chapleau than in those sampled at Mattawa and Whyte. The striking differences between regions in bark beetle activity recorded from the stem sections examined (Table 1, last column) confirm that there was a heavy bark beetle population level at Whyte, a moderate level at Mattawa, and a very light level at Chapleau (Fig. 2). No evidence of bark beetle activity was observed in three of the 12 trees sampled at Chapleau. Nuptial chambers, a more reliable indicator of bark beetle populations and activity within trees than holes in the bark, were not found in nine of the 12 Chapleau trees.

Sap Stain and Sap Rot

In all three regions the extent of sap stain and sap rot development in the trees sampled when they had been dead for less than one year is shown in Table 2. The occurrence of heart rot (butt rot and trunk rot present in the central stem tissue before death) is also shown. There was no appreciable difference in the extent of sap stain among the samples from the three regions. Sap rot had not had time to progress to the advanced stage in any of the trees; however, incipient to moderate sap rot was the most extensive in the sample from Whyte and almost absent in the sample from Chapleau.

Table 3 is similar to Table 2, but presents data from trees examined one year later, that is, between 1 and 2 years following death. There was considerably more sap rot in these trees than in those that had been dead for less than one year. Again, the most

Table 1. Evidence of secondary insect activity on the stems of balsam fir trees dead up to one year and from one to two years.

Region	Sample trees, no. of years dead	Total stem length examined (m)	Woodwasps[a]			Sawyer beetles[a]			Bark beetles[a]		
			Ovipo-sition holes	Exit holes	Total activity	Entrance holes	Exit holes	Total activity	Visible holes through bark	Cambium nuptial chambers	Total activity
Chapleau	0-1	7.6	0.08	0.03	0.11	0.1	–	0.1	*b*	0.1	0.1
"	1-2	7.5	0.02	0.01	0.03	0.2	*b*	0.2	0.2	*b*	0.2
Mattawa	0-1	7.9	0.02	*b*	0.02	0.2	–	0.2	4.1	0.9	5.0
"	1-2	7.6	0.05	0.03	0.08	0.2	*b*	0.2	3.5	0.9	4.4
Whyte	0-1	7.3	0.01	–	0.01	0.3	–	0.3	10.2	3.2	13.4
"	1-2	7.5	0.01	0.01	0.02	0.2	*b*	0.2	6.4	2.1	8.5

[a] Insect activity expressed as total number of holes or nuptial chambers per dm^2 of stem surface area.

[b] Present as trace amount.

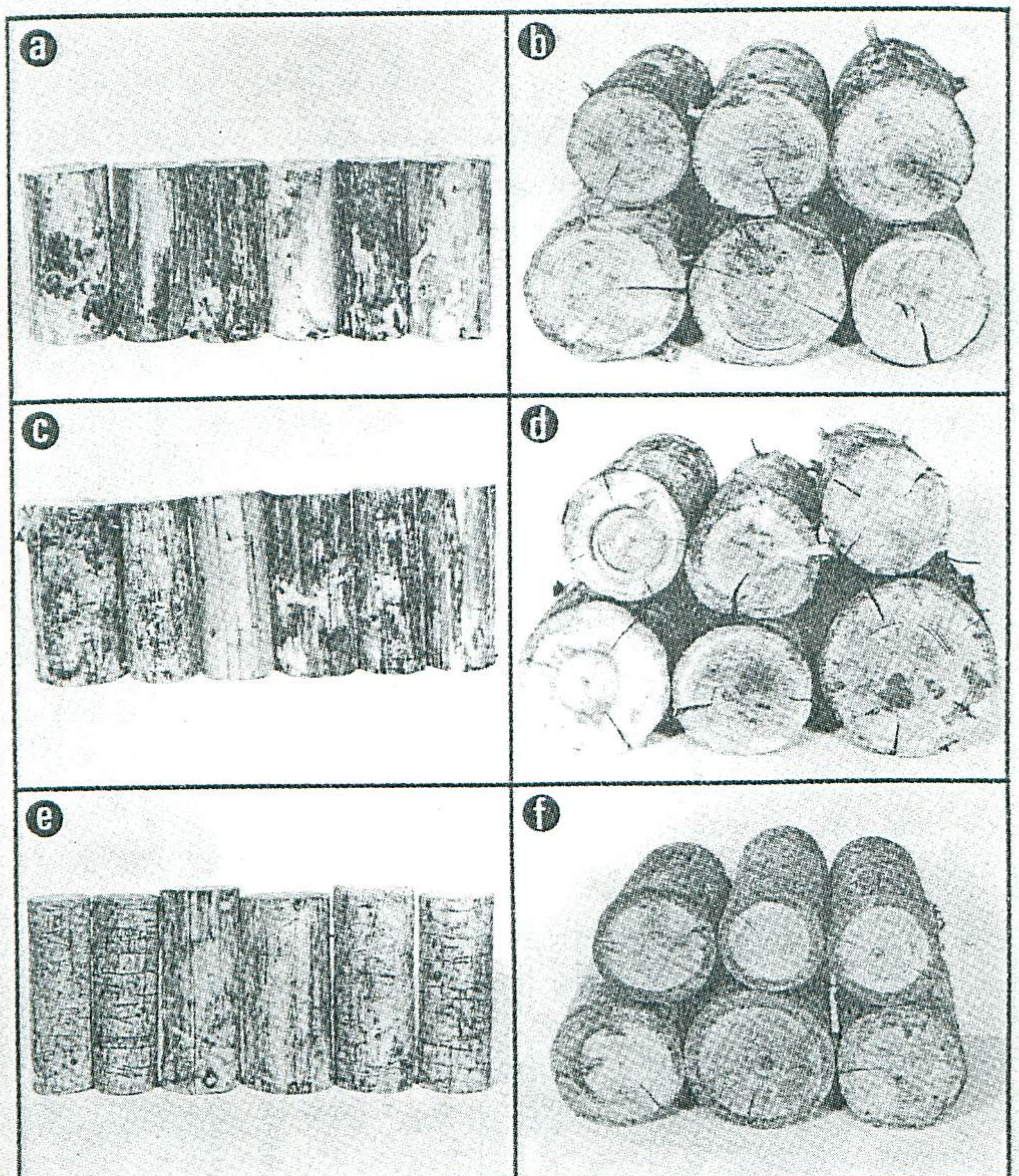

Figure 2. 30-cm bolts at heights of roughly 3 m, from balsam fir trees sampled between 1 and 2 years following death. a) and b): trees from Chapleau plot, showing very little bark beetle activity and very little sap rot. c) and d): trees from Mattawa plot, showing moderate bark beetle activity and patches of sap rot. e) and f): trees from Whyte plot, showing heavy bark beetle activity and considerable sap rot.

Table 2. Deterioration (sap rot and sap stain) in the stems of balsam fir trees dead less than one year. Basis, six trees per region.

Region	Avg tree diameter (cm)	Avg tree merchantable volume[a] (dm^3)	Percentage of total merchantable volume							
			Clear wood	Heart rot	Sap stain	Sap rot			Total sap rot	Total deterioration
						I[b]	M[b]	A[b]		
Chapleau	15.7	98.3	72.6	1.5	25.3	0.4	0.2	0.0	0.6	25.9
Mattawa	16.0	105.1	65.5	3.2	28.5	2.0	0.6	0.0	2.6	31.1
Whyte	13.2	62.3	71.8	0.0	23.1	4.1	1.0	0.0	5.1	28.2

[a] From stump height of 15 cm to a 7.6 cm diameter top.

[b] I: incipient, M: moderate, A: advanced.

Table 3. Deterioration (sap rot and sap stain) in the stems of balsam fir trees dead between one and two years. Basis, six trees per region.

Region	Avg tree diameter (cm)	Avg tree merch-antable volume[a] (dm^3)	Percentage of total merchantable volume							
			Clear wood	Heart rot	Sap stain	Sap rot			Total sap rot	Total deter-ioration
						I[b]	M[b]	A[b]		
Chapleau	15.5	88.6	65.0	0.9	20.8	12.3	1.0	0.0	13.3	34.1
Mattawa	15.2	90.6	59.5	2.4	11.7	10.9	11.7	3.8	26.4	38.1
Whyte	13.2	62.3	60.0	1.9	7.1	10.7	14.9	5.2	31.0	38.1

[a] From stump height of 15 cm to a 7.6 cm diameter top.

[b] I: incipient, M: moderate, A: advanced.

extensive sap rot was found in the Whyte sample (Fig. 2) and the least in the Chapleau sample (31.0% and 13.3% of the total merchantable volume, respectively). The breakdown of sap rot into the three stages of development is significant. There was still no sap rot in the advanced category in the Chapleau sample, but in the Mattawa and Whyte samples it amounted to 3.8% and 5.2% of the merchantable volume, respectively. Moderate sap rot accounted for only 1% of the volume of the Chapleau sample, in comparison with 11.7 and 14.9% of the Mattawa and Whyte sample volumes. Practically all of the sap rot in the Chapleau trees was in the incipient stage. Sap stain volumes decreased in all three regions as a result of the gradual replacement of sap stain by sap rot. There was little difference in the volume of deterioration on a percentage basis in the samples from all three regions. However, over half of this deterioration in the Whyte sample was composed of advanced or moderate sap rot, whereas in the Chapleau sample, approximately 3% of the deterioration was moderate sap rot, 36% incipient rot and 61% sap stain. In the Mattawa sample sap rot development was consistently intermediate between the rapid development at Whyte and the very slow development at Chapleau.

Relationship between Bark Beetles and Sap Rot

Figure 3 shows, for individual trees dead from 1 to 2 years, the relationship between the extent of advanced and moderate sap rot and the level of bark beetle activity observed on the stem. It is clear from this figure that, whereas there was a good positive relationship between these two factors on a stand basis (Tables 2 and 3), this did not hold true for individual trees. For example, of the six Chapleau trees, the two with the most rot had the lowest bark beetle activity--virtually none. The Mattawa tree with the most sap rot (27.5% by volume) had far less bark beetle activity than three other trees from this six-tree sample. The two points in the upper left portion of Figure 3 represent two of the trees sampled at Whyte that had relatively extensive sap rot, but showed little more bark beetle activity than the six trees from Chapleau, the area with the lightest bark beetle population. On the other hand, the point at the lower right of Figure 2 represents the tree that showed the highest level of bark beetle activity of all trees examined to date, yet it had the least amount of advanced sap rot of the six trees sampled at Whyte.

Microorganisms Associated with Deterioration

Table 4 lists the names of most of the fungi isolated from sap stain and sap rot in the trees sampled 0 to 1 and 1 to 2 years following tree death. It also shows the frequency with which each was isolated in the two years this study has been under way. *Trichoderma viride* Pers. ex Fr. was associated only with advanced

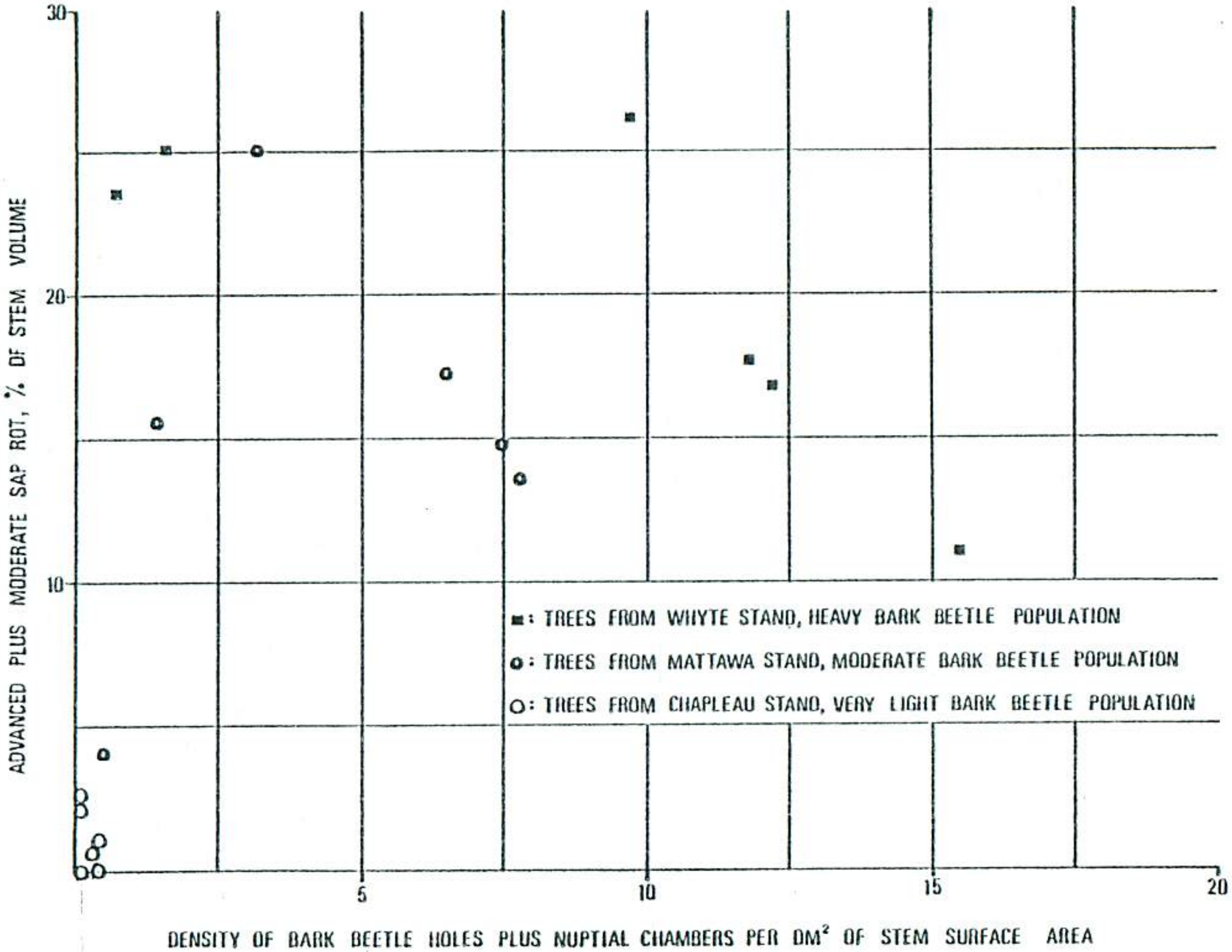

Figure 3. Relationship in individual trees dead 1 to 2 years, between intensity of bark beetle activity and incidence of sap rot.

Table 4. Occurrence of microorganisms isolated from sap rot and sap stain in balsam fir trees dead 0-1 and 1-2 years following spruce budworm attack.

Isolated microorganisms	Frequency of occurrence of microorganisms: Trees dead 0-1 year		Trees dead 1-2 years	
	No. of trees	% of total isolation attempts[a]	No. of trees	% of total isolation attempts[a]
Trichoderma viride Pers. ex Fr.	8	17.6	11	23.4
Polyporus abietinus Dicks. ex Fr.	3	4.0	10	21.5
Bacteria	11	12.9	17	18.8
Stereum chailletii (Pers. ex Fr.) Fr.	13	27.0	10	17.8
Nectria fuckeliana Booth	9	13.4	7	7.6
Cerotocystis spp.	9	15.9	5	4.6
Coniophora puteana (Schum. ex Fr.) Karst.	2	2.7	3	4.4
Armillaria mellea (Vahl ex Fr.) Kummer	7	4.0	6	3.5
Trichoderma sp.	4	3.2	3	2.8
Hyphoderma setigera (Fr.) Donk	0	–	4	2.5
Yeasts	10	4.2	4	2.3
Graphium sp.	7	3.2	3	2.3
Rhinocladiella sp.	6	2.5	1	1.2
Merulius himantioides Fr.	0	–	2	0.5
Cephalosporium sp.	5	2.2	1	0.2
Verticillium sp.	1	0.2	1	0.2
Misc. Basidiomycetes	2	0.7	7	3.5
Misc. Ascomycetes	12	7.7	13	11.1
Negative (sterile)	3	1.0	2	0.5

[a] Several attempts yielded more than one microorganism. A total of 403 attempts were made from trees dead 0-1 year, 432 attempts from trees dead 1-2 years.

sap rot; it is believed to be limited to a secondary role and not involved in the actual mechanisms of deterioration except perhaps as a competitor. Bacteria were isolated as well as fungi; they are also strictly secondary, and if competitors, they are relatively weak compared with *T. viride*.

The relative frequency of isolation of microorganisms (Table 4) is quite similar to that encountered in past studies of the deterioration of balsam fir stems killed following spruce budworm attack in Ontario (*N. fuckeliana* has been referred to as *Cephalosporium* sp., or as Fungus F, in past studies). *Stereum chailletii* was the fungus most frequently isolated from trees dead less than one year, being associated with sap stain in all three sample areas. In trees dead from 1 to 2 years it was less common, mainly because it was found in only one of the six trees sampled at Whyte. This is a reflection of the relatively fast establishment of the sap rot fungus, *P. abietinus*, in the Whyte trees. In trees dead less than one year *P. abietinus* was isolated from only three of the 18 trees, all in the Whyte plot, and the 10 trees dead 1 to 2 years from which it was isolated included all six trees from Whyte, three from Mattawa, and only one from Chapleau.

DISCUSSION AND CONCLUSIONS

The task of salvaging extensive areas of dead balsam fir is generally a formidable one, and the forest manager may feel that the obstacles to profitable operations are insuperable. The mixture of trees dead for different periods of time, the intensity of attack by a variety of secondary stem insects, the rate of development of sap stain and sap rot, local climatic conditions, etc., will influence the period in which economical salvage is possible. Not dealt with in this report, but known to be significant, are losses due to breakage during harvesting, slashing, and transportation (Sewell and Maranda 1978), fibre volume losses due to the removal of much of the advanced sap rot during the debarking process, poorer chip quality, and reductions in the quality of pulp manufactured from dead, deteriorated wood. Nevertheless, it is obvious that the more knowledge available to the forest manager concerning the nature, causes, and factors influencing the rate of deterioration of budworm-killed balsam, the easier it is for him to organize feasible and intelligent salvage plans. Secondary stem insects have little direct impact on the usability of the wood; only sawyer beetles cause noticeable volume losses by their tunneling, and for the average tree size and amount of tunneling reported in this study it has been estimated that volume losses of only 0.8% would be sustained (Wilson 1961). The development of advanced sap rot in killed trees is clearly of prime importance. A 15 cm (6 in.) bolt with sap rot penetrating to an average depth of 2.5 cm (1 in.)

suffers a reduction of roughly one-third its volume of sound, commercially valuable wood.

Two recent reviews of the deterioration of timber, mainly balsam fir, affected by spruce budworm outbreaks have included statements indicating that balsam stands with a relatively low incidence of mortality develop advanced sap rot at a faster rate than stands with high levels of mortality (Sewell and Maranda 1978, Lee and Field 1978). The reason given for this is that in stands with considerable mortality the dead, standing stems are subjected to more sunlight and hence the outer wood dries more rapidly, becoming in this way less susceptible to fungus deterioration. One of these reviews (Lee and Field 1978) cites Basham et al. (1953) in arriving at this conclusion; however, that paper deals with stem decay in living balsam fir and makes no mention of mortality rates or deterioration in budworm-killed stands. I cannot recall writing anything, at any time, in support of this viewpoint. Lee and Field also cite the paper by Stillwell and Kelly (1964) which deals with balsam fir deterioration in New Brunswick. This was the only paper on the subject cited in the second review (Sewell and Maranda 1978), and it does provide valid support for the theory. However, in Ontario at least, caution is advised in accepting this theory. In the Lake Nipigon budworm epidemic of the early 1950s, several sample plots contained 90 to 100% balsam fir mortality in which every tree examined that had been dead for 1 to 2 years had extensive sap rot. On the other hand, the Chapleau plot in the present study had the lowest mortality rate and the highest density of the three sample plots, yet the trees examined therein that had been dead for 1 to 2 years had virtually no advanced rot at all, in contrast to those in the other two plots (Table 3). It should be pointed out that Stillwell and Kelly based their conclusion on one stand with 50 to 100% mortality in which trees dead up to 7 years were examined, and on one stand with 10% mortality in which trees were examined only until they had been dead for 2 years (Stillwell and Kelly 1964). Other factors, such as secondary stem insects, climate, fungus spore abundance, etc., may well have been responsible for this situation rather than mortality rate and stand density.

Two well documented studies of the rate of deterioration of the stems of killed balsam fir have been carried out in Ontario. The first of these, conducted in the 1950s, dealt with balsam fir killed in the Lake Nipigon region following widespread, severe spruce budworm defoliation (Basham and Belyea 1960). The second, two decades later, involved trees killed by girdling to simulate budworm mortality. This was carried out in Ontario in two balsam fir stands, one in the Lake Nipigon region and the other almost 1000 km to the east near Huntsville, as part of an interregional study throughout eastern Canada (Basham et al. 1976). In both studies, dead balsam fir stems in Ontario as a rule developed faint red sap stain (discolored but firm wood) in the outer sapwood during the first year after death. Most trees dead longer than one year developed sap rot throughout much or all of the sapwood, making salvage operations at this time risky and uneconomical. This was in strong contrast to trees examined in a study of budworm-killed balsam fir in New Brunswick in the 1960s (Stillwell and Kelly 1964), and in the trees killed by girdling in Newfoundland, New Brunswick, and Quebec (Basham et al. 1976). In the majority of these trees, three or more years elapsed following death before appreciable sap rot developed. The interregional study (Basham et al. 1976) was undertaken mainly to try to explain the distinctly different regional deterioration patterns. It was concluded that, whereas climatic differences may have some influence, the principal explanation appeared to be secondary stem insect activity. Much heavier attacks by woodwasps in recently killed trees were recorded in the three eastern provinces than in Ontario, and these resulted in more extensive sap stain there because the principal causal fungus of sap stain, *Stereum chailletii*, relies almost completely on woodwasps for transmission from dead to recently killed balsam fir (Stillwell 1966). On the other hand, far more intensive attacks by bark beetles occurred in both studies in Ontario than in the three eastern provinces, and these were associated with a much more rapid and extensive development of sap rot in the balsam fir killed in Ontario.

In the present study, balsam fir trees which had been dead between 1 and 2 years had moderate to light development of sap stain caused by *S. chailletii* in all three locations, in comparison with the rapid, extensive sap stain development noted earlier in the three eastern provinces. As in the previous Ontario studies, woodwasp activity in the three study areas was far less than that recorded in New Brunswick and Newfoundland (Basham et al. 1976), and this confirms the earlier correlation between incidence of woodwasp attack and sap stain development. As far as sap rot is concerned, the sample trees dead for 1 to 2 years at Whyte closely resembled those examined in the two earlier Ontario studies; i.e., there was relatively extensive sap rot, much of it in the advanced stage, associated with heavy bark beetle activity. However, at Mattawa and Chapleau, where bark beetle activity was moderate to very light, there was very little sap rot in trees 1 to 2 years after death, particularly at Chapleau where no advanced sap rot was found (Table 3). Hence at Mattawa and Chapleau where bark beetle populations were unusually low for Ontario, at levels similar to those observed in earlier studies in New Brunswick and Newfoundland, sap rot development was also very slow and, again, comparable to that previously recorded in the eastern provinces.

The results from this study, and from all past studies in eastern Canada where bark beetle activity has been assessed, reveal a consistent positive relationship between the development of sap rot in budworm-killed stands of balsam fir, and bark beetle activity in the dead stems. However, since some individual trees were found with heavy bark beetle attack and relatively little sap rot, and vice versa (Fig. 3), it is unlikely that bark beetles directly influence the rate of development of sap rot. It would appear that the conditions that favor a buildup of bark beetle populations also favor a relatively rapid development of sap rot in dead balsam fir.

Bark beetle activity in dead balsam fir can easily be detected visually, and may be a good indicator of the rate of development of sap rot in stands containing budworm-killed balsam fir. As a rule, beetle populations vary considerably in different forest regions, fluctuating with time. Their abundance at any one time depends on many factors including long-term and recent climatic conditions, and stand history as it affects the presence and amount of suitable breeding material. It is postulated that bark beetle populations in northeastern Ontario are currently at a low level because the severe spruce budworm outbreak throughout that region in the 1940s virtually eliminated mature and overmature balsam fir. Prior to 1972 when trees began dying there from budworm defoliation, there was very little balsam fir mortality because of the young age classes, and this resulted in a scarcity of breeding material for the beetles. In the Lake Nipigon budworm outbreak of the 1940s and 1950s, all recently killed trees that were examined in the early 1950s were very heavily attacked by bark beetles, and all contained considerable stem sap rot 2 years after death (Basham and Belyea 1960). However, it was observed in a simultaneous but less widespread outbreak roughly 70 km away, where all of the balsam fir was relatively immature, that bark beetles were difficult to find in dead stems, and sap rot development was extremely slow (Basham and Belyea 1960). It is probably safe to assume that the balsam fir bark beetle population in northeastern Ontario is increasing rapidly at present, and that balsam fir trees dying there in the near future will be heavily attacked by bark beetles. In all likelihood this will be accompanied by a much faster rate of sap rot development than is occurring at present in that region.

Recommendations have been made concerning the length of time killed balsam fir may be left before significant volumes of sap rot are likely to develop and jeopardize profitable salvage operations. These have varied for different regions and provinces (Basham and Belyea 1960, Stillwell and Kelly 1964, Basham et al. 1976, Hudak et al. 1978). In general, it has been suggested that dead trees left for longer than 1 year in Ontario are likely to develop considerable sap rot, whereas in Quebec, New Brunswick, and Newfoundland trees can be left 3 or 4 years after death before serious sap rot development occurs. In the light of the present report, these recommendations should be modified. It appears that the level of activity of the balsam fir bark beetle, *Pityokteines sparsus*, in killed balsam fir stems can be used as an indicator of the rate of sap rot development in the stand. When bark beetle levels are high in Ontario, the 1-year recommendation appears valid; however, for the first time budworm-killed stands with very little bark beetle activity have been studied in Ontario. In these latter stands, 2 years after death, the trees examined had very little or no sap rot, and were still suitable for utilization. To my knowledge, bark beetle activity levels as high as those that have been observed in Ontario have never been recorded in the three eastern provinces. Should such high levels occur there in budworm-damaged stands, it is quite possible that balsam fir trees dead for longer than 1 year would have questionable salvage value.

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