STEM DECAY IN LIVING TREES IN ONTARIO'S FORESTS: A USERS' COMPENDIUM AND GUIDE

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ABSTRACT

All of the commercially important tree species of Ontario are affected to some degree by internal stem decay or stain. These defects can have a serious impact on harvesting costs and efficiency and on product values. For the most part they are hidden defects, and therefore difficult to assess or predict. Without burdening the reader with unnecessary scientific and technical details, this report outlines the stem-decay process, the ways in which the extent of stem decay can be assessed, the economic impact of stem decay, and the methods that can be used to combat stem decay. Individual sections on each of the major forest-tree species of Ontario deal with stem-decay relationships, causes, external symptoms, and the minimization of the impact of decay through silvicultural and management procedures.

RÉSUMÉ

Toutes les essences d'importance industrielle de l'Ontario sont touchées, à un degré ou à un autre, par la carie ou les taches colorées de la tige. Ces défauts internes, la plupart du temps cachés, donc difficiles à évaluer ou à prédire, peuvent avoir des répercussions graves sur les coûts et l'efficacité de la récolte ainsi que sur la valeur des produits. Sans ennuyer le lecteur de détails scientifiques et techniques inutiles, le rapport décrit le processus de la carie, les façons d'en évaluer la gravité, les répercussions économiques et les méthodes qui peuvent être utilisées pour la combattre. Des sections sont affectées à chacune des principales essences forestières de l'Ontario et s'occupent des relations, des causes et des symptômes extérieurs de la carie des tiges de même qu'elles cherchent à en réduire au minimum les répercussions par des méthodes d'aménagement et de sylviculture.

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INTRODUCTION

My aim in this report is to provide forest managers and others with information on combating or avoiding heavy losses from stem decay. A considerable body of literature on stem decays in Ontario and in adjacent provinces or states has been published over the past 50 to 60 years. Much of it, however, is highly technical, and of limited use to the field foresters who are responsible for dealing directly with decay problems. In this report I attempt to summarize, from those publications and from my own unpublished data and observations, all information on stem decays in living trees that I am aware of that might be helpful to users in the field, particularly in Ontario.

In 1947, when the Canadian government first became involved in forest pathology research in Ontario, the provincial forestry department had very little information on stem decay. What it did have was based almost entirely on timber-scaling experience and on observations made during harvesting operations. Each major tree species was more or less arbitrarily assigned a single percentage figure to represent the volume of stem decay, a cull-factor "guesstimate". Federal researchers believed, on the basis of investigations carried out in other provinces and countries, that this was a very misleading and inaccurate policy. In 1947 and 1948, they initiated three studies on stem decays (which represented about 50% of their total research program), partly because of requests received from the province and the forest industry. It soon became clear that in Ontario, as elsewhere, the incidence of decay in individual tree species could differ greatly among locations as a result of several factors, including tree age, diameter, site conditions, geographic region, cover type, and stand history. In a cooperative study conducted from 1952 to 1957, federal and provincial researchers felled, dissected and carefully measured the extent of decay in 22,739 trees of commercial size throughout Ontario's Boreal and Great Lakes–St. Lawrence forest regions. Though designed primarily for forest-inventory purposes, this survey provided the first accurate cull (decay) factors and relationships for most of the commercially important forest tree species in Ontario. In the early 1970s, questionnaires sent to 182 hardwood-processing industries in southern Ontario south of the Canadian Shield formed the basis of a report on decay problems in hardwood tree species in the Deciduous Forest Region of Ontario (Basham 1973a).

I was involved in stem-decay investigations in Ontario for roughly 30 years. In addition, I studied the deterioration of dead stems after fire and insect outbreaks. This report includes my research results, both published and unpublished, on stem decay, as well as those of many of my colleagues in this field. It deals only with decay in living trees, not in dead stems. Except for some of my research on aspen, all of my experience is in stands of natural origin. Future harvests, particularly in spruce and pine, will increasingly be of plantation origin; others will have their origin in unplanted cutovers. Nevertheless, for the next three or four decades, harvesting will likely continue to be carried out predominantly, or at least frequently, in natural stands. Furthermore, in determining stem-decay relationships in a stand of a particular species originating from a plantation and/or cutover, a knowledge of stem-decay relationships in natural stands is a valuable asset.

This report is concerned only with stem decay and stain, i.e., with internal defects within the merchantable portion of the stem. The merchantable portion is now considered to start 15 cm above ground. Readers should bear in mind that in the aforementioned provincewide decay survey of the 1950s, and most other decay studies carried out before 1970, 30 cm above ground was regarded as the merchantable limit. Hence, in those studies, decay in the butt regions between 15 and 30 cm was missed, and the total volume of stem decay was slightly underestimated. Decay in the root systems, generally called root rot, and decay within the stumps, are referred to but are not discussed quantitatively in this report. Root rot is widespread in Ontario's forests, and is responsible for considerable damage in the form of windfall, reduced tree increment and tree mortality (Whitney 1988). The fungi responsible for root rot can spread from infected to healthy trees via root grafts, root-system wounds, dead roots, or subterranean strands of fungal material. The decay caused by these fungi can extend into the basal stem region, although the majority of infections probably do not extend above stump height. Hence, fungi such as *Armillaria mellea* (now believed to be mostly *A. ostoyae* plus other *Armillaria* species [Dumas 1988]), one of the most widespread and serious of the decay-causing fungi or groups of fungi in Ontario's forests, can have a far greater impact than their incidence as decay within merchantable stems would indicate.

The scientific names (i.e., Latin binomials) of the various tree species in this report are not used throughout the text, but are provided in Appendix A. Scientific names of the fungi responsible for stem decay in Ontario's forests will neither concern nor interest many readers of this report. However, they will be important to some, and hence have been included, particularly since common names for many of the decay-causing fungi either do not exist or are virtually meaningless. No attempt was made to list all of the fungi known to cause decay in each species; instead, only those fungi responsible for the major (i.e., most serious) stem-decay problems are included. A more comprehensive list of the occurrence of fungi in Ontario has been provided by Myren and Davis (1989) for the pines, and by Davis and Myren (1990) for conifers other than pines; similar reports for hardwood species are being prepared by these authors.

Unfortunately, most fungi included in this report have undergone at least one name change since the 1940s. Some readers will be familiar with the older but not with the newer name, whereas the reverse may be true for other readers. Therefore, it is imperative that both names be given. In such cases, the older name appears first, and is followed within parentheses by the new (proposed or accepted) name. Because some readers may read only those parts of the report dealing with one or two species, when the same twice-named fungus caused decays in two or more species it was necessary to repeat this information under each species. All fungi with two scientific names are listed in Appendix B.

The first sections of this report deal with the general stem-decay problem and opportunities for reducing it. The remaining sections deal with stem decay in individual tree species. A more-or-less standard format is used in the latter sections, in which the sequence of topics is roughly as follows: the relative amount of defect present; the relationship between tree age and stem decay; the pathological rotation age; the relationship between decay and site, growth rate, diameter, geographic location, etc.; the relative proportions of trunk and butt decay; the main fungi responsible for decay; a description of major decays; the entrance courts of decay fungi; external indications of stem decay; problems with respect to wood utilization; and the avoidance of excessive losses to decay through silvicultural or management procedures.

STEM DECAY: CAUSES, PROCESSES AND CHARACTERISTICS

"Decay" and "rot" are the terms used to describe wood within the stem of a living tree that has been noticeably weakened by the breakdown of some or all of its cell walls. Decay or rot occurs in pockets or columns of all sizes, from tiny pockets little larger than a cubic centimetre to columns that occupy almost all of the xylem for several metres of stem length. All tree species in Ontario's forests are susceptible to stem decay.

Several members of a group of fungi called the Hymenomycetes, which belong to the class Basidiomycetes, are the cause of most stem decay. They are referred to as decay fungi, and are capable of degrading and metabolizing cell-wall substances. These fungi frequently pass from cell to cell through bore holes in the walls, which they form by enzyme action. The subsequent enlargement of the bore holes results in a gradual, progressive reduction in the mechanical strength of the invaded woody tissues. In the advanced stage of decay, the wood loses virtually all structural strength.

When decay fungi initially invade stem wood, sometimes there is no visible evidence of infection and they can be detected only with a microscope or by careful isolation of the fungi in a laboratory. More frequently, there is a color change in the wood, particularly in deciduous trees, that ranges from slight to pronounced. However, the discolored wood may remain just as hard and firm as sound wood for a time. There is a tendency, even among some forest pathologists, to call this discolored wood decay or rot. This can be very misleading, because there are other types of discoloration in firm wood that are very similar in appearance but that are not caused by decay fungi. In some tree species, the central core of the stem is eventually discolored because of the normal aging process and death of the cells. This "true" heartwood is just as strong as clear, sound wood. In most species, stem wounds or branch stubs that result in exposure of the xylem to the atmosphere can lead to pronounced discoloration, partly as a result of the oxidation of certain chemicals.

Microorganisms other than decay fungi, namely bacteria, yeasts and non-decay fungi, can also invade stem wood and cause discoloration; again, these are more common in deciduous trees. But of all these types of discoloration, only that caused by decay fungi will eventually weaken (decay) the wood unless, of course, the other discolored areas are subsequently invaded by decay fungi. All discolored, firm wood can be used with few or no drawbacks in most manufacturing processes, such as chemical pulping. Therefore, I recommend that all firm, discolored wood, regardless of type, be referred to in terms of discoloration or stain. When the softening or weakening of the wood can first be detected, the term "incipient decay" should be used, to distinguish it from stain and from the very soft, weak wood of the advanced-decay stage.

Stem decays are frequently classified as either trunk decays (trunk rots) or butt decays (butt rots). Trunk decays are located in the main and upper portions of the stem, although they sometimes extend down almost to ground level. Butt decays occur within the basal 2 m or so of the stem. They are generally widest at or near ground level, and extend upwards in the shape of a cone.

Decay fungi can be divided into two broad classes, called "white rots" and "brown rots", on the basis of their effects on wood. The basic difference between the two is that white rots degrade the lignin component of cell walls, whereas brown rots leave lignin virtually undigested. White-rot fungi degrade cellulose and hemicelluloses at roughly the same rates, but lignin is usually decomposed at a somewhat faster rate. Brown-rot fungi degrade and utilize only the cellulose and hemicellulose of the cell wall. These differences result in decays distinctly different in appearance. White rots are generally yellow or orange, with a stringy or spongy texture, and in some cases they contain white pockets composed of almost pure cellulose. Brown rots are pale to medium brown, with a dry, cracked, cubelike appearance, and when they are in the advanced stage, affected wood can be crumbled between the fingers.

Although two or more Basidiomycetes may invade the stem through a single wound, one of them will, as a rule, be the most aggressive or most suited to the microenvironment of the colonized wood, and will inhibit or even eliminate the others. Hence, a decay pocket or column that originated from a wound will generally have a uniform appearance and characteristics that depend on the identity of the dominant fungus.

FACTORS INFLUENCING THE OCCURRENCE AND SPREAD OF DECAY

Most stem decay originates from the germination of spores, usually air-borne, of decay-causing fungi after their deposition on suitable host substrates. The exceptions are those cases in which a decay originates from an already established decay, either by moving up into the stem from the root system or by moving from one stem to another via stems that are connected at their basal region.

Fungal spores are produced by specialized structures of the fungi called "fruiting bodies" (sporophores). These can be the familiar hoof-shaped, or inverted bowl-shaped, conks on tree stems or logs, crusts of matted fungal material on wood surfaces, or, in the case of some butt-decaying fungi, mushrooms growing on the forest floor. Some sporophores have been found to produce many billions of spores daily. Because they are so small and light, spores can be carried great distances in the air. To germinate successfully, they must be carried by air currents (or in some cases by insects or animals) and deposited on trees of species that they are capable of infecting. However, even then, spore germination will by no means ensure infection of the host tree, since the hyphae (narrow, tubelike fungal filaments) cannot penetrate intact bark or living sapwood and soon die unless they happen to be deposited on exposed and consequently dead sapwood or heartwood.

On living trees, bridges that enable the spores to bypass intact bark and healthy sapwood occur in branch stubs, dead branches, broken or dead tops, and stem wounds caused by fire, falling trees, sunscald, cankers, frost cracks, lightning, animals, etc., in which the bark is scraped or knocked off, or dies and sloughs off with time. But even when spores are deposited in such areas and germinate, the hyphae have numerous obstacles to overcome before reaching, colonizing, and decaying the stem heartwood. Many other fungal spores and bacteria are present in the air, and several microorganisms can be deposited on the same tissue, all competing for the same substrate and nutrients. Bacteria and non-decaying fungi (usually non-Hymenomycetes) frequently establish themselves first, and cause discoloration of the tissue. Some of these "pioneer" microorganisms appear to alter the substrate, making it either more or less suitable for the decay fungi. Some decay-causing Basidiomycetes are stopped or slowed by pioneer microorganisms, whereas others appear to be dependent on the presence of certain pioneer species before they can become established.

Apart from the intense and complex interactions among the invading microorganisms, the host tree itself is by no means passive. Living trees attempt to cover up exposed wood through external closure of the wound by the formation of callus tissue. However, this is a relatively slow process, far too slow to prevent massive invasion by microorganisms in all but the tiniest wounds or branch stubs. A second healing mechanism, internal compartmentalization, is far more effective and allows trees to survive countless invasions by microorganisms during their lifetime. The process is far too complex to explain here in detail. Basically, the living parenchyma cells in the vicinity of a wound or branch stub react chemically and anatomically to form barriers around the wound or stub. This can be regarded as an attempt to isolate or "compartmentalize" the wound and protect the wood behind the barrier both from invasion by microorganisms and from further moisture loss. This process involves the production of substances that inhibit, or are toxic to, the invading microorganisms. Some of these substances plug the vessels and tracheids as part of the barrier. Many of the parenchyma cells die, the phenolic compounds that are formed are oxidized, and the barrier zone frequently is considerably discolored and darkened.

The tree has another defense mechanism against microorganisms that succeed in penetrating the series of protective barriers that form successively towards the stem center. The callus, mentioned earlier, that develops over exposed wood or branch stubs is composed of wood (produced by the cambium) that has been stimulated by the nearby wound to form xylem tissue differing markedly from normal stem tissue. The callus wood has a far higher proportion of living parenchyma cells, other cells have thicker walls, and there are more of the inhibitory substances mentioned previously. This is a very effective anti-fungal barrier, and as a result, invading microorganisms and wound-related discolorations are frequently confined to wood already formed when the stem wound occurred or when the branch died.

Before World War II, it was generally assumed that the majority of stem-decay infections occurred via branch stubs, simply because they were present on all mature trees and were usually far more numerous than stem wounds. In the two decades after the war, many intensive stem-decay investigations were carried out in North America. In most cases, relatively little stem decay appeared to have originated at branch stubs, whereas stem wounds were increasingly revealed as the main culprit. This outline of the decay infection process and the defensive reactions of trees help to explain why this is so. Most branches die from suppression when they are of relatively small diameter. The "wound area" on the stem associated with a branch stub is seldom larger than 4 to 5 cm^2. Consequently, the protective barriers formed by the living xylem tissue at the base of the dead branch, combined with the relatively rapid callus closure over small branches that break off flush or nearly flush with the stems, are more likely than stem wounds to prevent invasion by decay fungi, as stem wounds frequently involve a much greater wound surface area. In some tolerant hardwoods, dead branch stubs are often associated with columns of discoloration that can extend into the central core of the stem, but these are very seldom decayed. The situation is different with dead branches of relatively large diameter. Before dying, large branches have relatively few living cells, if any, in their central core, so that if a protective barrier forms in the base of the branch, it is relatively weak and often penetrated by decay fungi. In addition, branch stubs of large diameter take considerably longer to be completely enclosed by callus.

The sequence of events that leads to the development of an extensive decay column associated with a stem wound is generally believed to be somewhat as follows. After the wound is inflicted, hundreds, perhaps thousands, of different microorganisms reach the exposed wood. The majority probably die with very little or no biological activity. Bacteria, yeasts and molds do best on the dead, somewhat desiccated, exposed tissue, as they can directly utilize the simpler compounds found there. Slowly, another group of fungi becomes dominant; these belong to the class Ascomycetes and are capable of utilizing some of the more complex compounds present. The Ascomycetes are probably the first organisms to test the tree's protective barriers, and some are capable of penetrating the barriers by breaking down and detoxifying the inhibitory compounds. The invaders may even utilize the byproducts of this breakdown. This barrier penetration triggers an attempt by the tree to form another chemical barrier, or reaction zone, ahead of the invaders. The interaction between the invading Ascomycetes and the tree continues, but as the "battle zone" moves inwards, the proportion of living to dead xylem cells usually decreases steadily, and thus the chemical barriers get progressively weaker. Meanwhile, the Ascomycetes thrive and inhabit the invaded zone at increasing densities. Despite intensive competition among themselves for available nutrients, eventually they completely overcome the ability of the tree to arrest their inward (radial), vertical, and, to a lesser extent, tangential spread. The only persistent barrier is that between the wood formed before and after wounding.

About this time, the Basidiomycetes are able to compete with the Ascomycetes after detoxification of the chemical barriers by the latter organisms. Whereas Ascomycetes stain the wood, they cannot attack the cell walls, and therefore decay does not take place until Basidiomycetes move in. As a rule, one of the Basidiomycetes eventually dominates the central core of the stem in the vicinity of the wound, almost to the point of excluding all other microorganisms. A zone of stained wood frequently surrounds the decay column; this is frequently inhabited by a few of the Ascomycetes and even by some yeasts and bacteria.

Massive stem decay generally develops from a stem wound only if the wound exposes a relatively large area of wood, as often occurs with fire scars, severe felling wounds, sun scald, large cankers, and man-made wounds such as blazes or skidding scars. Even in these cases the tree has a chance to prevent or compartmentalize the decay if it is healthy and vigorous and therefore can react efficiently to wounding and fungal invasion. Clearly, anything that reduces the vigor of a tree or stand, as happens naturally with increasing age and competition or as a result of man's activities (e.g., some types of harvesting operations, air pollution, fire, etc.), will lower the ability of the tree(s) to fend off the invasion of decay-causing fungi. It is not surprising that in almost all tree species, age is the factor most closely related to the extent of internal stem decay. Besides becoming less vigorous, trees, as they age, are much more likely to suffer severe stem wounds (Fig. 1) and to have more large branch stubs, which are the principal entry points for decay. As stands become overmature the percentage of stem volume decayed may even decrease, simply because of the progressive removal, through breakage, windfall, and mortality, of the most extensively decayed individual trees. Relatively poor sites, which result in below-average tree vigor, will also tend to increase the susceptibility of trees to stem decay.

The inner stem core of mature or overmature trees invaded by decay-causing Basidiomycetes has no living xylem cells, or very few, above and below the decay column. Therefore, the decay column spreads mainly vertically. The average annual rate of spread in Ontario is relatively slow, ranging from 3 or 4 to 11 or 12 cm. Decay can continue until the inner stem is completely hollow. Eventually, when decay is very advanced, many Basidiomycetes produce fruiting bodies (conks, etc.) on the outer surface of the stem, frequently on branch stubs. Only a few Basidiomycetes produce fruiting bodies on living trees; the majority do so only after the tree is dead. These fruiting bodies produce spores that are carried by air currents or by other means to stem wounds or branch stubs on younger trees, and the disease cycle continues.

ASSESSING THE EXTENT OF STEM DECAY

Because stem decay has such an adverse effect on most utilization practices, some idea, no matter how rough, of the extent of decay in different stands is helpful in planning harvesting operations. Clearly, the closer the estimates are to the actual extent of stem decay, the better the chances for efficient harvesting and utilization. Because there are so few reliable external indicators of stem decay in most species, in many instances decisions are made to bypass temporarily stands that appear to be relatively sound and decay-free. Only later is it discovered that, whereas these trees could have been

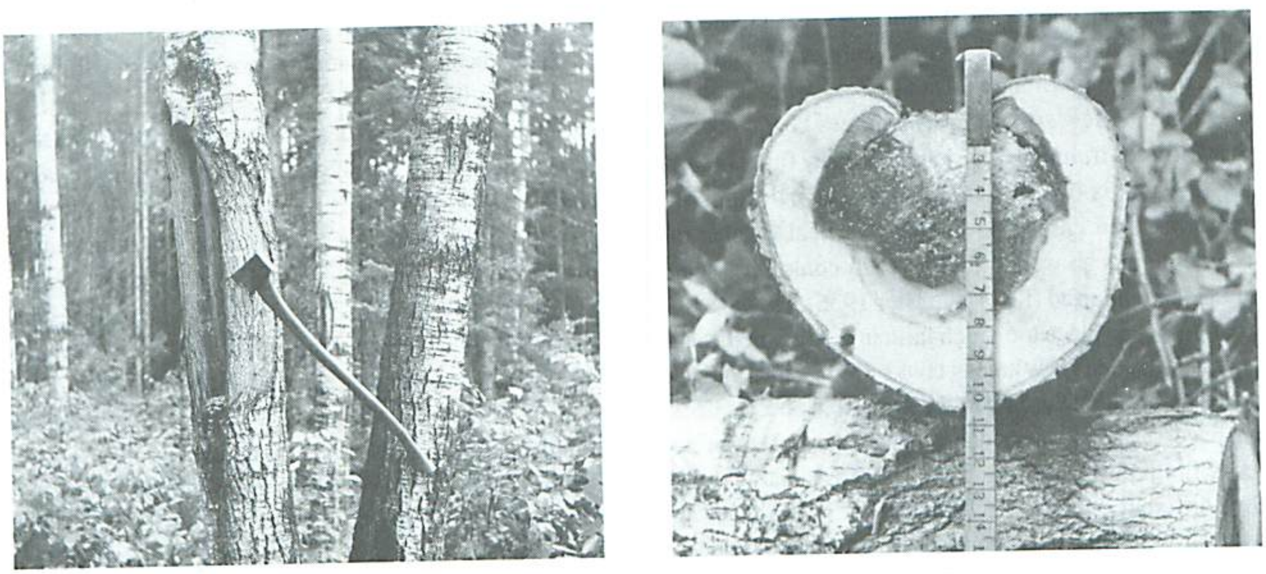

Figure 1. Stem decay associated with a severe stem wound on aspen. (left) standing tree, (right) felled tree with extensive advanced decay at the wound.

profitably harvested in the first instance, stem decay has become so extensive that harvesting is now economically impractical. Major underestimations of the extent of stem decay over a wide area can have a devastating effect if a mill has been established at considerable expense and it is discovered that extensive stem decay has greatly reduced the opportunities for profitable operations. On the other hand, major overestimations of stem decay can result in decisions not to construct mills and/or harvest in certain regions that could have supported very profitable operations.

From the preceding section on the occurrence of stem decay, it is obvious that stand age, or the distribution of age classes in the case of uneven-aged stands, is the first parameter to measure when one is estimating the incidence of stem decay. In Ontario, tables and graphs have been prepared to show the average relationships between age and decay for most of the major commercial forest species (Morawski et al. 1958). This publication is now out of print; however, in 1978, the Ontario Ministry of Natural Resources (OMNR) reproduced these tables (with measurements in metric units) in pocketbook form for use in the field (Anon. 1978). With these tables, graphs available from the earlier publication, and a knowledge of stand ages, a rough estimate of percentages of volume culled for different tree species can be made. If site, soil conditions, tree growth rate, and other stand parameters indicate that the stand is of below- or above-average vigor, these estimates can be raised or lowered accordingly.

Although visible external indicators of stem decay are rare on living trees, they should certainly be used to estimate the extent of internal stem decay when they are present. In the few species in which trees bear conks or other forms of fruiting bodies of stem decay fungi before they die, this is one of the most reliable indicators of decay. In some cases, the average vertical extents of decay columns above and below each conk have been studied and reported (Riley and Bier 1936). However, it is dangerous to place too much faith in fruiting bodies as indicators of decay. Whereas conks are reliable indicators, the absence of conks in the same tree species does not necessarily mean the absence of decay. Different decay fungi produce fruiting bodies in association with very different amounts of stem decay. Fungi that can grow only on patches of dead sapwood may also produce fruiting bodies on a wound or branch stub; these indicate superficial decay but not internal stem decay. Large branch stubs, broken or dead tops, stem wounds, or scars that represent callused-over wounds indicate that stem decay could be present. Attempts have been made to estimate the extent of decay in living trees, or the percentage of merchantable volume culled because of decay, on the basis of the presence, type, size, severity and location of external indicators of decay. There are several drawbacks to estimating the extent of stem decay in a stand solely from external indicators. In many cases, and in virtually all cases for certain tree species, extensive columns of advanced stem decay are not reflected by any externally visible sign or symptom. Furthermore, stem abnormalities such as excessive branching, galls and burls are not usually associated with stem decay. Finally, a stem wound or large branch stub may appear to be a likely source of extensive stem decay, but unless the tree is felled and dissected, or the wound area is probed in some way, there is no external indication of the outcome of the battle between the invading microorganisms and the tree's protective mechanisms.

The desirability of developing a nondestructive method of detecting decay within the stems of living trees has been recognized for some time. Increment borers can detect widespread decay, but can miss pockets that are off-center. Other methods that have been researched include X-ray scanners, ultrasonic devices, electrical-resistance meters, microwaves and magnetic resonance. Most of these methods can detect the presence and perhaps even the extent and stage of decay in the vicinity of the portion of stem tested. However, they are of limited practical value in forest stands because they are expensive, many are not very mobile, and it is difficult or impossible to get readings at heights above 2 m, where the decay situation may well be quite different from that below 2 m.

Until a quick, non-destructive method of assessing the extent of stem decay throughout the merchantable length of a living tree has been developed, the best estimate is still based on the extrapolation of data obtained from intensively measured, felled trees selected to represent as closely as possible the stands to which the results are to be applied. To be of the greatest value, data should be collected, and decay relationships calculated, on the basis of tree and stand age, history, site, diameter class, height class, and growth rate (as an indication of vigor). Decay or cull factors can then be assigned to stands for which some or all of those parameters are known. Since the impact of certain stains and incipient decays frequently depends on utilization practices, all such defects throughout the merchantable stem should be mapped and described as accurately as possible. Indeed, all internal defects in addition to decay and stain should be recorded, as well as stem wounds and other external indicators of decay. Because the extent of stem decay can vary so widely among individual trees, even within even-aged stands on uniform sites, the accuracy and reliability of the results generally increase with the number of trees sampled. For the same reason, the results are applicable to extensive stands but are of limited value in predicting stem decay in only a few trees.

EFFECTS OF DECAY ON UTILIZATION

Most readers of this report who are likely to apply the results will be familiar with how decay and stain affect their particular utilization procedures. Consequently, this section presents merely a general overview of the situation. In subsequent sections that deal with individual species, more details will be presented.

As far as the pulp and paper industry is concerned, the utilization of decayed timber involves several disadvantages, and no apparent advantages. Because brown-rot fungi decompose the cellulose while leaving the lignin component of the cell walls virtually untouched, wood that they have decayed should never be used, even in the incipient stage. The fact that cell walls in decays caused by white-rot fungi are partially delignified suggests that those fungi may be beneficial in pulping. White rots frequently produce pulp that differs very little in yield, on a weight basis, from pulp produced from sound wood. However, the decomposition of the lignin by white-rot fungi is always accompanied by some decomposition of the cellulose and the hemicelluloses. Consequently, the fibers tend to be shorter and weaker than normal, even in the case of fungi that cause decays containing white pockets of almost pure cellulose. The result is pulp of inferior quality. Interest is growing in the development of techniques for using white-rot fungi or their delignifying enzymes in biological pulping processes. Some of these biotechnology studies show considerable promise for the future. For example, using mutants of white-rot fungi that have minimal effects on cellulose to remove even small amounts of lignin from wood or from mechanical pulp reduces the energy required for mechanical refining (Kirk et al. 1983). However, inclusion of naturally decayed wood almost always has a detrimental effect on the manufacture of pulp and paper.

The groundwood pulping process appears to be the most seriously affected by the presence of decay. Stained wood that is as firm and hard as sound wood has little effect on fiber strength, since even if the stain is of fungal origin, the fungi responsible do not decompose the cell walls. However, staining causes such losses in brightness that such wood is generally not used by groundwood mills. Decay, even in incipient stages, causes serious brightness problems and pronounced reductions in groundwood pulp strength. Groundwood pulp yield also decreases with increasing amounts of decay. Processing problems as a result of foaming and sticking have also been reported.

Although few studies have been carried out on the relatively new process of thermomechanical pulp (TMP) production, such pulp appears to be far less seriously affected by decayed wood than is groundwood pulp. Decays caused by white-rot fungi appear to have little effect on pulp yields or on brightness. Strength properties are reduced, but far less than in the case of groundwood pulps.

As far as chemical pulps are concerned, the results of different tests do not always agree, probably because of differences in the methods used, tree species, stages and types of decay, and proportions of decayed to sound wood. The general consensus appears to be that sulfate (kraft) pulps suffer noticeable reductions in yield but only moderate reductions in quality when decayed wood caused by white-rot fungi is used. Sulfite pulps generally show relatively little reduction in yield and moderate-to-slight reduction in quality; however, appreciable losses in brightness are frequently reported. In both sulfate and sulfite pulps, strength is reduced because the decay fungi and the chemical pulping processes combine to shorten the fibers and make them more flexible; tear strength is the property most seriously affected. Besides causing quality, yield and brightness problems, the use of decayed wood in chemical pulping processes can result in increased alkali consumption, non-uniform pulping, and increased recovery-boiler loading. If a decision is made to allow a certain proportion of decayed wood in chemical pulping, such wood should be mixed as uniformly as possible with sound wood to minimize problems with cooking, pulp freeness control, and energy consumption.

In lumber manufacturing, reductions in product value and increases in sawmill processing costs are likely as the amount of decay in logs increases. Decayed material is avoided in veneer manufacture because of serious product-value reductions and because of the difficulty of holding such material in a lathe. Logs that contain decay can be used in the manufacture of waferboard, largely because much of the decayed wood breaks up and is separated out as "fines".

OTHER ECONOMIC IMPACTS OF STEM DECAY

A prerequisite for determining the economic impact of stem decay is some idea of the losses it causes, either as wood volume rendered unmerchantable or in terms of the dollar value of that wood. Losses in the form of seedling, tree or stand mortality caused by forest fires or by forest pests can be determined fairly easily. Losses in the form of stem deformities and reduced increments caused by pests that seldom or never kill trees can also be determined, albeit with greater difficulty. However, losses from decay within the stems of living trees are extremely difficult to quantify or put a value on, for several reasons.

For most tree species in Ontario, there are few or no reliable, externally visible signs of internal stem decay. For reasons already outlined, it is impossible to obtain an accurate assessment of the overall extent of stem decay in Ontario's forests and the rate at which that volume changes annually. Even when estimates based on available knowledge and data are made, other questions arise. Should decay in overmature stands that are so defective that harvesting is financially impractical, or in mature stands that are so far away from the mills and so inaccessible that they will never be harvested, be included or disregarded as irrelevant? Should the annual increase in volume of stem decay in the total accessible forest resource be considered, or only the decay volume in the average annual resource that is harvested? In many cases it is not practical to attempt to use the remaining sound wood in logs or trees that contain considerable decay; consequently, the loss in commercial wood volume is much greater than the actual volume of decayed wood. Furthermore, wood affected by incipient decays and even by some types of advanced decay can be used to a limited degree for certain purposes but not for others.

Finally, it is generally assumed that stem decay does not kill trees because the decay fungi do not attack the phloem or cambium, and seldom the outer sapwood, of the stem. But how safe is this assumption? When a tree dies, some harmful agent conspicuous at the time of death is usually blamed. It is reasonable to believe that in some cases this agent could not have caused death if the tree's vigor had not been substantially reduced by years or decades of stress involved in attempting to compartmentalize several decay columns.

Despite all of these reasons why losses attributable to stem-decay fungi are impossible to quantify accurately, forest pathologists are frequently asked to provide some estimate of overall losses caused by stem decay, usually on an annual basis. Consequently, there are numerous reports of annual losses caused by stem decay in various parts of North America (in some cases, values were converted to million m^3 for ease of comparison): United States, 1952, 33 million m^3 (Anon. 1958); eastern and southern United States, 1961(?), 28 million m^3 (Hepting and Fowler 1962); Canada, 1965-1966, 24 million m^3 (Anon. 1967); Canada, 1976, 25 million m^3 (Anon. 1979); British Columbia, 1964-1973, 11 million m^3 (Dobie 1976); and Ontario, 1977-1981, 9 million m^3 (Gross 1985). Few details are provided in these reports as to how these figures were calculated. The figures are estimates of annual losses from stem decay within the total forest resource, and are clearly of considerable magnitude.

After completing the Ontario-wide decay study in the 1950s, referred to in the Introduction, my provincial colleagues and I calculated annual stem losses in Ontario. However, in contrast with the above reports, our calculations were confined to losses incurred during harvest operations, and were based on summaries of the volume of each tree species cut annually in Ontario that were contained in the 1960, 1961 and 1962 Annual Reports of the Minister of Lands and Forests of Ontario. Both the designation of ages considered most likely to approximate average harvesting ages for each species and decay-study data indicating the percentage of total merchantable volume affected by stem decay for each species at those harvesting ages were used in these calculations; this was carried out in consultation with senior officers of what was then the Timber Branch, Department of Lands and Forests. After the decayed-volume percentages had been converted to percentages representing volumes culled in accordance with the Ontario timber-scaling regulations in effect at that time, the volume of annual harvest that would be culled because of stem decay was calculated. This volume, which was 6.3% of the annual gross merchantable volume cut, amounted to 620,000 m^3.

Since the annual revenues from Crown stumpage charges by species were also available from the Minister's Annual Reports, we were able to calculate that the theoretical loss of harvested volume caused by stem decay represented a loss in revenue of $880,000. Details of all these calculations, with tables and other supporting information, have been published (Basham and Morawski 1964). As this paper is no longer in print, the tables and the text that accompanies them have been reproduced in Appendix C.

Clearly, these figures, 620,000 m^3 of culled wood and $880,000 in lost stumpage revenue, are not particularly meaningful. First of all, they are based on cutting and revenue data that are about 30 years old. Even if the lost stumpage revenue could be updated and increased to represent the actual mill or market value of the wood volume lost, it would not mean a great deal. The figure of 6.3% of harvested timber culled because of stem decay is useful because it has not likely changed appreciably over the years. However, the wood required to satisfy market or mill demands will usually be obtained, regardless of the amount of stem decay present in the stands harvested. Hence, there will be no real loss of stumpage revenue. The real economic impact of stem decay lies in the fact that decay renders the part of the tree it occupies useless for most purposes, and more trees or stands must be cut to obtain the required volume of wood for the mill. This raises the cost and lowers the efficiency of logging operations. Furthermore, it is usually impossible to avoid including some decayed timber in the harvest. At the mill, it is costly to separate this decayed timber from the sound timber, and some or all of it is used, with the result that the yield and value of the product are reduced.

The fact that decay is present in all stands and usually increases steadily with age has additional economic consequences. Mills with a high proportion of stands that reach rotation age at roughly the same time, or that are in inaccessible areas, may be forced to bypass some of those stands, which in time become too decadent for profitable harvesting. Areas that support such stands are considered unproductive and are therefore abandoned until they burn or break up naturally, which may take several decades. In other areas in which the timber resources are limited or the annual allowable cut is being used fully, bypassing stands that are marginally defective in favor of relatively sound stands could, in the long run, effectively reduce the resource base, with serious economic consequences.

In view of the difficulty of assessing the overall economic effect of stem decay in the forest, and the wide variety of utilization practices and standards, any calculations of decay impact on a national or provincial basis, or even attempts to quantify the volume of wood lost because of stem decay, are not particularly meaningful except that they provide rough estimates of the overall seriousness of the stem-decay problem.

COMBATING STEM DECAY

We know how to prevent or minimize stem decay in individual trees. Because some cost is usually involved, such procedures are generally limited to accessible areas in which the health of each tree is of some concern (e.g., urban regions, public campsites, etc.). In forest stands or extensive woodlots, treatment of individual trees is usually not practical, and the elimination or prevention of stem decay is virtually impossible. However, by using information on the relationships between the occurrence of stem decay and other factors, losses attributable to decay can to some extent be predicted and avoided, and the impact of stem decay can be minimized.

Although the prevention of stem decay is unlikely to be the principal factor that governs decisions about silvicultural and management procedures, forest managers should nevertheless be aware of how those procedures can minimize decay. As a rule, any treatment that reduces competition and improves tree vigor will tend to reduce the extent of stem decay. Thinnings and improvement cuts should remove trees that bear conks or large stem wounds, as well as trees with crooked or malformed trunks. Pruning branches before they reach a diameter of 2 cm will greatly reduce the chance of their becoming a source of stem decay. This can be done artificially or naturally (self-pruning), by maintaining a relatively high stand density while stands are young and the branches are relatively small. The latter should be followed by a release thinning to increase the growth rate and vigor of the remaining potential crop trees.

Prevention of stem wounding is an obvious means of minimizing stem decay. Some wounds are unavoidable, but many of the most serious types are caused by man. In thinning or any harvesting procedures other than clearcutting, care should be taken that the residual trees are not wounded by the trees that are felled or by the harvesting machinery. Suddenly exposing trees to the sun's rays from the south or west, particularly trees of thin-barked species, can result in sunscald injuries. Felling as little as is silviculturally necessary in a stand will reduce the risk of decay among residual trees.

Because stem decay is so closely related to the age of a stand, the simplest means of combating it is to harvest stands before they reach an age at which the extent of decay is likely to become economically unacceptable. With many species, the volume of stem decay will eventually begin to increase faster than the volume of sound wood if stands are left uncut. Stands should be harvested before then if serious losses from decay are to be avoided. The maximum age at which a stand should be cut on this basis is called the pathological rotation age, and it will vary with the site, general stand vigor, and utilization practices. Rotation ages are probably very seldom determined exclusively by the progressive development of stem decay, but in the case of relatively defective, short-lived species, decay should be seriously considered along with other factors in reaching a decision.

A recent approach to combating stem decay, and one which holds great promise in the future, is the biological control of stem-decay fungi. A few bacteria and fungi isolated from clear, sound stems of living trees have been found to be distinctly antagonistic towards decay-causing fungi, both in the laboratory and when inoculated in standing trees. These organisms appear to do very little, if any, harm to the tree. Attempts are being made to introduce them into trees by inoculation of seedlings. Strains are being sought that are particularly antagonistic to decay fungi and will spread systemically from the seedlings throughout the tree. In this way, it may eventually be possible to produce mature, relatively decay-resistant trees at reasonably low cost.

STEM DECAY IN ONTARIO, BY SPECIES

Conifers

White Pine

White pine blister rust and the white pine weevil are generally considered the major pest problems of white pine. With trees or stands less than 125 years old, this is usually true. However, when stands more than 125 years old are harvested, stem decay can be an even more serious problem. I am aware of only one extensive decay study of white pine in or near Ontario in which many trees of different ages were felled and carefully dissected to determine the extent of decay in each stem. This study was carried out between 1947 and 1949 by White (1953), who examined 1,012 trees with a minimum DBH of 15 cm in overmature, mature and younger stands. White's results indicate that until trees are in the 101- to 120-year age class, white pine stems are fairly sound, and that decay is certainly not a problem in trees less than 100 years old (Table 1). However, in stands between 120 and 200 years old, from 14 to 17% of the stem volume is composed of decay or stain (although White found relatively little stain). The 33% figure in Table 1 for trees in the 201- to 220-year age class is suspect because of the small number of trees (8) sampled. Although decay increased dramatically after age 120, because of rapid tree growth and the accumulation of sound wood for the next few decades, White suggested that stands could be left until trees entered the 160- to 170-year age class before stem decay would have a serious economic impact (Fig. 2).

White pine (and red pine) were not included in the provincewide decay survey of the 1950s referred to in the Introduction, because they were considered too valuable to sacrifice the number of trees that would be required to provide reliable estimates of decay relationships. I suspect that this explains, to some extent, why no other white pine decay studies have been carried out in or near Ontario. The only other detailed examination of white pine stem decay that I am aware of involved trees killed in the vast Mississagi fire between Blind River

Table 1. Occurrence of decay and stain in the stems of 1,012 white pine in Ontario. Based on data from Table 5 in White (1953). Trees were in stands in the Temagami Lake and Ottawa Valley regions.

Age class (years)	No. of trees	Avg. stem vol. (dm^3)	Avg. decay and stain[a] vol. (dm^3)	Stem vol. defective (%)
41–60	113	303.0	8.50	2.6
61–80	490	371.0	11.33	3.0
81–100	51	484.3	16.99	3.5
101–120	10	393.6	28.32	7.1
121–140	57	909.1	158.59	17.5
141–160	120	1367.9	240.72	17.6
161–180	110	1821.0	266.21	14.6
181–200	53	2347.7	345.50	14.7
201–220	8	2449.7	809.95	33.1

[a] Very little stain was present.

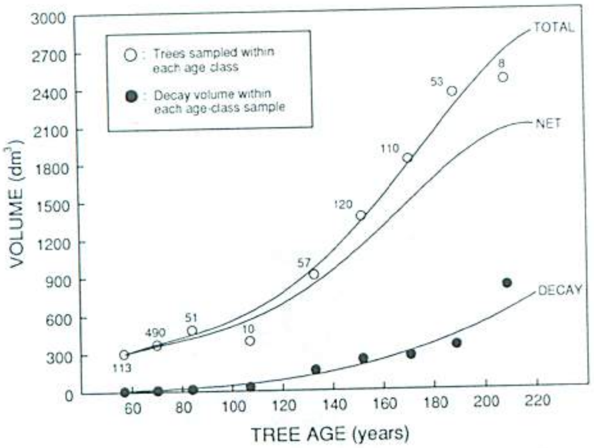

Figure 2. Average total volume, decay volume, and net volume of white pine stems in relation to tree age. Volume-age data obtained from curves in White's (1953) figure 5.

and Chapleau, Ontario in 1948. Between 1950 and 1953, 156 killed white pine trees in 10 stands from 100 to 185 km north of Blind River were felled to study the rate of development of sap stain and sap rot in the dead stems (Basham 1958a). The occurrence and extent of decay in heartwood, almost all of which would have been present before the death of the trees, were also recorded. All of the trees were in the 140- to 160-year age class, and an average of 14.1% of the stem volume was composed of decay or stain. (Again, this included very little stain.) These results are comparable with those obtained by White (1953) for this age class in the Lake Temagami and Ottawa Valley areas. However, the Mississagi white pine at this age had an average merchantable volume of 1.05 m^3 in comparison with 1.37 m^3 in White's study. This suggests that a somewhat-younger pathological rotation age than White's recommended 160 to 170 years may apply in the northern Algoma region of Ontario.

White's study revealed that there was no relationship between tree diameter and the extent of decay within single age classes of white pine. However, when trees in even-aged stands were divided into fast-growing and slow-growing groups (trees with average growth rates were excluded), both the percentage of trees with stem decay and the percentage of stem volume decayed were greater in the slow-growing trees.

Trunk decay was far more widespread than butt decay, and accounted for 87.6% of the total stem-decay volume. Approximately 85% of the total decay was caused by *Fomes pini* (renamed *Phellinus pini* [Fig. 3]) (White 1953). This fungus accounted for all of the trunk rot in white pine, and was occasionally found in the butt region. It belongs to the white-rot group of fungi; in the advanced stage, the decay consists of numerous spindle-shaped pockets or cavities parallel to the wood's grain, separated by fairly firm reddish-stained wood. These pockets are frequently filled with soft, white masses of almost pure cellulose (Fig. 3). The remainder of the decay was primarily butt decay caused by five or six species of fungi. Yellow-orange butt decays caused by white-rot fungi, with a soft, stringy texture, were somewhat more common than the brown, cubical butt rots caused by brown-rot fungi. These butt decays occupied much of the central stem region at stump height but seldom extended more than 2 to 2.5 m above that height.

In a later report, White (1960) stated that *F. pini* frequently enters white pine stems through leaders killed by the white pine weevil. Others have found evidence that as much as 80% of *F. pini* stem decay has its origin in weevil injuries (Ostrander and Foster 1957; Brace 1971). A study of weevil-damaged white pine, roughly 37 years old, in a plantation near Thessalon, Ontario, revealed no evidence of decay associated with leaders killed 17 to 20 years earlier (Basham 1971). However, Brace noted that although very little decay occurs until 30 years after weevil injury, thereafter it increases rapidly. In well established *F. pini* infections of white pine in northern New York state, the average annual vertical spread of decay columns was 25 cm (Silverborg and Larsen 1967). In a study on the effects of logging wounds on residual white pine stems during a partial cutting to release pole-sized trees, *F. pini* decay was found associated with one skidder gouge wound (Whitney and Brace 1979). Although very little stem decay was associated with all wounds examined 5 years after logging, the presence of decay fungi in the exposed wood of felling scrapes, skidder scrapes and gouges, and broken tops suggests that such logging wounds could have serious consequences as far as decay is concerned when the trees reach harvestable age.

Since *F. pini* seldom forms sporophores on the stems of living white pine, trees that appear healthy may have extensive trunk decay. The rare occurrence of *F. pini* conks, irregular brownish growths usually shaped somewhat like brackets or hooves, indicates extensive decay above and below the conks. Other external indicators of decay are white pine weevil injuries in the form of crooks, swollen or punky knots, bleeding branch stubs, large woodpecker holes, and any other noticeable stem wounds or scars. One of the fungi that causes a brown,

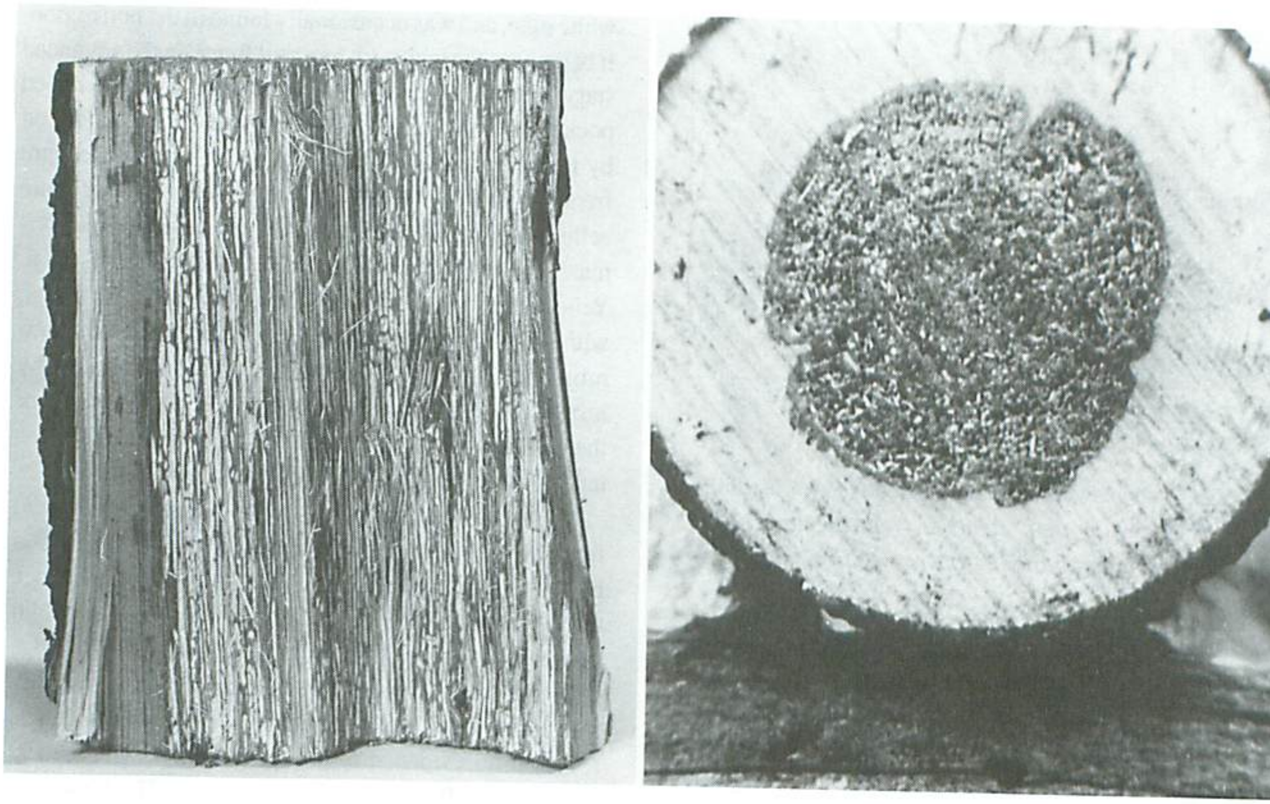

Figure 3. White pine stem decay caused by Fomes pini (Phellinus pini*). (left) transverse section of advanced decay, (right) closeup of radial section, showing pockets of cellulose in decayed wood.*

cubical butt rot, *Polyporus schweinitzii* (renamed *Phaeolus schweinitzii*), may produce conks at the base of infected trees or on the ground nearby. These are thin, bracket-shaped protrusions with velvety upper surfaces when fresh.

In the management of white pine, any steps that can be taken to minimize weevil damage and stem wounds will promote healthier, less decadent stands. In any case, serious decay losses are unlikely if trees are cut before they reach 120 to 130 years of age.

Red Pine

In Minnesota, red pine has long been considered one of the most disease- and insect-resistant trees in natural stands (Eyre and Zehngraff 1948). The same is true in Ontario and, largely on the basis of logging and sawmill experience, it is generally regarded as virtually free of stem decay. For this reason, and because of the relatively high value of the species, no extensive red pine stem-decay studies have been carried out in or near Ontario.

The only quantitative data available on red pine stem decay are those collected in the study of the rate of deterioration of fire-killed jack pine, red pine, and white pine trees in the Mississagi region between Blind River and Chapleau, Ontario, which was discussed in the section on white pine. In all, 462 red pine trees from six stands located roughly 100 km north of Blind River were felled, and the stems were dissected to reveal the extent of sap stain and sap rot (Basham 1958a). The occurrence and extent of heartwood decay, almost all of which would have been present before the trees died, were also recorded. All of the trees were in the 141- to 160-year age class. An average of 1.0% of the merchantable stem volume of these trees was recorded as decayed or stained (very little of this was stained). This can be compared with the 14.1% figure obtained for white pine of a similar age class in this study, and confirms the widely held opinion that red pine stems are relatively free of decay. Stem decay can probably be safely ignored in determining rotation or harvesting ages for red pine stands.

It is of interest to note that whereas only 12.4% of the stem decay in white pine was in the butt region of the stem (White 1953), 75.0% of stem decay in red pine was butt decay (Basham 1958a). In the trees sampled in

White's white pine decay study and in the Mississagi fire-killed pine study, butt decay in mature (141- to 160-year-old) trees was only about twice as common in white pine as in red pine. The main difference was in trunk decay, which was rarely encountered in red pine.

The fungus responsible for the most stem decay in red pine is *Polyporus tomentosus* (renamed *Inonotus tomentosus*). This fungus causes a white-pocket butt decay very similar in appearance to the decay caused by *Fomes pini* (renamed *Phellinus pini*). For a description of this decay, refer to the previous section on white pine. The brown-rot fungus *Polyporus schweinitzii* (renamed *Phaeolus schweinitzii*) causes a brown, cubical butt decay, but is only about one-third as common as *P. tomentosus*. The third most common cause of stem decay is *F. pini*, which is responsible for the extremely limited amount of trunk decay found in red pine. A very small amount of yellow-orange, stringy butt decay is caused primarily by two other fungi.

Because most stem decay in red pine occurs in the butt region of the stem, one should concentrate on this region when looking for external indications of decay. Besides basal scars, the presence of fruiting bodies of the fungi responsible for butt decay, either on the stems or growing on the ground nearby, are the most reliable signs. *Polyporus tomentosus* fruiting bodies appear annually, mostly in August, September and October. They occur on the base of the stem as bracket-shaped protrusions, where they are tan to dark brown, often with pronounced white margins, and on the ground near the tree as shallow, funnel-shaped sporophores on short stalks, of the same color as those growing on the tree but usually with a somewhat narrower whitish margin (Whitney 1977). Fruiting bodies of *P. schweinitzii* may also be present; these are described in the previous section on white pine. Regardless of the age at which stands are cut, it is improbable that stem decay in red pine will have a serious economic impact.

Jack Pine

Jack pine is sometimes regarded as a relatively decadent tree species. This reputation is undeserved, and is based for the most part on operations carried out in overmature stands more than 120 to 130 years old, in which stem decay can be extensive. Only black spruce was sampled in greater numbers than jack pine in the provincewide decay survey of the 1950s. Table 2 shows the relationship between age class and the percentage of merchantable stem volume decayed in 4,287 jack pine sampled throughout the Boreal Forest Region of Ontario. Comparing the impact of stem decay in jack pine with that in white pine is difficult because white pine is a much longer-lived and faster-growing species than jack pine. However, if one assumes an average desirable harvesting age of 80 to 90 years for jack pine and 120 to 130 years for white pine, trees at roughly the same stage of maturity can be compared. From Tables 1 and 2 it can be seen that, at these ages, roughly five times as much stem decay, on a percentage-volume basis, can be expected in white pine as in jack pine. Table 2 and Figure 4 show clearly that, beyond age 100, stem decay in jack pine increases rapidly. Under average conditions in the Boreal Forest Region of Ontario, it is recommended that jack pine stands be left no longer than 100 to 105 years if serious losses from stem decay are to be avoided. However, it will be shown later that this

Table 2. Occurrence of decay and stain in the stems of 4,287 jack pine sampled in the Boreal Forest Region of Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s. Trees were in stands throughout the Boreal Forest Region.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. decay and stain[a] vol. (dm^3)	Stem vol. as advanced decay (%)	Stem vol. defective (%)
21–40	275	54.8	0.07	0.0	0.1
41–60	533	95.9	0.88	0.1	0.9
61–80	930	202.9	3.20	0.4	1.6
81–100	1,073	265.4	9.59	1.1	3.6
101–120	678	393.0	40.18	3.0	10.2
121–140	560	503.8	80.21	4.7	15.9
141–160	129	586.6	144.37	7.6	24.6
161+	109	725.3	262.31	23.0	36.2

[a] Very little stain was present.

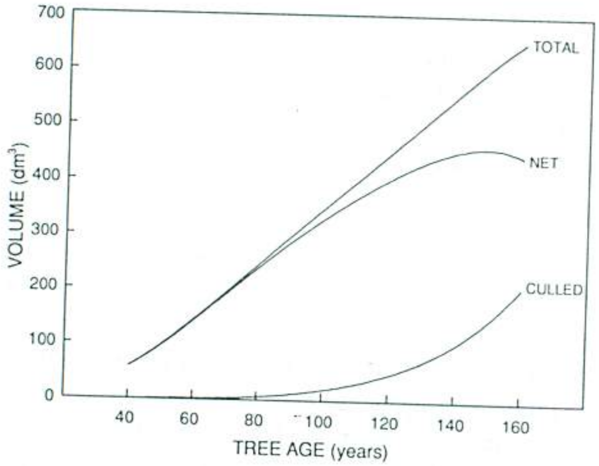

Figure 4. Average total merchantable stem volume, volume culled as a result of decay, and net volume of jack pine in relation to tree age. Volume-age data obtained from curves in Morawski et al.'s (1958) figure 8, courtesy of the Ontario Ministry of Natural Resources.

pathological rotation age should be lowered or raised somewhat depending on the location of the trees within the Boreal Forest Region and on site and soil conditions.

Two other investigations of stem decay in jack pine were carried out, both in the Lake States before World War II. Although detailed results are not presented, Weir (1915) reported that, on dry pine barrens, "jack pine reaches its normal age without much defect in the wood... although exceptionally old trees of 90 years and more frequently show considerable decay." He also stated that, in mixed stands, *Fomes pini* (renamed *Phellinus pini*) "causes considerable heart-rot in trees of 60 years and older. In general, however, this fungus is in negligible quantities." Weir concluded that stem decay fungi "... do not produce any appreciable decay till after the tree reaches its period of decline", which he placed at approximately 60 to 80 years. In another study, carried out in Michigan, Watson (1937) made increment borings in 2,000 jack pine trees and found evidence of stem decay in roughly 25% of them. There was a distinct relationship between age and decay, but decay was more than twice as common in fire-scarred trees as in trees with no fire scars (Watson 1937). Watson recommended that rotations should be 10 to 20 years shorter in jack pine stands in which light surface fires have occurred repeatedly.

The amount of stem decay in jack pine in the Boreal Forest Region of Ontario was strongly related to tree growth rate, which in turn was closely linked to site: the drier the site, the slower the growth rate (Morawski et al. 1958; Basham 1967). For similar age classes, stands more than 80 years old had the most decay on sites with soil moisture regime 0 (very dry) and the least on sites with soil moisture regime 2 or 3 (moderately fresh) (Table 3 and Fig. 5). Furthermore, in stands on moisture regime 0 sites, 57.9% of stem decay was in the advanced stage; on moisture regime 1 sites, advanced decay was 56.6% of the total, and on moisture regime 2 to 3 sites, only 43.1% of stem decay was in the more serious advanced form. Although the slower-growing trees tended to have a higher percentage of stem volume decayed than the faster-growing trees within stands, each on fairly uniform sites, this difference was not statistically significant. Analysis-of-variance calculations indicated that soil moisture regime was significantly related to the percentage of stem volume decayed in jack pine in Ontario (Basham 1967). In Ontario and in the Lake States, the fact that jack pine grows more slowly, on average, on very dry sand-plain sites with relatively deep water tables than on less dry sites has been known for some time (Weir 1915; Rudolf 1958; Chrosciewicz 1963; Benzie 1977). In the more than 4,000 trees sampled in Ontario in the provincewide decay survey, the fastest growth occurred on sites with soil moisture regimes 3 and 2, followed by regimes 1 and 0, in that order. Since growth rate is largely

Table 3. Relationship between soil moisture regime, age and stem decay in 4,034 jack pine in the Boreal Forest Region of Ontario (curved values). Trees sampled on sites with moisture regimes 4 and 5 and trees more than 160 years old (253 trees) constituted samples that were too small to show relationships and are not included.

Soil moisture regime	Avg. tree age (years)	Stem decay in advanced stage (%)	Merch. stem vol. defective (%) by age class (years)					
			41–60	61–80	81–100	101–120	121–140	141–160
0 (dry)	82	57.9	0.9	1.6	5.2	12.0	20.1	26.2
1 (moderately fresh)	93	56.6	0.3	1.3	3.7	7.7	13.6	23.9
2–3 (fresh)	97	43.1	1.1	1.6	2.3	4.1	10.0	19.7

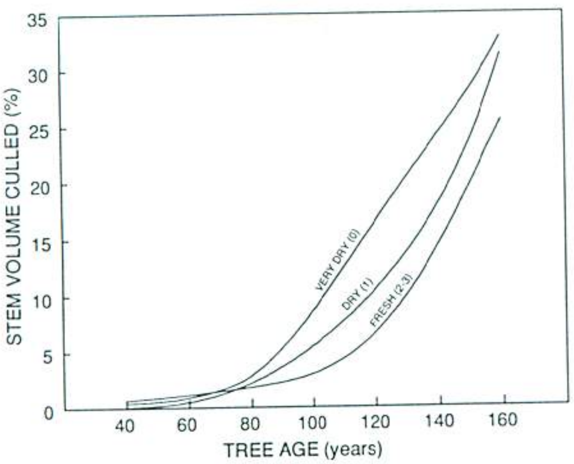

Figure 5. Average percentage of merchantable volume culled as a result of decay, in relation to tree age, for jack pine growing on three different sites in Ontario. Soil moisture regimes within parentheses. Percentage-age data obtained from curves in Morawski et al.'s (1958) figure 11, courtesy of the Ontario Ministry of Natural Resources.

a reflection of tree vigor, this relationship suggests that site may be related to the amount of stem decay in jack pine at least partly because of its effect on tree vigor.

An even more statistically significant relationship than that between site and the amount of stem decay was found between the geographical location within the Boreal Forest Region and the amount of stem decay in jack pine (Basham 1967). The sample plots containing significant numbers of jack pine were divided into three groups on the basis of their location. Northwestern Ontario, that part of the province west of a line running north from Thunder Bay, was roughly the same as the present Northwestern Region of OMNR. A total of 1,612 jack pine, with an average age of 91 years, was sampled there. North-central Ontario, from northwestern Ontario to a line running north from Sault Ste. Marie, is roughly the same as OMNR's present North Central Region. In the decay survey, 1,294 trees with an average age of 91 years were sampled there. The area from north-central Ontario east to the Quebec border, i.e., northeastern Ontario, approximates OMNR's Northern Region. There, 1,381 jack pine, with an average age of 86 years, were sampled. In each age class from 61–80 to 120–160 years, two to three times as much decay was present in the trees sampled in northwestern Ontario as in trees sampled in northeastern Ontario. Jack pine in north-central Ontario were consistently more defective than northeastern jack pine and less defective than northwestern jack pine (Fig. 6). In addition to having significantly less stem decay on a percentage-volume basis than trees in the other two regions, jack pine in northeastern Ontario had the smallest proportion of stem decay in the more serious advanced stage.

Although many possible reasons have been discussed (Basham 1967), no satisfactory explanation has been given for the significantly different levels of stem decay in jack pine in the three zones of the Boreal Forest Region. Soil moisture-regime differences were suspected, as trees from regimes 2 and 3 were sampled more frequently, and from regime 0 less frequently, in northeastern Ontario than in north-central or northwestern Ontario. However, analyses of variance indicated that, when site was eliminated as a variable, differences in the extent of stem decay among the three regions remained statistically significant.

In view of the significant effects of soil moisture regime and of geographic location on the occurrence of stem decay in jack pine, it is clear that modifications are required in the recommendation made earlier that jack pine stands be harvested no later than age 100–105 if serious losses from stem decay are to be avoided. It is probably safe to leave jack pine stands growing on sites with any soil moisture regime other than 0 in northeastern Ontario until age 120, whereas in northwestern Ontario, stands on sites with soil moisture regime 0 are likely to develop serious stem decay problems after age 90.

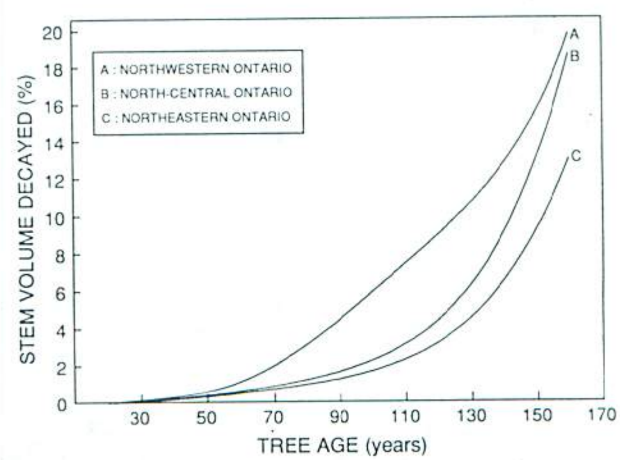

Figure 6. Average percentage of merchantable volume decayed, in relation to tree age, for jack pine growing in three regions of Ontario. Percentage-age data obtained from curves in Basham's (1967) figure 2.

Trunk decay in the 4,287 jack pine sampled in the Ontario decay survey accounted for 80.9% of the total stem-decay volume; the remainder was butt decay. This can be compared with 87.6% for white pine and 25.0% for red pine. As in the two other pines, very little stain (firm, discolored wood) was found. In all age classes up to 160 years, incipient decay was slightly more common than advanced decay; in trees more than 160 years old, almost all stem decay was in the advanced stage. Two fungi, *Fomes pini* and *Peniophora pseudopini* (formerly named *Stereum pini*), were responsible for all but 2.5% of the decay volume (Fig. 7). Both fungi cause trunk decay primarily, although both were also associated with some butt decay in this study. Most of the remaining 2.5% of the decay was butt decay caused by *Polyporus tomentosus* (renamed *Inonotus tomentosus*) and *Corticium galactinum* (renamed *Scytinostroma galactinum*). Almost all of the advanced decay was white pocket rot caused by *F. pini* and *P. tomentosus*, which are described in detail in the section on white pine. Incipient decay was slightly softened (weakened) wood, predominantly red but ranging from light orangey-pink to brownish-red. About 60% of this incipient decay was caused by *F. pini*, the remainder by *P. pseudopini*, which belongs to the white-rot group of fungi and rarely causes advanced decay. A relatively small number of jack pine were infected with white pocket or yellow stringy butt decays, caused mainly by *P. tomentosus* and *C. galactinum*, respectively (both white-rot fungi). Very few trees that were sampled had brown cubical butt decay. *Polyporus schweinitzii* (renamed *Phaeolus schweinitzii*), a brown-rot fungus reported to be one of the major causes of stem decay in jack pine in the Lake States (Weir 1915), was isolated only from four of the 4,287 trees.

Fomes pini, by far the major cause of advanced decay in jack pine, appears to enter the trunk through stem wounds such as felling or fire scars, through rust cankers, or through dead or broken tops, but seldom through dead branches (Basham 1975). The fungus was not found entering broken tops 8 years after a severe ice storm that occurred near Chapleau, Ontario, in May of 1960 (Basham 1971). In this case, tree tops had been broken off at diameters ranging from 2.5 to 9 cm, and a light-red stain that extended down about 40 cm into the stem was associated with trees examined 6 to 8 years after the damage. No decay fungi were isolated from the stain; however, the results of other studies indicate that, had the tops been broken off in late fall or winter, decay would probably have occurred (Davidson and Etheridge 1963). *Peniophora pseudopini* is an occasional invader by way of dead branch stubs (Basham 1975), but the majority of infections probably originate at stem wounds. The butt-decay fungi, including *P. tomentosus* and *C. galactinum*, enter the basal stem regions from infected root systems or through basal stem wounds such as fire scars.

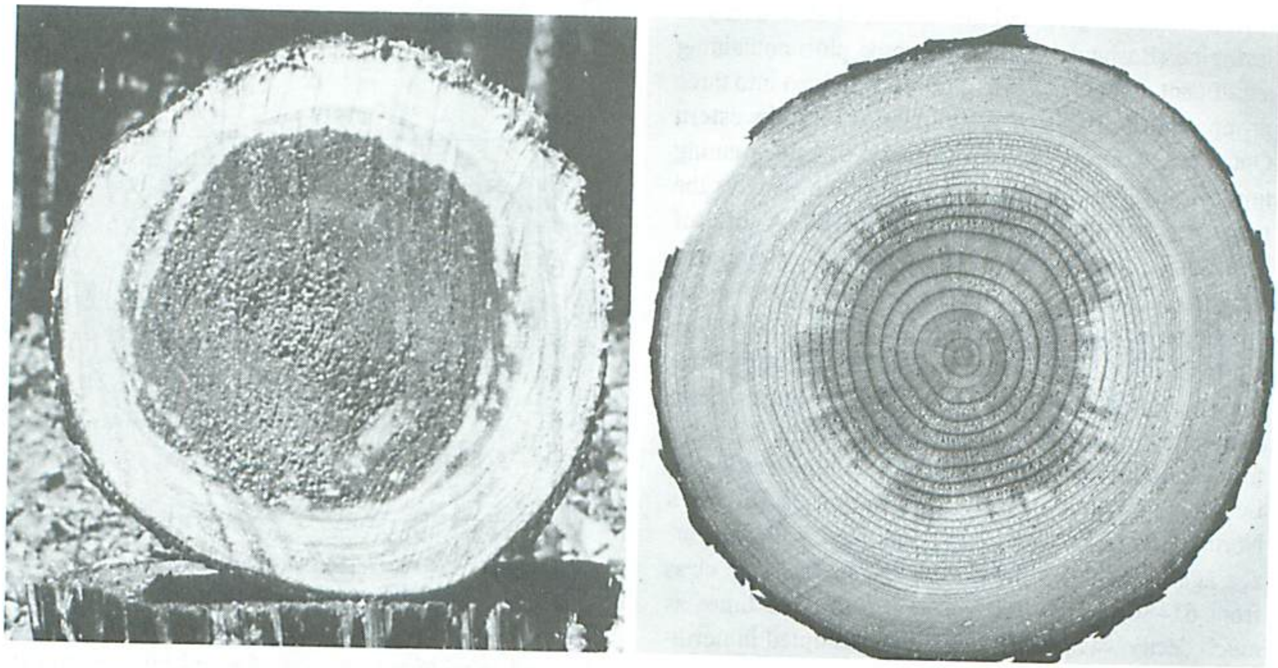

Figure 7. Jack pine stem decays. Transverse stem sections showing (left) advanced decay caused by Fomes pini *(*Phellinus pini*), and (right) incipient stem decay caused by* Peniophora pseudopini *(*Stereum pini*).*

There are few reliable external indications of stem decay in living jack pine. Fruiting bodies of *F. pini* and *P. tomentosus*, described in the sections on white pine and red pine, respectively, occur very rarely, and visible fruiting bodies of *P. pseudopini* and *C. galactinum* almost never occur. Stem wounds such as fire scars, felling scars, rust cankers (particularly those of the sweetfern rust, *Cronartium comptoniae*), and broken tops are the most reliable signs that some internal stem decay is probably present.

Except in the groundwood process, stem decay in jack pine is not a serious problem for the pulpwood industry. Because stained wood causes brightness losses and incipient decay causes some losses in yield in groundwood pulp, mills employing the groundwood process should use relatively short rotations on the poorer sites (such as those with soil moisture regimes of 0), on which some stain and even a small amount of incipient decay can occur in stands as young as 40 years. As far as chemical pulps are concerned, stem decay is not a serious problem, as the two fungi responsible for trunk decay both belong to the white-rot group and cause only some delignification. Furthermore, at customary rotation ages for jack pine, virtually all the decay they cause is in the incipient stage and seldom amounts to more than 3% of the merchantable volume. For sawlog production, dry sites (soil moisture regime 0) should be avoided if possible because of the slower growth of the trees and the more rapid development of stem decay on such sites.

As mentioned earlier, to avoid significant losses to stem decay, jack pine stands should be harvested no later than between 90 and 120 years of age, depending on the site and the region of the province. Regardless of how the harvested trees are utilized, stem decay will have less impact if young stands are sufficiently dense to promote good self-pruning, and if stands are subsequently protected as much as possible from stem wounds such as fire scars, felling scars, rust cankers, and broken tops.

Black Spruce

In general, black spruce is second only to red pine among the commercial forest tree species of Ontario in having the lowest percentage of its merchantable stem volume affected by decay and stain. Only 3.0% of the merchantable volume of the 6,269 black spruce examined in the Boreal Forest Region of Ontario in the decay survey of the 1950s was in the form of decay or stain. Unlike in other species, the percentage of defective stem volume in black spruce does not increase with age up to the oldest age classes. Instead, defect peaks at ages 121 to 160 and then begins a steady decrease (Table 4). This is contrary to the accepted theory that the number of entrance courts for decay fungi tends to increase as trees age, while existing decay pockets expand and tree growth tends to slow down; for these reasons, decay as a percentage of tree volume should increase continually. Black spruce does not follow this general pattern for two reasons: first, there is a very strong relationship between site (as expressed by soil moisture regime) and

Table 4. Occurrence of decay and stain in the stems of 6,269 black spruce sampled in the Boreal Forest Region of Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s. Trees were in stands throughout the Boreal Forest Region.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. decay and stain[a] vol. (dm^3)	Stem volume as advanced decay (%)	Stem volume defective (%)
21–40	24	13.1	0.00	0.0	0.0
41–60	383	48.0	0.62	0.3	1.3
61–80	1,036	71.3	0.72	0.4	1.0
81–100	1,284	85.1	1.01	0.7	1.2
101–120	1,421	107.8	2.68	1.3	2.5
121–140	1,156	119.2	5.61	2.0	4.7
141–160	582	146.5	6.31	2.1	4.3
161–180	254	141.7	5.39	1.2	3.8
181–200	80	129.4	5.04	1.7	3.9
201–220	38	121.2	1.58	1.1	1.3
221+	11	122.9	3.70	2.8	3.0

[a] Very little stain was present.

stem decay, and second, a high proportion of advanced decay in black spruce occurs in the form of butt decay. Indeed, ages at which stem decay becomes serious cannot be discussed without these two factors being considered first.

Butt decay accounted for 58.2% of the stem-decay volume and 71.8% of the advanced stem decay in black spruce (Basham and Morawski 1964). Had the 30-cm stumps been examined and included, these percentages would have been higher, as the vast majority of butt decays are upward extensions of extensive root-system decays. In a survey of the root systems of 570 black spruce in northwestern Ontario, Whitney (1976) found root decay in 530 (93%) of them. Black spruce has a relatively shallow root system (Vincent 1965). As black spruce age, more and more of the infected root systems are subject to advanced decay, more roots die, and the trees with the most extensive decay in the root system and butt regions are uprooted or sustain wind breakage. Hence, as stands become overmature, the majority of trees that are eliminated in this way are those with relatively extensive stem decay, and the overall defectiveness of the remaining stand can actually decrease with age.

The strong relationships between site (soil moisture regime) and the incidence of stem decay in black spruce, as well as tree growth rate and longevity, provide additional explanations for the unusual relationship between age and extent of decay in this species. Statistical analysis (ANOVA) conducted on the 6,269-tree sample from the Boreal Forest showed that both age and soil moisture regime were very significantly ($P<0.01$) related to the extent of stem decay in black spruce, but that the extent of decay was much more strongly related to moisture regime than to age (Basham 1973b). This is not surprising for a species in which such a high proportion of stem decay in the butt region originates as root rot, since the fungi responsible for such decays are primarily subterranean organisms. A greater proportion of the merchantable volume of black spruce stems was decayed on the drier sites than on the wetter sites (Fig. 8). Except for borderline cases, black spruce within the 6,269-tree sample were separated into two groups, those on upland, relatively well drained dry-to-fresh sites, and those on lowland, moist-to-wet sites with somewhat impaired drainage. After 80 years of age, considerably more decay, primarily butt decay, was found on the upland sites than on the lowland sites (Morawski et al. 1958). Similar relationships have been reported in the Lake States (LeBarron 1948; Heinselman 1957; Johnston 1977). In northwestern Ontario, decay within the root systems of black spruce was far more extensive on drier (moisture regime 0 to 3) sites than on wetter (moisture regimes 4 to 8) sites, with the least decay found on wet (moisture regimes 7 and 8) sites (Whitney 1976). Black spruce grows faster in Ontario on upland sites with predominantly mineral soils than on lowland sites with organic soils (Vincent 1965; Arnup et al. 1988), a relationship that held true for the black spruce sampled in the decay survey (Morawski et al. 1958; Basham 1973b). In the cull survey, an attempt was made to select stands for sample plots that were representative of all sites, cover types, and age classes for each species in all regions of Ontario. Of the 6,269 black spruce sampled, the majority of trees older than 150 years were on lowland sites on which the incidence of stem decay was much lower than on upland sites. This is perhaps the principal explanation for the unusual decrease in the extent of stem decay with age in the older black spruce age classes.

On wetter lowland sites with somewhat impaired drainage, stem decay is seldom a serious problem in black spruce. Because of its slower growth and greater longevity on such sites, rotation ages are necessarily long but it is highly unlikely that more than 5% of stem volume in stands, regardless of age, would ever be decayed. On well-drained upland sites in Ontario, on the other hand, Whitney (1976) stated that "more than one-third of the volume of average upland black spruce stands 75 years of age, was lost because of root rot", primarily as a result of windfall and mortality. Fortunately, faster growth on such sites compensates for these losses to some extent; in many cases, trees reach merchantable pulpwood size before they reach that age.

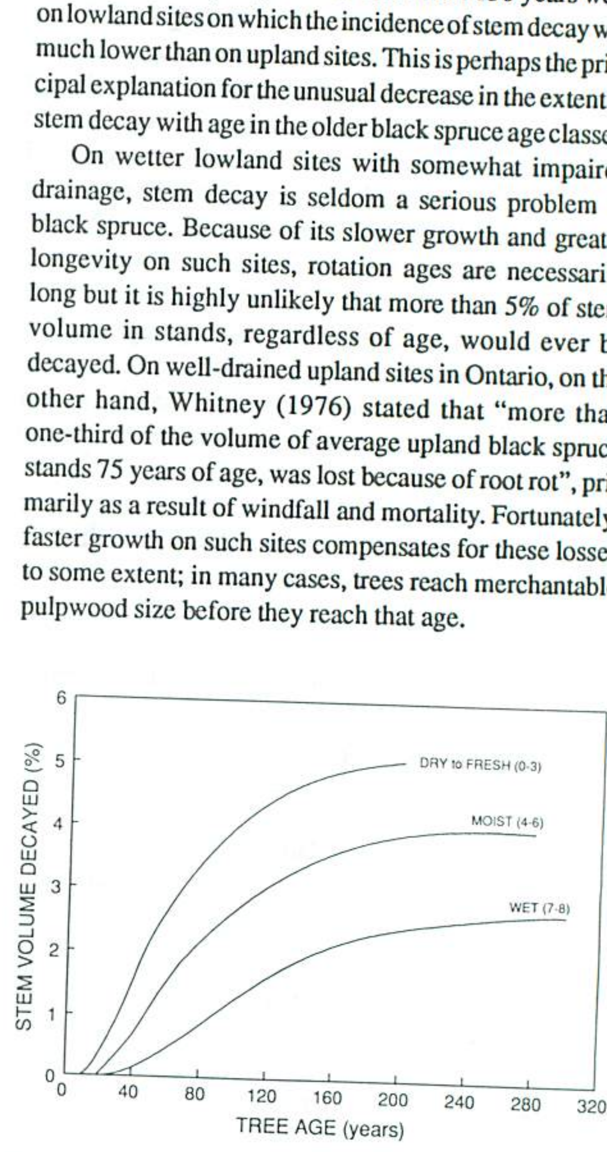

Figure 8. Average percentage of merchantable volume decayed, in relation to tree age, in black spruce growing on three different sites in Ontario. Soil moisture regimes are within parentheses. Percentage-age data were obtained from curves in Basham's (1973b) figure 6.

Within soil-moisture-regime groups in the Boreal Forest of Ontario (7 and 8 = wet, 4 to 6 = moist, and 0 to 3 = dry–fresh), it was found that black spruce trees with average diameter growth rates greater than the stand average had greater-than-average amounts of stem decay, whereas trees with below-average diameter growth rates had lower-than-average amounts of decay (Basham 1973b).

Advanced, soft decay accounted for roughly two-thirds of all decay found in 6,269 black spruce (Basham and Morawski 1964). The predominance of decay in the butt region rather than in the trunk has already been pointed out. The principal organisms causing butt decay in black spruce in Ontario are *Fomes pini* (renamed *Phellinus pini*) and *Polyporus tomentosus* (renamed *Inonotus tomentosus*), which are responsible for white pocket decay (Fig. 9), and *Corticium galactinum* (renamed *Scytinostroma galactinum*), which causes a yellow stringy decay. *Fomes pini* is the principal cause of the less common trunk decay, but, over all, is associated with more stem decay in black spruce than any other fungus in Ontario (Basham and Morawski 1964). In an examination of root systems and 30-cm stumps of 570 black spruce in northwestern Ontario, Whitney (1978) found *Armillaria mellea* (now believed to be mostly *A. ostoyae*) to be the principal cause of decay. This fungus was rarely isolated above the 30-cm stump height in black spruce in the provincewide decay survey, a reflection of the fact that although *Armillaria* is the primary cause of root decay in black spruce in the Boreal Forest Region of Ontario, it seldom extends into merchantable stems. Appreciable amounts of a reddish trunk decay in black spruce caused by *Stereum sanguinolentum* (renamed *Haematostereum sanguinolentum*) have been reported in the Prairie provinces (Whitney and Denyer 1970), Quebec (Lavallée 1965), and the Lake States (Lorenz and Christensen 1937). Very few infections caused by this fungus in Ontario were found in the decay survey of the 1950s (Basham and Morawski 1964). Brown cubical butt decays are rare in Ontario; of those encountered in the decay survey, most were caused by the brown-rot fungus *Coniophora puteana*.

Some 300 stem wounds on 190 black spruce in Quebec were examined as possible entry points for trunk decay (Lavallée 1965). Broken tops were found to be the

Figure 9. Black spruce stem decays. (top) transverse and radial views of incipient Fomes pini (Phellinus pini) *decay, (middle) transverse section of advanced* F. pini *decay, (bottom) radial closeup view of advanced decay caused by* Polyporus tomentosus (Inonotus tomentosus).

most common point of entry, followed by felling wounds. Branch stubs were of minor importance. *Fomes pini* was most frequently isolated from stem decay associated with the wounds, followed by *S. sanguinolentum*. In Ontario, *F. pini* was rarely found in black spruce branch stubs (Basham 1973c), and it is presumed to enter mainly through stem wounds of other kinds. Although *F. pini* was the fungus most frequently associated with butt decay in black spruce in Ontario, it differed from the other butt-decay fungi in that, in most cases, it extended downwards into the butt region from higher entry points. The other butt-decay fungi (*P. tomentosus*, *C. galactinum*, etc.) frequently extend upwards into the butt region after infection of the root system. Basal stem wounds such as fire scars provide exceptions to these rules and permit entry of both *F. pini* and the root-decay fungi, and result in butt decay.

Reliable external indications of internal stem decay in living black spruce are very rare. Apart from fruiting bodies of *P. tomentosus* in late summer and early fall (described in the section on red pine), fruiting bodies of decay-causing fungi are seldom present. Broken tops, felling scars, and fire scars, unless they are relatively recent, are indications that stem decay has probably formed. However, it should be remembered that the most serious kind of decay in black spruce, root and stump decay, is completely hidden for the most part (Whitney 1988).

Practically all stem decay in black spruce is caused by fungi that belong to the white-rot group, so that in the incipient stage of decay, at least, the wood can be used for chemical pulps with little harmful effect. Most butt decays, particularly those that originated as root rots, have relatively short incipient stages and, at stump height, frequently appear as extensive advanced decay. However, these decays seldom extend more than 1 m above ground and can be avoided by "jump butting" and removing the lowermost 0.5 to 1 m.

Polyporus tomentosus root rot and butt decay of black spruce can, under certain circumstances, become exceptionally heavy and cause serious losses in the form of stand openings as a result of mortality and windthrow. This condition can occur on acidic soils low in nutrients and in moisture-holding capacity, and where the rooting depth is restricted by shallow or compact soils (Whitney 1977). In such stands, Whitney recommended clearcutting and conversion of the stand to less susceptible species such as pines, balsam fir, or hardwoods. The occurrence of root rot can be minimized by taking care that residual trees are not severely wounded during partial cutting with large multi-operation machinery, by exposing buried, infected, dead material during site preparation, and by removing as much dead material as possible from the site (Whitney 1988). Upland sites should be harvested before lowland sites where age classes are the same or similar, as mentioned earlier. Rotation ages of 50 to 60 years on sandy upland sites, and 70 to 80 years on finer-textured upland soils, have been recommended for black spruce to avoid root-rot and butt-decay losses (Whitney 1979). Because faster growth in black spruce is frequently associated with more stem decay (Basham 1973b), procedures to accelerate the growth rate of black spruce, such as fertilization or site improvement by drainage, may well raise productivity but are also liable to increase the incidence of stem and root decay appreciably.

White Spruce

The percentage of merchantable stem volume affected by decay or stain, by age class, in the 564 white spruce examined in the provincewide decay survey of the 1950s is shown in Table 5. A comparison of this table

Table 5. Occurrence of decay and stain in the stems of 564 white spruce sampled in Ontario. Based on trees examined as part of the federal–provincial decay survey of the 1950s. Of the 564 trees, 481 were in the Boreal Forest Region and 83 were in the Great Lakes–St. Lawrence Forest Region.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. decay and stain[a] vol. (dm^3)	Stem volume defective (%)
41–60	93	78.7	0.31	0.4
61–80	106	152.8	1.54	1.0
81–100	95	212.7	4.67	2.2
101–120	179	301.2	10.25	3.4
121–140	67	489.5	11.27	2.3
141+	24	805.5	33.01	4.1

[a] Very little stain was present.

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141+	24	805.5	33.01	4.1

[a] Very little stain was present.

the older age classes been sampled, the incidence of stem decay would have negligible effects on the selection of rotation ages for either pulpwood or lumber.

The relationship between site and the extent of stem decay in white spruce sampled in the decay survey of the 1950s was not analyzed because too few trees were sampled to negate the influence of other factors such as age, cover type, region, etc. However, white spruce damage from root decay (butt decay, windthrow, etc.) has been reported to be greatest on dry sites and least on wet or moist sites (Whitney 1976). The relationship was similar to that in black spruce, but was not as strong.

Butt decay accounted for 62.3% of the stem-decay volume and 72.9% of the advanced decay present in the 564 white spruce examined in the provincewide decay survey. Similar results were found in the Maritime provinces, where 72% of the decay volume was composed of butt decay (Davidson and Redmond 1957). In Ontario, almost three-quarters of the stem decay was in the advanced stage (Basham and Morawski 1964). Almost half of the advanced decay was white pocket decay, caused primarily by *Fomes pini* (renamed *Phellinus pini*) in the trunk and *Polyporus tomentosus* (renamed *Inonotus tomentosus* in the butt regions (Fig. 10). Most of the incipient decay was red, and was also caused by these two fungi. A detailed description of white pocket decay is presented in the section on white pine. Most of the rest of the stem decay was yellow stringy butt decay, a yellow-orange to yellow-brown decay with pockets in the spring wood that sometimes coalesce and cause separation of the annual rings. In the more advanced stages of infection, the wood is reduced to a loose, stringy mass of fibers, and eventually cavities form in the center of the stems. *Corticium galactinum* (renamed *Scytinostroma galactinum*) was the principal cause of this defect (Fig. 10), although several other fungi caused decays similar in appearance. The principal cause of root decay was *Armillaria* sp. (probably *A. ostoyae*) (Whitney 1978), although it was never isolated from the 564 white spruce in the decay survey of the 1950s. As in the case of black spruce, this is a reflection of the fact that *Armillaria* generally stays within the root system or does not extend very far up into the stem.

In a study of the association of stem scars caused by logging with stem decay in white spruce in British Columbia, it was found that, after 15 years, practically all root and ground-contact scars were infected, as were 70% of the scars in the butt region and 38% in the upper bole (Parker and Johnson 1960). However, nearly 100% of scars with an area greater than 0.09 m^2 (1 ft^2) were infected, regardless of position. Scars on relatively large-diameter trees were more frequently infected than scars on smaller-diameter trees. As in black spruce, decayed white spruce frequently look exactly the same as sound trees. The only useful external indicators of decay are stem wounds, broken tops, and fruiting bodies of *P. tomentosus* on the lower stems or on the ground nearby in late summer and early fall (for a description, see the section on red pine).

All stem decays in white spruce, with the exception of relatively rare brown cubical butt decays, are caused by white-rot fungi, and therefore wood in the incipient stage of decay can be used in chemical pulping processes, as can small amounts of wood in the advanced stage, provided it is mixed as uniformly as possible with sound wood. The volume of stem decay in white spruce is seldom extensive enough to be of concern, regardless of age when harvested. Windthrow and mortality caused by root and butt decay can be serious in stands over 120 years of age. This danger can be minimized by reducing the likelihood that basal stems and roots will be injured, particularly by fire or during harvesting operations, and by minimizing exposure of trees or stands to wind.

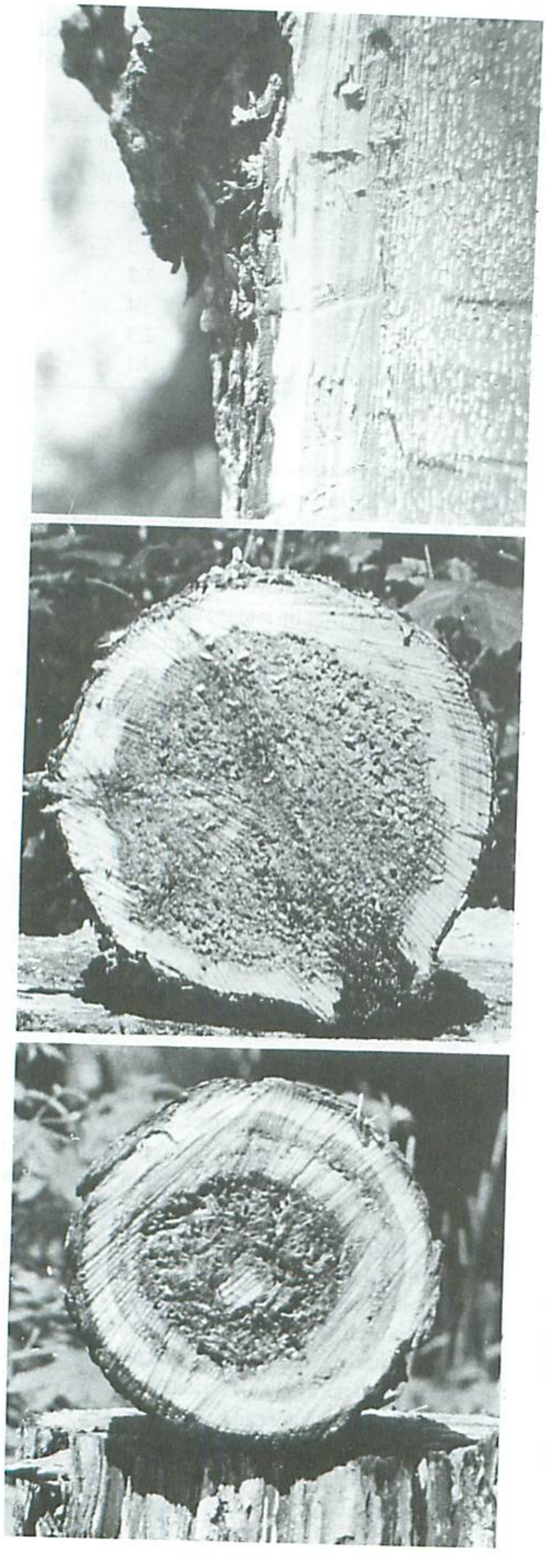

Figure 10. White spruce stem decays. (top) radial closeup view of advanced decay caused by Fomes pini (Phellinus pini) *showing pockets of cellulose, (middle) transverse view of advanced decay caused by* Polyporus tomentosus (Inonotus tomentosus), *(bottom) transverse section of basal stem region with advanced decay caused by* Corticium galactinum (Scytinostroma galactinum).

Balsam Fir

Of Ontario's coniferous species, balsam fir is the most susceptible to stem decay. This is evident in Table 6, which shows the percentage of merchantable stem volume decayed or stained, by age class, for the 1,388 balsam fir sampled in the provincewide decay survey. Only very overmature jack pine, older than 140 years, had higher percentages of decay volume. Changes with age in average volumes culled as a result of decay, as well as changes in total and net merchantable stem volumes for the 1,388 balsam fir, are shown in Figure 11.

Because of the high incidence of decay in balsam fir, a relatively large number of studies of stem decay in this species had been carried out by 1957 (McCallum [1928] and Pomerleau[1] for Quebec, Kaufert [1935] for the Lake States, Spaulding and Hansbrough [1944] for New England and New York, Basham [1950] for Ontario, and Davidson [1957] for the Atlantic provinces). Despite differences in climate, soil conditions, tree growth rates, etc., the researchers conducting these studies drew remarkably similar conclusions about the age at which balsam fir should be harvested to avoid serious decay losses, namely, 70 to 80 years. Their results were based on the progress of decay within individual trees, but in a study of balsam fir stem decay in the Lake States, a similar pathological rotation age was arrived at on a stand basis (Gevorkiantz and Olsen 1950). In most of these studies it was mentioned that tree mortality and windthrow as a result of butt and root decay were not fully taken into account, and that had this been done, somewhat lower rotation ages would probably have been recommended. Redmond (1957), studying root rot in young balsam fir stands in New Brunswick, observed that windthrow was often common in stands by age 75, and therefore recommended the shortest rotation that would produce trees of merchantable size. The first study of balsam fir decay that included careful observations of

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[1] Pomerleau, R. 1957. Studies on decay of balsam fir and red spruce in the eastern townships region of Quebec. Dep. Agric., For. Biol. Div., Quebec City, Que. Interim Rep. 1957-1. 19 p. (unpubl.)

Table 6. Occurrence of decay and stain in the stems of 1,388 balsam fir sampled in Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s. Of the 1,388 trees 1,139 were in the Boreal Forest Region and 249 were in the Great Lakes–St. Lawrence Forest Region.

Age class (years)	No. of trees	Avg. merch. volume (dm^3)	Avg. decay and stain[a] vol. (dm^3)	Stem volume defective (%)
21–40	17	31.9	0.23	0.7
41–60	222	57.3	4.51	7.9
61–80	568	92.7	5.67	6.1
80–100	352	132.3	13.50	10.2
101–120	148	132.5	26.22	19.8
121–140	55	169.9	25.56	15.1
141+	26	187.5	43.30	23.1

[a] Very little stain was present.

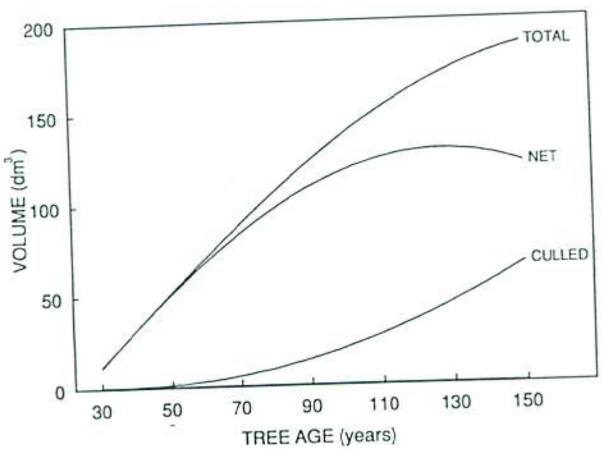


Figure 11. Average total merchantable volume, volume culled as a result of decay, and net volume of balsam fir in relation to tree age. Volume-age data obtained from curves in Morawski et al.'s (1958) figure 14, courtesy of the Ontario Ministry of Natural Resources.

mortality and windthrow caused by root and butt decay was carried out in Upper Michigan by Prielipp (1957). He recommended three rotation ages, depending on site and soil conditions (discussed below), with an average rotation age of 55 to 60 years. In the first study in which root decay was examined and measured in the Boreal Forest of Ontario, Whitney (1989) found that root decay in stands up to age 90 was more extensive in balsam fir than in spruce, and total losses to windthrow and butt decay were higher. He recommended a rotation age for balsam fir of less than 65 years when potential crop-tree mortality, windthrow and stem-decay losses are considered.

Prielipp (1957) found that balsam fir in Upper Michigan grew best but had the most decay and losses to decay on uplands, whereas it was relatively sound, but grew more slowly, on wet sites. He recommended earlier rotation ages on upland sites for that reason. Other investigators found that stem decay in general, and butt decay in particular, were more extensive in balsam fir growing on upland sites or "mixedwood slopes" than on lowland sites or "softwood flats" (Kaufert 1935; Heimburger and McCallum 1940; Basham et al. 1953). Brown cubical butt decays, in particular, were rarely found in balsam fir on softwood flats (Basham et al. 1953). Whitney (1976) reported that root decay in balsam fir was more extensive on dry or fresh sites than on moist or wet sites in the 31- to 60-year age class, was most extensive on dry sites in the 61- to 90-year age class, but was of roughly the same intensity on all sites at ages above 90 years. This very likely reflects the fact that many of the balsam fir trees that develop the most extensive root decay on dry and fresh sites are eliminated from the stands by the time they reach 90 years of age.

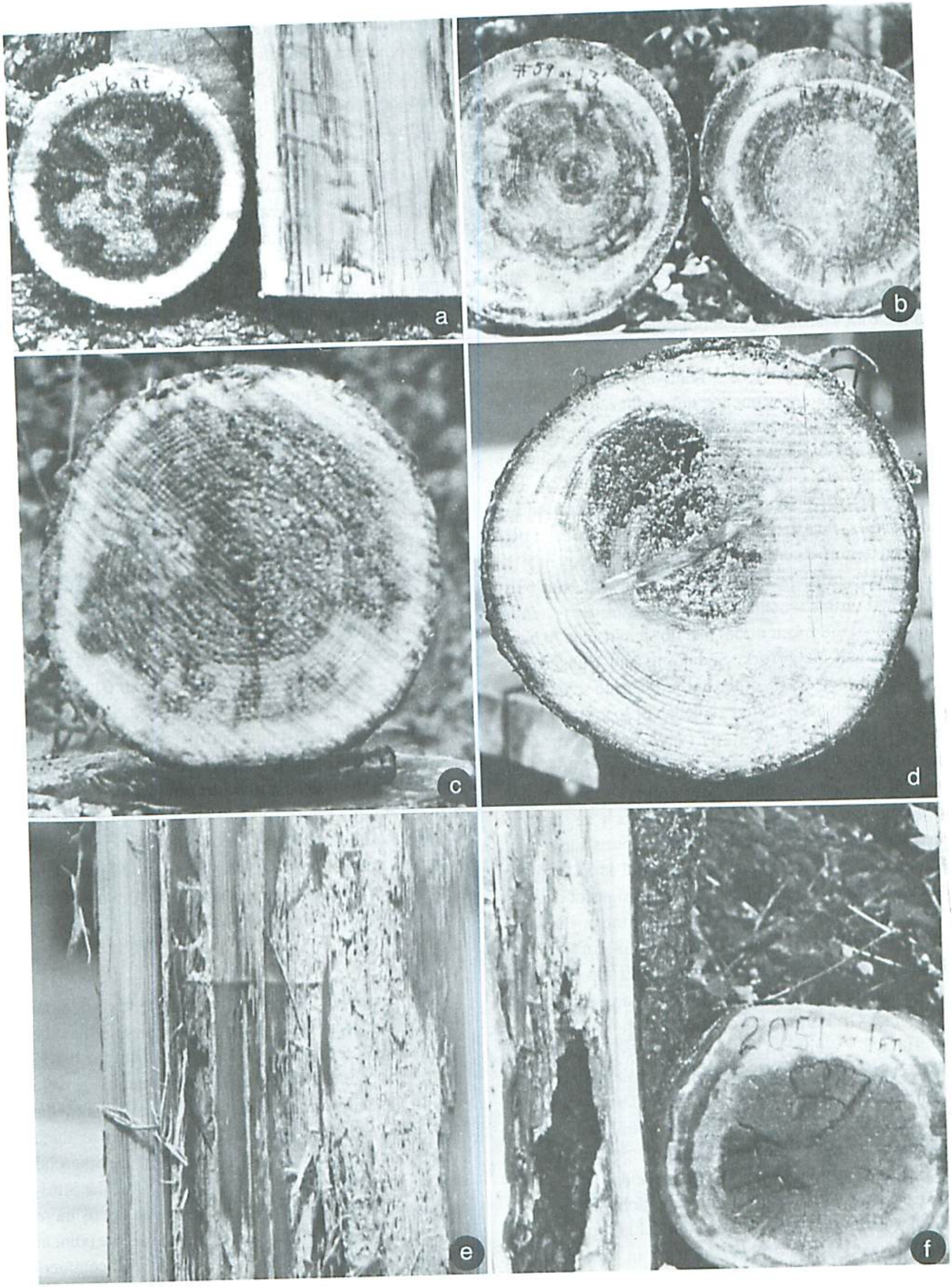
According to Whitney and MacDonald (1985), there is a relationship between the presence of butt decay 15 cm above ground level and the growth rate of balsam fir trees in northern Ontario. In 1,612 trees of all ages, these researchers reported that trees with butt decay had average height and diameter increments over the most recent 3 years that were 13.5 and 10.9% smaller, respectively, than trees with no butt decay. Spaulding and Hansbrough (1944) and Basham (1950) reported higher percentages of decay in merchantable stem volume of balsam fir in slower-growing than in faster-growing trees up to about age 70 in the northeastern United States and in Ontario, after which the situation is reversed. Both of those studies showed that the extent of stem decay increases with tree diameter, not only in volume but also as a percentage of the merchantable stem volume. Balsam fir grew much faster in the northeastern United States than in northern Ontario, with a 70-year-old tree averaging 210 dm^3 in the former region and 93 dm^3 in the latter. Therefore, whereas Spaulding and Hansbrough (1944) recommended harvesting stands before average diameters of over 11 in. (28 cm) were reached in the northeastern United States because of stem decay, Basham (1950) recommended 7 to 8 in. (18-20.5 cm) as the diameter limit in Ontario.

Trunk decay accounted for 74.6% of the stem decay encountered in the 1,388 balsam fir sampled in the provincewide decay survey of the 1950s (Basham and Morawski 1964). In another study in which 933 balsam fir in Ontario were examined, the percentage of trees with butt decay was greater than that of trees with trunk decay up to age class 61–80 years, after which the reverse was true (Basham 1950). In Michigan, Prielipp (1957) found that the percentage of the merchantable stem volume of balsam fir affected by butt decay was greater than that affected by trunk decay until 80 years, after which the situation was reversed.

The most extensive type of stem decay in balsam fir is a reddish-brown decay frequently called "red heart rot". In its incipient stage, it is red to red-orange. Primarily a trunk decay, it is occasionally found in the butt region. This decay is caused by *Stereum sanguinolentum* (renamed *Haematostereum sanguinolentum)*, which belongs to the white-rot group of fungi (Fig. 12a,b,c). On the transverse face of infected logs, rays often extend outward from the central core of the decay, or the decay can appear as irregular patches. In an advanced stage of decay, wood becomes dry and friable, and develops a stringy texture. Trees with advanced "red heart" frequently have decay extending for a considerable length within the stem. This type of decay accounts for roughly 80% of the defect in balsam fir stems in Ontario (Basham and Morawski 1964). The remainder is butt decay, most of which is yellow-orange with a stringy texture and is caused by several fungi that belong to the white-rot group. *Corticium galactinum* (renamed *Scytinostroma galactinum*) is the most common of these (Fig. 12d,e), followed by *Odontia bicolor* (renamed *Resinicium bicolor*), *Armillaria* sp. (probably *A. ostoyae*), and *Poria subacida*. Brown cubical butt decay is more widespread in balsam fir than in any other conifer in Ontario. In eastern North America, this decay was found in approximately 10% of 2,800 trees sampled, but on mixedwood slopes (uplands) the percentage increased to 15.3% (Basham et al. 1953). In the early stages of brown cubical decay, the wood becomes yellowish to light buff in color, and is slightly softened. As the decay progresses, the wood becomes dark brown and breaks up into irregular cubical sections. In the advanced stage, these cubes can be crushed easily to a fine powder. Three fungi—*Coniophora puteana* (Fig. 12f), *Polyporus balsameus* (renamed *Tyromyces balsameus*), and *Merulius himantioides* (renamed *Serpula himantioides*)—cause brown cubical butt decay in balsam fir, apparently with roughly the same frequency. These are all members of the brown-rot group of wood-decaying fungi. In examining root systems and 15-cm stumps of 650 balsam fir in northwestern Ontario, Whitney (1978) isolated, in order of frequency, *A. mellea*, *C. galactinum*, *O. bicolor*, *C. puteana* and *S. sanguinolentum*, as well as several other fungi.

For many years it was believed that *S. sanguinolentum*, the cause of virtually all of the trunk decay in balsam fir, entered stems via dead branches and branch stubs. In the early 1960s, Davidson showed that, although most infections entered by way of live branches, the fungus rarely infected dead branches or branch stubs; the fungus became established in living branches through wounds on those branches, or through dead and broken branch terminals (Davidson and Newell 1962; Davidson and Etheridge 1963). Branches more than 2.5 cm in diameter had six times as many infections as branches less than 1.3 cm in diameter. Stillwell (1956) found that balsam fir leaders more than 1.2 cm in diameter that were killed as a result of defoliation by spruce budworm were almost invariably entrance points for *S. sanguinolentum* decay. This fungus can also gain entry to stem heartwood through forks, frost cracks, felling scars and broken tops, but large wounded or tip-killed branches are by far the most common means of entry. The discovery by Whitney (1978) of *S. sanguinolentum* in about 6% of the balsam fir root systems he examined does not necessarily mean that the fungus can also infect trees through root systems. The decay is known to spread vertically in the stem

Figure 12. (facing page) Balsam fir stem decays. (a) transverse and radial views of "red heart" caused by Stereum sanguinolentum (Haematostereum sanguinolentum)*, (b) and (c) transverse sections of "red heart" caused by* S. sanguinolentum, *(d) transverse view and (e) radial view of yellow stringy butt decay caused by* Corticium galactinum (Scytinostroma galactinum), *(f) transverse radial views of brown cubical butt decay caused by* Coniophora puteana.


a
b
c
d
e
f

relatively rapidly, and as mentioned earlier, was sometimes observed extending down to stump level. Its presence in root systems very likely represents further downward extensions from stem infections.

In tracing the origin of balsam fir butt decays, Spaulding and Hansbrough (1944) determined that 91% entered through root systems and the remainder through basal stem wounds such as frost cracks or mechanical wounds. Because balsam fir is a shallow-rooting tree, lateral roots near the stem are frequently exposed, predisposing them to wounding and infection by butt-decay fungi. Redmond (1957) reported that stone bruises in the root systems were major courts of entry for butt decays in balsam fir.

Because balsam fir is a relatively defective, widespread tree of some economic importance, the search for reliable external indicators of internal decay in living trees has involved balsam fir more than any other species in northeastern and north-central North America. The largely negative results reflect the general situation for forest trees, that stem decay is frequently a hidden disease condition. Kaufert (1935) found stem decay in 59% of the balsam fir he examined in Minnesota, but only 18% had visible wounds or indications of decay, and a minority of these latter trees had no stem decay. In New England and New York, Spaulding and Hansbrough (1944) found that 88% of the balsam fir with stem decay had absolutely no external evidence of that fact. Of the trees with suspicious signs (such as frost cracks, mechanical wounds or forks), an average of 30% had completely sound stems. These authors reported that dead branches or branch stubs with much larger than average diameters are likely entrance courts for decay, but that these were as common in sound as in decayed trees. In more recent studies of external signs of balsam fir stem decay, Basham (1950) in Ontario, Prielipp (1957) in Michigan, and Lortie (1968) in Quebec basically agreed that the best indicators are exposed, damaged roots, mechanical injuries, large branches, frost cracks, forks and woodpecker holes.

Hunt and Whitney (1974) tested yellow stringy butt decay and "red heart" decay (mostly incipient) of balsam fir for use in the kraft-pulping process. They concluded that both defects had "somewhat lower kraft pulp yields and pulp strength values than the corresponding sound wood", but that there would be no economic losses and the harmful effects would hardly be noticed if defective wood were limited to 10% of total mill chip supply. Such decayed wood should never be used in groundwood pulping, even when the decay is in the incipient stage, and brown butt decays should never be used in any pulping process. Although he did not state which pulping process(es) he was referring to, Mook (1966) claimed that incipient yellow butt decays in balsam fir "do not appreciably reduce wood-fiber strength, and little bleaching is needed". He also stated that *S. sanguinolentum* red heart, unless in the advanced stage, can be pulped "without appreciable loss in product strength".

As with other conifers, butt decays in balsam fir that appear extensive at stump height usually extend less than 1 m up the stem, and can be largely eliminated by bucking short lengths (often as little as 0.5 m) from the base of the stems. Because large-diameter branches are the main source of trunk decay, relatively high-density young stands that promote early self-pruning will help to minimize this problem. Any steps that promote tree vigor and rapid growth will also reduce the incidence of stem decay. Where small balsam fir sawlogs are produced, treatments to induce faster growth are almost essential. Releasing balsam fir overtopped by hardwoods, and periodic thinnings in which wounded, forked, or large-branched trees are removed, are also recommended, but injuries to uncut trees should be kept to a minimum. To avoid extensive stem decay, and mortality or windthrow as a result of root and butt decay, balsam fir should not be left much beyond 60 years on upland sites, 70 years on "transition" sites, and 80 years on lowland sites. In pulpwood operations, accessible balsam fir stands are generally harvested before these ages are reached because many trees attain merchantable size before those ages and early harvesting reduces the chance that they will be destroyed by the spruce budworm. If stands must be left beyond those ages, serious losses from root and stem decay and from budworm-caused mortality are almost inevitable.

Larch

To my knowledge, no studies have been carried out in Ontario on stem decay in larch (tamarack). When the provincewide decay survey was carried out in the 1950s, larch was not included. At that time, mature trees were rare because of severe decimation of the species by the larch sawfly some 50 years earlier, and there was some doubt that the species would ever be of commercial importance in the future. At the present time, the introduction of larch sawfly parasites appears to have reduced the impact of this pest in Ontario to the point at which the restoration of larch as a useful and commercially important species can be anticipated.

In a survey of forest-tree diseases in the Lake States, Lorenz and Christensen (1937) concluded that stem decay in larch was less serious than it was in other conifers. They found some trunk decay caused by *Fomes pini* (renamed *Phellinus pini*), some butt decay (with the brown cubical type apparently more common than the yellow, stringy type), and root decay caused by *Armillaria* sp.

Hemlock

For the 387 hemlock sampled in Ontario in the provincewide decay survey, the percentage of merchantable volume that was affected by stem decay within various age classes is shown in Table 7. Although hemlock is more defective than many other conifers in the province, particularly in the younger age classes, the increase with age in the percentage of stem volume decayed is relatively gradual. There is no dramatic increase as trees pass from maturity to overmaturity as there is in jack pine, white pine and balsam fir. This fact, coupled with the longevity of hemlock and the relatively rapid, steady increase in merchantable volume with age even in older trees, makes stem decay of relatively minor importance in the selection of harvest age.

The sample of 387 trees was too small for meaningful comparisons of the development of stem decay in hemlock on different sites. The data did suggest that variations in the extent of decay on different sites were minor and of little practical significance (Morawski et al. 1958). As tree diameter increased there was a fairly uniform increase in the volume culled as a result of stem decay and in the volume rendered unusable by the presence of shake (separation of wood along the boundary between annual rings) (Fig. 13).

Trunk decay accounted for 81% of the volume of stem decay in the 387 hemlock sampled. Ninety percent of the trunk decay was advanced "red heart" decay or incipient red decay caused by *Stereum sanguinolentum* (renamed *Haematostereum sanguinolentum* [Fig. 14]). These decays have been described in the section on balsam fir. The remaining 10% of trunk decay was a yellow stringy decay caused by several different fungi.

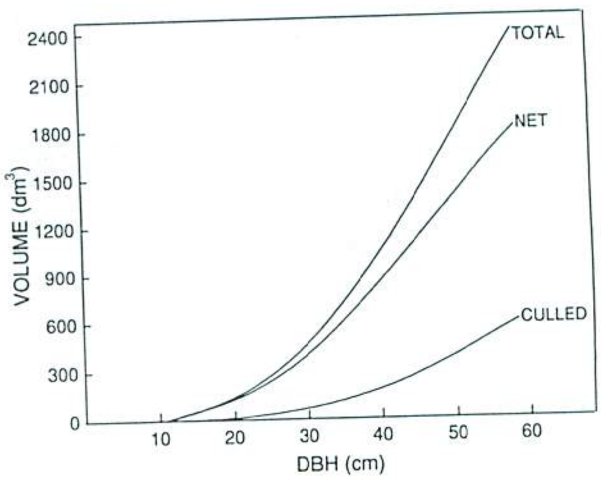


Figure 13. Average total merchantable volume, volume culled as a result of decay and shake, and net volume of hemlock in relation to tree diameter. Volume-diameter data obtained from curves in Morawski et al.'s (1958) figure 38, courtesy of the Ontario Ministry of Natural Resources.

Table 7. Occurrence of decay and stain in the stems of 387 hemlock sampled in Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s. Trees were in stands throughout the Great Lakes–St. Lawrence Forest Region, mostly in the Algonquin ecological section.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. decay and stain[a] vol. (dm^3)	Stem volume defective (%)
61–80	8	15.0	0.25	5.0
81–100	29	33.0	1.19	5.2
101–120	40	56.1	4.55	8.1
121–140	38	95.1	8.63	9.1
141–160	46	173.6	14.77	8.5
161–180	66	379.0	38.29	10.1
181–200	64	469.2	56.29	12.0
201–220	43	866.4	99.64	11.5
221–240	28	1,085.8	148.77	13.7
241+	25	2,069.3	384.85	18.6

[a] Very little stain was present.

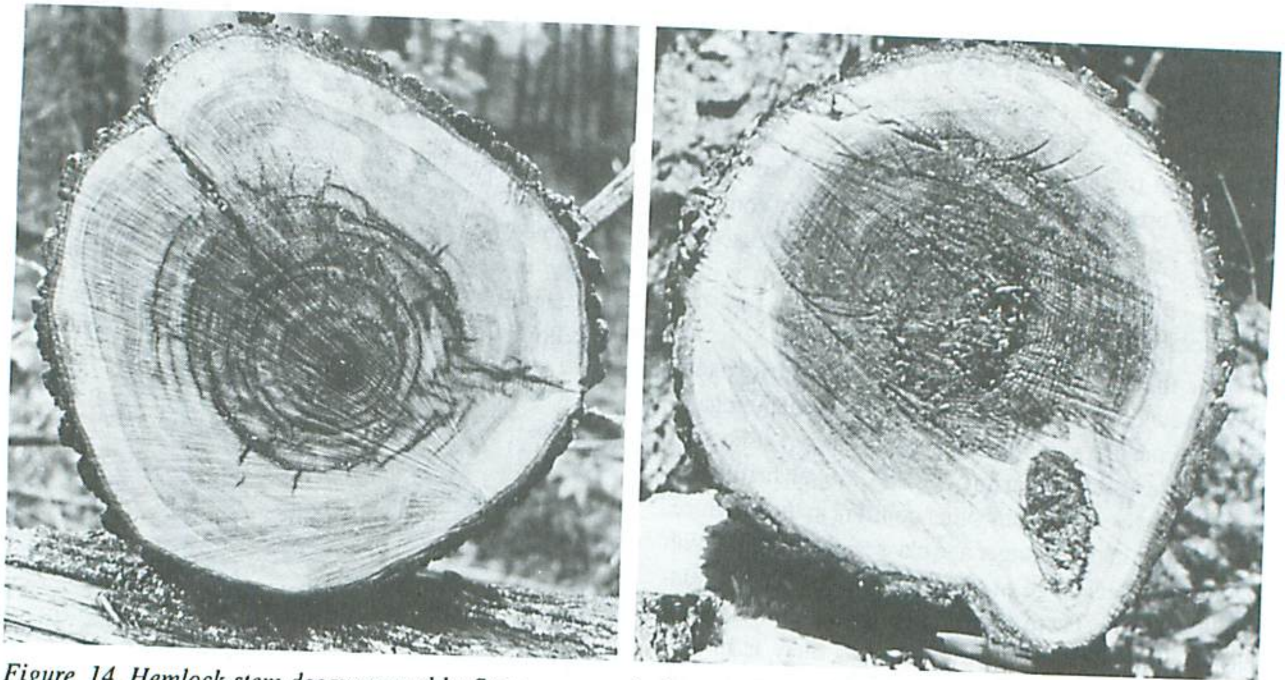


Figure 14. Hemlock stem decay caused by Stereum sanguinolentum (Haematostereum sanguinolentum). *Transverse views of (left) incipient-to-advanced decay, and (right) advanced decay, with a lateral decay pocket associated with a branch-stub protuberance.*

Slightly more than half of the butt decay was made up of *S. sanguinolentum* "red heart" or extensions of incipient red decay downwards into the butt region. Most of the remainder was yellow stringy butt decay, caused by *Corticium galactinum* (renamed *Scytinostroma galactinum*) and other members of the white-rot group of fungi. This type of decay has been described in detail in the section on white spruce. Brown cubical butt decay was extremely rare. Shake was quite common in the lower trunks of the larger overmature trees; though not caused by fungi, this condition reduces recoverable volumes.

Little is known about how hemlock stem-decay fungi enter the host trees. It is safe to assume that *C. galactinum* and the other butt-decay fungi enter through the root system and perhaps through basal stem wounds. *Stereum sanguinolentum* probably uses the same entry points as in balsam fir, namely wounds or dead tips on living branches (especially large-diameter branches), broken or dead tops, and other stem wounds. Again, the prevention of stem and branch wounds, excessively large branches, and dead tops will help to minimize the extent of stem decay in this species.

Eastern White Cedar

A relatively small sample of 116 white cedar trees was processed in the provincewide decay survey of the 1950s, entirely within the Great Lakes–St. Lawrence Forest Region. The occurrence of stem defect in the sample, by age class, is shown in Table 8. Only one age class, 41 to 60 years, was adequately sampled. However, the results do give an indication of how much stem decay can be expected in white cedar in south-central Ontario.

Table 8 shows that, whereas white cedar stems under age 60 years were virtually defect-free, trees aged between 60 and 120 years had roughly 4.6% of their merchantable stem volumes decayed, and trees more than 120 years old were quite heavily (>20%) decayed. Most of the decay was in the advanced stage, and brown cubical decay was the most common type; it accounted for about 70% of the advanced decay in this species. The remaining advanced decay was either a reddish stringy decay or a yellow-brown stringy decay. These three types of advanced decay were present in both trunk and butt regions of the stem. About 10% of the entire defective volume in white cedar was a reddish-brown incipient decay, present in the butt region but much more common in the trunk region. Several decay-causing fungi were isolated from these decays in white cedar stems, with no single fungus dominant in frequency of occurrence.

White cedar was encountered mostly on wet-to-moist sites. It was observed that trees on the drier portions of swamps and on knolls tended to have

Table 8. Occurrence of decay and stain in the stems of 116 white cedar sampled in the Great Lakes–St. Lawrence Forest Region of Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. decay and stain[a] vol. (dm^3)	Merchantable volume defective (%)
21–40	11	39.6	0.0	0.0
41–60	45	70.6	0.21	0.3
61–120	16	118.1	5.41	4.6
121–140	12	175.6	34.60	19.7
141–160	10	246.4	63.84	25.9
161+	22	401.6	122.48	30.5

[a] Very little stain was present.

more decay than trees on wetter sites. Because cedar is a relatively shallow-rooted tree, windthrow caused by butt and root decay is fairly common. According to Baxter (1943), woodpecker holes and unusually rough bark are two of the most reliable external indicators of internal stem decay.

HARDWOODS

Trembling Aspen

The presence of stem decay and stain in living trembling aspen is a major reason that this species is underutilized in Ontario and elsewhere. Stain (discolored but firm wood) accounts for 50 to 65% of the stem-defect (decay plus stain) volume in aspen 20 to 60 years of age in Ontario, and for 35 to 48% in aspen more than 60 years old (Basham and Morawski 1964). Unfortunately, gross overestimations of the extent of stem decay in aspen have been published because authors did not differentiate between stain and decay, and referred to both as decay (or rot). Nevertheless, the second-last column of Table 9 shows that decay alone is more extensive in aspen, at comparable age classes, than decay plus stain is in many of Ontario's major coniferous species (Tables 1 to 8). Table 9 and Figure 15 are based on the 2,458 aspen sampled throughout Ontario in the decay survey of the early 1950s. Figure 15 indicates that, within individual aspen, the increase in decay and stain volume is so relentless that the average net (sound) merchantable volume begins to decrease after age 125.

About the same time the provincewide decay survey was initiated, the federal forest pathology laboratory in Ontario received requests from the pulp and paper industry for more information on aspen stem decay. Consequently, a separate investigation directed specifically at aspen decay was carried out in the Caramat–Stevens–Manitouwadge region of northern Ontario

Table 9. Occurrence of decay and stain in the stems of 2,458 trembling aspen sampled in Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s. Of the 2,458 trees, 2,343 were in the Boreal Forest Region and 115 were in the Great Lakes–St. Lawrence Forest Region.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. defective (decay and stain) vol. (dm^3)	Merch. vol. decayed (%)	Merch. vol. defective (%)
21–40	28	61.7	4.81	2.6	7.8
41–60	638	136.4	18.17	6.3	13.3
61–80	666	291.2	50.64	9.2	17.4
81–100	538	516.8	122.50	12.9	23.7
101–120	186	803.3	261.05	21.1	32.5
121–140	350	705.6	262.49	19.9	37.2
141+	52	907.3	382.86	25.9	42.2

wadge region are particularly favorable for aspen development and growth. It is not surprising, therefore, that the aspen in this region have a smaller percentage of merchantable stem volume containing defects than the provincial average.

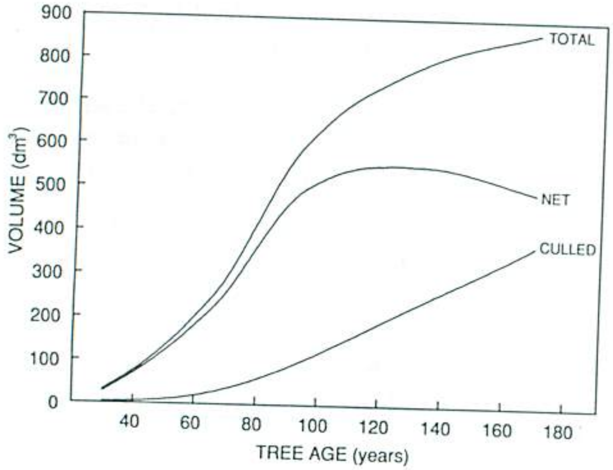


Figure 15. Average total merchantable volume culled as a result of decay and net volume of aspen, in relation to tree age. Volume-age data obtained from curves in Morawski et al.'s (1958) figure 17, courtesy of the Ontario Ministry of Natural Resources.

(Basham 1960). This was on the timber limits of one ofthe companies that was pioneering the use of aspen for pulp at that time, Marathon Paper Mills of Canada Limited. The results of this study are shown in Table 10,which indicates that somewhat less total defect at ages above 100 years and much less decay at all ages were found in aspen in this region than in the Boreal Forest Region as a whole (Table 9). The differentiation of stain and early, very incipient decay is somewhat subjective, and this may account for some of the differences in the reported extent of decay. However, observations and discussions with others indicate that soil, climate and other conditions in the the Caramat–Stevens–Manitouwadge region are particularly favorable for aspen development and growth.

In the Caramat–Stevens–Manitouwadge region, the percentage of aspen with stem decay increased steadily with age (Basham 1958b). In the 41- to 60-year age class, 27% of the trees had some stem decay, and by the 161- to 180-year age class, 100% were decayed, with the biggest increase occurring between age classes 81–100 (58%) and 101–120 (89%) years. Of perhaps greater significance is the fact that when only trees with stem decay were considered, the average volume of decay per tree was 8.5 dm^3 in age class 41–60 years in comparison with approximately 200 dm^3 in trees more than 140 years old (Basham 1958b). On a stand basis, when defect deductions were made in accordance with Ontario's scaling regulations, the net merchantable volume per hectare reached a peak at age 90 years and the net merchantable mean annual increment peaked at age 60 (Basham 1960). Undoubtedly, some tree mortality as a result of windfall and suppression is reflected in these results.

For Ontario as a whole, a rotation age of not more than 80 years has been recommended for trembling aspen to avoid extensive losses to stem decay and stain (Basham and Morawski 1964). For pulpwood, an even shorter rotation of 60 years has been suggested (Morawski et al. 1958). In the Lake States, pathological rotation ages (i.e., the ages at which trees should be harvested to minimize the volume lost to decay) of 55 to 60 years (Strothmann and Zasada 1957) and 50 years (Anderson et al. 1978) have been recommended for aspen.

Table 10. Occurrence of decay and stain in the stems of 1,754 trembling aspen sampled in the Caramat–Stevens–Manitouwadge region of Ontario from 1952 to 1955.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. defective (decay and stain) vol. (dm^3)	Merch. vol. decayed (%)	Merch. vol. defective (%)
41–60	131	180.1	24.50	1.0	13.6
61–80	271	373.2	64.93	2.7	17.4
81–100	553	461.4	106.59	5.0	23.1
101–120	357	548.1	147.96	8.1	27.0
121–140	165	874.1	276.23	8.0	31.6
141–160	238	1,150.9	428.11	14.6	37.2
161–180	39	1,141.1	470.15	16.8	41.2

Before the relationships between stem decay in aspen and factors other than age are considered, the clonal growth habit of this species warrants attention. The majority of aspen stands in Ontario originate from suckers that develop from tree root systems. Many, perhaps most, of those stands are composed primarily of groups (clones) of genetically identical trees. Each clone originated, perhaps centuries ago, from a single tree of seedling origin. Hence, whereas each tree is an individual and unique genotype for most other tree species, all the trees in a single group may be of identical genotype for trembling aspen. Pronounced interclonal variability has been documented for several traits, including growth rate, stem form, phenology and wood properties (Kemperman 1977). In Manitoba, Wall (1971) found highly significant differences among aspen clones in the percentage of stem decay, and in decay volume, gross tree volume and net tree volume. In northern Ontario 60 clones in six different aspen stands (10 clones in each stand) were studied, and several clones with relatively fast growth rates and superior stem form were easily identified. However, the majority of these superior clones had excessive stem decay, and only two of the 60 clones could be classed superior as far as growth rate, stem form, and stem soundness (relatively little decay) were concerned. In Manitoba, Wall (1971) also found that relatively fast tree growth combined with relatively little stem decay was seldom found in a single clone.

It is clear that, in aspen stands composed largely of clones, the clone rather than the individual tree should be the basic sampling unit. The fact that this was not done in most studies before 1970 casts doubt on the validity of results concerning relationships between the extent of stem decay in aspen and factors such as site, tree growth rate, and diameter. It is not surprising that most attempts to relate the extent of aspen stem decay to site in such studies yielded inconclusive results. Using height growth of trees to classify sites, Riley (1952) and Morawski et al. (1958) found no relationship between site and stem decay in Ontario. When soil moisture regime was used to differentiate sites, the drier sites tended to have the most stem decay, but this relationship was not particularly strong (Strothmann and Zasada 1957; Basham 1958b; Morawski et al. 1958). In the provincewide decay survey of the 1950s, the majority of the 2,343 aspen sampled in the Boreal Forest Region were on fresh sites (moisture regimes 2 or 3), whereas almost all of the 115 aspen sampled in the Great Lakes–St. Lawrence Forest Region were on dry sites (moisture regimes 0 or 1). Most trees in the latter region were in the 41- to 60-year or 61- to 80-year age classes. The average percentage of merchantable stem volume affected by decay or stain was greater for aspen in both of these age classes in the Great Lakes–St. Lawrence Forest Region than in the Boreal Forest Region. This suggests that aspen on sites with moisture regimes of 0 or 1 are more defective than aspen on sites with moisture regimes of 2 or 3, although other factors such as climate, soil depth, soil nutrients and, of course, clonal differences may have been partly or wholly responsible for the observed difference in average extent of stem decay. In one study of a single aspen clone that had grown to cover three adjacent but distinctly different sites (on the basis of soil moisture regimes), analysis of variance revealed that the only significant difference was in tree height; differences in the extent of decay were not significant (Weingartner and Basham 1985). In Manitoba, Wall (1971) found that, where aspen from the same clone grew on different sites, differences in the percentage of stem volume decayed were not significant. Consequently, it appears that if site has any influence on the extent of stem decay in trembling aspen, it is of minor importance in comparison with clonal (genetic) influences.

In the aspen-decay study carried out in the 1950s in the Caramat–Stevens–Manitouwadge region of Ontario, the 1,754 trees sampled were divided into two groups, those <24 cm DBH and those ≥24 cm DBH (Basham 1960). Figure 16 shows that a greater percentage of the gross merchantable volume of the smaller trees than of the larger trees within even-aged stands was culled because of stem decay (Ontario scaling regulations). The difference increased with increasing stand age, and was particularly pronounced in stands more than 90 years old. Clones were not considered in that study, but this result fostered the hope (later dashed) that faster-growing clones would be more decay resistant than slower-growing clones. From more recent studies of aspen clones and stem decays, we can now postulate that, within clones, the trees with lower diameter-growth rates have higher percentages of stem decay than do faster-growing trees, because the occurrence and rate of spread of stem decay is not dependent upon tree growth rate and is roughly the same in slow- and fast-growing trees.

All of the foregoing studies of aspen decay in Ontario were carried out on the Canadian Shield. Replies to a questionnaire were received from 39 hardwood industries that process poplar south of the Canadian Shield; these indicated that stem decay and stain in southern Ontario are not serious problems (Basham 1973a).

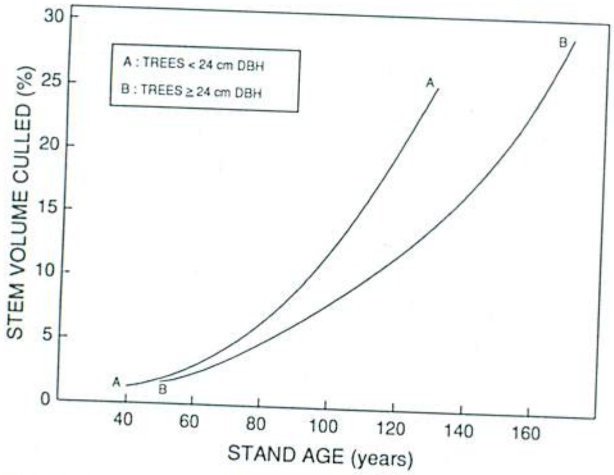


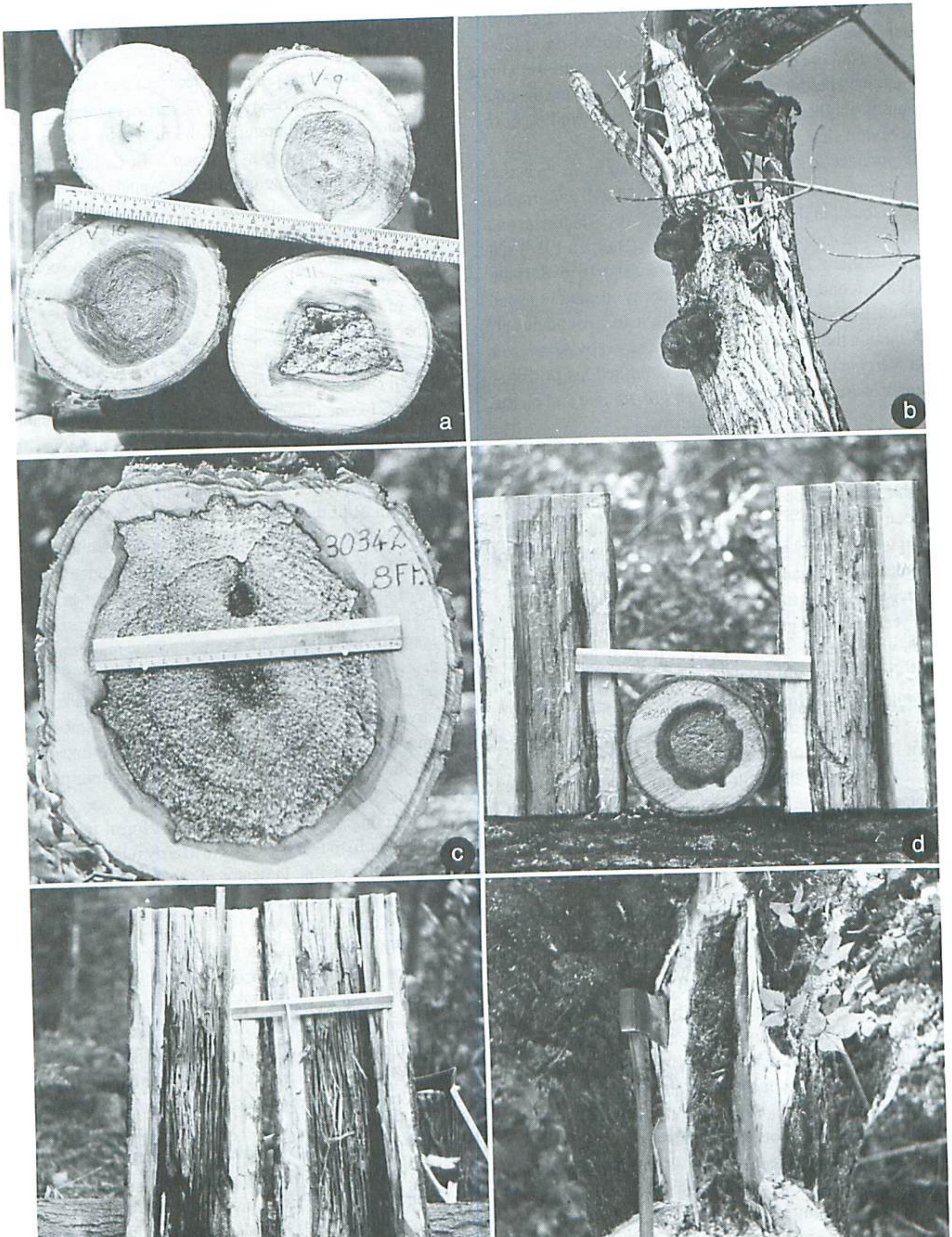
Figure 16. Average percentage of merchantable volume culled as a result of decay, in relation to stand age, in aspen trees <24 cm DBH and ≥24 cm DBH. Volume-diameter data obtained from curves in Basham's (1960) figure 31.

In the 2,458 aspen sampled across Ontario in the federal-provincial decay survey of the early 1950s, an overall average of 15.2% of the merchantable stem volume was decayed and 11.9% was stained (Basham and Morawski 1964). In the Caramat–Stevens–Manitouwadge study, which involved 1,754 aspen, these figures were 8.7% for decay and 19.9% for stain (Basham 1958b). When decay and stain are combined, the two studies yield quite similar results, 27.1% of the merchantable stem volume in the former study and 28.6% in the latter. Butt decay accounted for 12.5% of all stem decay, and 20.3% of the stain was in the butt region.

In both Ontario studies of aspen decay and stain, three broad types of decay and two distinctly different stains were observed. About 85% of the stain ranged from light brown to dark, grayish brown. A band of this stain usually surrounded decay columns; this band was relatively wide when associated with small or incipient decays but much narrower when it bordered extensive, advanced decays. Brown stain was usually extensive at stump height. The remaining 15% of stain volume was predominantly red, though usually mottled in appearance, with yellow, brown, and green hues as well. Occasionally, this mottled stain replaced brown stain around decay columns, and in many relatively old defective trees it was the only defect present in the smaller top logs cut in the crown region. Mottled stain was also frequently associated with knots and branch stubs in trees of all ages. Bacteria, yeasts, and non-decay fungi were frequently isolated from both stains, although Sucoff et al. (1967) have presented evidence that the initial development of these stains involves physiological and biochemical processes that take place without the presence of microorganisms. Similarly, the so-called "wetwood" commonly seen in freshly cut aspen logs is of non-microbial origin, but once formed, it supports a large bacterial population (Knutson 1973). Wetwood does not develop into decay, and in many cases it virtually disappears with time on exposed log faces.

The most common and most serious form of advanced stem decay in aspen in Ontario is a white spongy decay caused by *Fomes igniarius* var. *populinus* (renamed *Phellinus tremulae* [Fig. 17a,b,c]). This decay is sometimes called "white trunk rot", and accounts for approximately 75% of advanced stem decay in aspen. It occurs primarily as a trunk defect, but is also found in the butt region. *Fomes igniarius* belongs to the white-rot group of fungi. Columns of this decay are usually quite extensive, possibly because some originate from multiple infections. The average volume of white spongy decay in infected trees in Ontario has been estimated at 96 dm^3 (3.4 ft^3) (Basham 1958b). In the incipient stage, the wood is yellowish-white and slightly softened, often separated from the surrounding stained or sound wood by dark zone lines. The wood quickly becomes very soft, punky, or spongy, and more yellowish, often with irregular black zone lines in the decayed portion. Most of the remaining advanced stem decay in aspen is a yellow or yellow-brown stringy decay that occurs in both the butt and the trunk regions. In the trunk it is caused by *Radulum casearium* (Fig. 17a,d), which also causes some of the butt decay. Other yellow-brown stringy butt decays are caused by *Pholiota spectabilis* (renamed *Gymnopilus spectabilis* [Fig. 17e]) and *Armillaria* sp. (probably *A. ostoyae* [Fig. 17f]).

Figure 17 (facing page). Trembling aspen stem defects. (a) transverse sections showing lightly stained wood (upper left), incipient decay (upper right), advanced decay caused by Radulum casearium *(lower left) and by* Fomes igniarius (Phellinus tremulae) *(lower right), (b) conks of* F. igniarius *below stem breakage caused by advanced decay, (c) transverse view of decay caused by* F. igniarius, *(d) transverse and two radial views of decay caused by* R. casearium, *(e) bisected stem section, showing advanced stringy decay caused by* Pholiota spectabilis (Gymnopilus spectabilis), *(f) advanced stringy butt decay caused by* Armillaria *sp.*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The abovementioned relative frequencies of decay-causing fungi in aspen are based on studies carried out in Ontario in the 1950s, when stems were not examined below 30 cm above ground level, the average stump height at that time. More recent studies have revealed that *Armillaria* sp. is of far more relative importance in aspen than was indicated by its detection in those earlier studies. Decay caused by *Armillaria* has been found in the roots and root collars of dominant and codominant aspen suckers at ages 13 (Basham 1988) and 14 (Basham 1982a) years. Weingartner and Basham (1985) found considerable butt decay in mature aspen when trees were examined down to ground level. Although the extent of stem decay caused by *Armillaria* in merchantable stems of aspen is limited, its principal impacts are undoubtedly on tree growth rate and on the vulnerability of trees to windthrow.

Trunk decay in aspen caused by *F. igniarius* can begin as early as age 30 to 35 years, but yellow stringy trunk decay caused by *R. casearium* seldom occurs in aspen less than 70 years old. A third Basidiomycete fungus frequently isolated from defective wood in aspen trunks is *Corticium polygonium* (renamed *Peniophora polygonia*). This fungus is widespread in trees less than 60 years old, then gradually decreases in abundance until it is virtually nonexistent in trees more than 120 years old. It was frequently isolated from brown stain in very young trees, and from incipient yellow or yellow-brown decay. It appears incapable of causing advanced decay, as it was rarely isolated from such wood.

Slightly more than half of the stem decay in aspen in Ontario was classified as incipient decay (Basham and Morawski 1964). Brown or brown cubical decays, caused by fungi that belong to the brown-rot group, are extremely rare in this species.

In Ontario, 56 out of 1,754 aspen examined for stem decay had visible basal scars; yellow stringy butt decay was found in all 56 of them (Basham 1960). Some butt decays, particularly those caused by *F. igniarius* and *R. casearium*, which are normally trunk-decay fungi, enter through such scars, which appear to be caused primarily by fire, falling trees, or frost. The majority of butt decays, including most, if not all, of those caused by *Armillaria* and *P. spectabilis*, enter through root wounds and interconnected roots. Since most aspen originate as root suckers, one possible route is from the decayed stump or roots of the parent tree through the sucker-producing root into the root system and basal stem region of the sucker. Branch stubs are evidently the main avenue of entrance to the stem for *C. polygonium* (Etheridge 1961). Little is known about the means of entry of *R. casearium*.

Since aspen is a relatively decadent tree species, and the major cause of decay is *F. igniarius*, there are many references in the literature to the means by which this fungus gains entry to aspen stems. In Ontario, 75 of 1,754 aspen had pronounced trunk wounds or abnormalities, mostly mechanical injuries, frost cracks, or forked crowns; stem decay was associated with 63 (85%) of these, and many of the decays were the white spongy type caused by *F. igniarius* (Basham 1960). However, 90% of the trunk decays could be traced only to branch stubs, and the majority were *F. igniarius* spongy decays. Researchers disagree about whether the primary avenue of stem entrance for *F. igniarius* is branch stubs or stem wounds. In one clonal study (Weingartner and Basham 1985), 160 trees in an aspen stand approximately 40 years old in the Fort Frances region were examined. Small zones of decay characteristic of *F. igniarius* were present in 21 of the trees. We carefully dissected each of these recently developed decay zones, and without exception they appeared to have originated at branch stubs. More published reports support the idea that branch stubs are the principal point of entry for *F. igniarius* than support the view that trunk wounds are the main source. It is probably safe to conclude that *F. igniarius* can gain entry to aspen stem wood through both branch stubs and relatively severe stem wounds. Because branch stubs are so much more common than severe stem wounds on aspen stems, the majority of *F. igniarius* infections probably enter through branch stubs.

Trembling aspen differs from most forest tree species of Ontario in that it does have a fairly reliable, external and easily visible indicator of the extent of internal stem decay. About three-quarters of the advanced decay in aspen is the white spongy type caused by *F. igniarius*. In the 1930s Riley and Bier (1936) reported that conks (sporophores or fruiting bodies) of *F. igniarius* (Fig. 17b) on 11 aspen in the 60- to 70-year age class at Petawawa, Ontario, were invariably associated with advanced stem decay. The decay extended a mean distance of 30 to 180 cm above and below the highest and lowest conks. More recent studies not only confirmed this, but revealed that most of the aspen trees with moderate-to-large amounts of advanced *F. igniarius* decay had one or more conspicuous sporophores of the fungus growing from their stems. The sporophores are typically hoof- or shelf-shaped, with dark-brown to black ridged upper surfaces and tan to light-brown undersurfaces that contain small holes or pores visible to the naked eye.

Sporophores are usually formed at branch knots. In our study in the Caramat–Stevens–Manitouwadge region of northern Ontario we found that a series of *F. igniarius* sporophores on a single tree, or sporophores more than 10 cm wide, were invariably associated with extensive spongy decay (Basham 1958b). In the age classes between 60 and 180 years, from 79 to 97.6% of the aspen infected with *F. igniarius* stem decay bore one or more sporophores. Anderson and Schipper (1978) examined this relationship for aspen in Michigan, Wisconsin and Minnesota. They devised a nondestructive method for predicting the extent of *F. igniarius* stem decay in a stand that was based on the basal area of the trees that bore sporophores.

It should be borne in mind that the absence of *F. igniarius* sporophores in aspen does not necessarily mean that the trees have no stem decay. About 20% of trunk decay in aspen more than 70 years old is caused by *R. casearium*, which does not produce sporophores on the stems of living trees, and consequently this decay can be quite extensive in healthy-looking stems. Forked crowns or butts, mechanical injuries that produced stem scars, fire scars, frost cracks, and unsound knots are frequently associated with stem decay in aspen. The small, white, flat fruiting bodies of *C. polygonium* on or near branch stubs are a sign that extensive stain or incipient decay is likely present in the stem above and below the stub. Any basal wound, unless very recently inflicted, is almost certainly associated with yellow stringy butt decay. The presence of *Armillaria* sporophores at the base of aspen stems or on the ground nearby is a sign that the root system and perhaps the basal stem is decayed. These sporophores, or mushrooms, usually appear in clusters and have yellow to golden caps with brownish scales on top and white gills on the undersurface, and are supported by yellow to brown stalks that can be up to 20 cm tall.

Although trembling aspen is used in many manufacturing processes, including those used to produce veneer and sawlogs, it is employed mainly by the pulp and paper industry. Because its fibers are not as long as those of spruce and balsam fir, it lacks the strength of coniferous kraft pulp and is therefore usually combined with it, often at roughly 10% of the mix. In kraft-pulping tests carried out on sound and defective aspen wood from Ontario, the yield of oven-dry pulp from decayed (incipient and advanced) wood was 9.7% less on average than that from sound wood (Hunt et al. 1978). When only advanced decay was tested, the decrease in yield was 11.5%. The strength of pulp obtained from wood with incipient decay differed little from that of pulp obtained from sound wood. Advanced decay was responsible for substantial decreases in pulp strength, with tear factors 20 to 29% lower than for sound wood. Jackson et al. (1985) have shown that aspen can produce high-yield chemithermomechanical pulps displaying properties comparable with those of mechanical softwood and chemical hardwood pulps. However, they pointed out that decayed aspen wood produces pulp of inferior strength and poor brightness, deficiencies that cannot be compensated for by subsequent bleaching.

Harvesting aspen stands before they reach an age at which excessive stem decay has developed is essential if serious losses to decay are to be avoided. That age will largely depend on the product involved. For pulpwood in Ontario, 60 years is recommended. For sawlogs and veneer, where tree size is important, it is probably safe to allow stands to grow to 80 years except on drier sites, where decay may develop earlier in some clones. For waferboard production, in which some decayed wood can be used with little or no deleterious effect on the end product, a rotation age of 90 or even 100 years is feasible. The extent of stem decay in aspen stands can be reduced by maintaining fully stocked stands in which the crowns of adjacent trees touch. This promotes early natural pruning, which generally reduces the number and size of branch stubs, the main avenue of entrance to the stem for *F. igniarius* decay. Stem wounding by fire, logging, etc., should be prevented as much as possible. Although clonal management of aspen stands in Ontario has been proposed (Heeney et al. 1975), the difficulties involved in identifying relatively decay-resistant clones and the apparent scarcity of clones that combine this with other desirable characteristics appear to render clonal management unfeasible at present for reducing the incidence of stem decay in aspen. As far as post-harvest treatments are concerned, Perala (1971) in the Lake States and Basham (1982b) in Ontario have shown that herbicide spray treatments in young aspen stands may kill most leaders and some branches, but few trees are killed and the survivors will apparently produce crop trees with little or no reduction in quality. However, recent studies indicate that considerable stem and root decay is associated with scarification wounds of 3-year-old aspen suckers (Basham 1988). Suckers 2 years old or less sustain relatively little damage, and hence decay, from scarification treatments (Basham, data not yet published). For these reasons, the scarification of aspen suckers 3 years old or more is not recommended.

Other Poplars

Because largetooth aspen, balsam poplar, and eastern cottonwood are relatively uncommon in Ontario, insufficient trees have been examined to determine stem-decay patterns and relationships. In the Lake States, stem decay in balsam poplar caused by *Fomes igniarius* (renamed *Phellinus tremulae*) and by *Armillaria mellea* (now believed to be mostly *A. ostoyae*) has been reported (Lorenz and Christensen 1937). In Alberta, Thomas et al. (1960) studied stem decay in balsam poplar and trembling aspen. They found balsam poplar to be subject to a moderate amount of stem decay, but considerably less than trembling aspen. More than twice as much decay, on a volume-percent basis, was encountered in aspen than in balsam poplar. *Pholiota spectabilis* (renamed *Gymnopilus spectabilis*) was the fungus most frequently associated with butt decay in balsam poplar, followed by *A. mellea*. *Fomes igniarius* was the most common cause of trunk decay.

White Birch

White birch has one of the lowest incidences of stem decay among the deciduous species of Ontario. The second-to-last column of Table 11 shows that the percentage of the merchantable stem volume decayed in Ontario in trees less than 100 years old averages less than 5%. However, Table 11 also shows that stain is quite widespread in white birch stems. Indeed, 70% of the volume of defect in the 936 trees sampled in the provincewide decay survey was a reddish-brown stain. This is commonly known as "red heart", and most white birch in a study of 293 trees in Massachussetts had this stem defect by age 50 (Campbell and Davidson 1941a). Table 11 shows a steady increase, with age, in the extent of defect in white birch stems up to age class 121–140 years, then a decrease as trees get older. However, the small sample of 13 trees more than 140 years old casts doubt on the reliability of that result. When white birch grows where red heart is not a problem, the influence of decay on harvest age or rotation will be of little consequence (Table 11). However, red heart develops fairly early and can be a problem in trees used for products that require clear wood. Campbell and Davidson (1941a) report that red heart has little effect on wood strength or hardness, but tends to check and crack more than clear wood during drying. They report considerable red heart in white birch more than 70 years old.

The 936 white birch sampled throughout the Boreal Forest Region in the federal-provincial decay survey of the 1950s grew mostly in mixedwood stands. All but 6% of them grew on either fresh (59%) or dry (35%) sites (classified on the basis of soil moisture regime). Up to age 80 years, there was little difference in the extent of stem decay in trees growing on the two sites. However, after 90 years there was appreciably more decay in trees on the fresh sites; this was partly compensated for by the fact that tree growth was somewhat faster there than on the dry sites.

Replies to a questionnaire were received from 26 hardwood industries that process white birch in Ontario south of the Canadian Shield; these indicated that stem decay and stain were not serious problems in this region (Basham 1973a).

As already mentioned, stain or "red heart" accounted for about 70% of the stem defect in white birch. The remainder was decay, with advanced decay slightly more common than incipient decay. Butt defects accounted for 20% of all defective wood; as far as stain was concerned, 17.2% occurred in the butt region. Red heart has a water-soaked appearance when freshly cut, and is clearly different from true heartwood discoloration in that it has a higher moisture content

Table 11. Occurrence of decay and stain in the stems of 936 white birch sampled in the Boreal Forest Region of Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. defective (decay and stain) vol. (dm^3)	Merch. vol. decayed (%)	Merch. vol. defective (%)
21–40	2	35.3	0.00	–	–
41–60	77	43.7	1.70	0.9	3.9
61–80	304	81.1	4.86	1.2	6.0
81–100	284	148.9	16.84	2.3	11.3
101–120	165	296.4	61.04	6.7	20.6
121–140	91	253.7	52.28	8.2	20.6
141+	13	541.7	95.87	7.7	17.7

than the surrounding sapwood. Although it usually occurs by itself, in columns that surround the stem pith, when decay was present it was generally surrounded by a narrow collar of red heart radially, and by extensive red heart vertically. Siegle (1967) has shown that red heart in white birch is generally triggered by the enzymes of non-decay fungi, which usually enter the stem through mechanical injuries or frost cracks. This was confirmed by studies in which very few decay fungi were isolated from red heart (Basham and Morawski 1964).

The most common type of advanced decay in white birch stems was white spongy decay caused by *Fomes igniarius* (renamed *Phellinus igniarius*) (Basham and Morawski 1964). The appearance of this decay has been described in the section on trembling aspen. Though primarily a trunk decay in most tree species, including aspen, almost one-third of this defect was in the butt region in white birch. The remaining advanced decay was a yellow-brown stringy decay; slightly more than one-third of this defect occurred in the butt region. It was caused mainly by two fungi, *Stereum murraii* (renamed *Cystostereum murraii*), which was more common in the trunk than in the butt, and *Pholiota aurivella* (often incorrectly identified as *P. adiposa* before 1965), which was more common in the butt than in the trunk. Most of the incipient decay was yellowish and appeared to be caused by several different fungi, including *S. murraii.*

It is likely that *F. igniarius* enters white birch stems through branch stubs and, to a lesser extent, stem wounds, as in aspen. Stem wounds are probably entry points for the other decay fungi, and are implicated in the development and spread of red heart stain (Siegle 1967). Most butt infections originate in basal wounds and root systems. *Fomes igniarius* produces sporophores on the stems of living white birch, but far less frequently than on aspen; consequently, there are few external indications of internal defect in birch. Visible stem wounds certainly indicate that stem decay or at least red heart is present. However, trees with no visible wounds may also contain considerable defect. To minimize the impact of red heart, Cooley (1962) recommended partial cutting, with the least vigorous, slowest-growing trees removed first, and the removal of trees in the upper crown canopy that show signs of top death. Pruning (either natural or artificial) young trees when branches are small, and growing white birch only on appropriate sites, are also recommended (Marquis et al. 1969).

Yellow Birch

The sample of 1,418 yellow birch trees in Ontario dissected to measure the extent of stem decay and stain during the federal-provincial decay survey of the 1950s indicated that this is one of the most defective tree species in Ontario's forests (Table 12). Comparison of Tables 12 and 13 shows that yellow birch is generally more defective than sugar maple, with which it is frequently associated. It would appear, from Table 12, that approximately one-third of the merchantable stem volume of yellow birch between ages 100 and 160 years can be expected to be defective, and above age 160 years, about half may well be defective. Much of this defect is in the form of stain (70%); nevertheless, the average extent of decay alone is sufficient to rank yellow birch

Table 12. Occurrence of decay and stain in the stems of 1,418 yellow birch sampled in the Boreal Forest Region of Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. defective (decay and stain) vol. (dm^3)	Merch. vol. decayed (%)	Merch. vol. defective (%)
21–60	108	68.7	2.68	0.2	3.9
61–80	119	134.2	19.44	1.6	14.5
81–100	166	309.4	68.08	4.3	22.0
101–120	143	463.7	139.13	4.6	30.0
121–140	182	689.1	257.03	10.0	37.3
141–160	125	897.7	327.64	9.1	36.5
161–180	139	1,087.4	505.65	17.1	46.5
181–200	97	1,403.9	602.25	12.0	42.9
201–220	113	1,591.0	747.78	12.8	47.0
221–240	66	1,874.2	864.00	12.3	46.1
241–260	89	2,171.8	1,170.58	16.5	53.9
261+	71	2,588.1	1,426.07	21.8	55.1

among the most decadent species in Ontario. Again, if serious economic consequences of stem defectiveness are to be avoided, the maximum harvest or rotation age will depend on how yellow birch is used. To prevent significant amounts of decay, trees should be harvested before age 140 years, but if stain is an important consideration, yellow birch should be harvested before age 101 to 110 years. Because of the relatively high value of yellow birch logs, trees at those ages may in many instances be considered too small to harvest for veneer and sawlog operations. Postponing the harvest until the trees are larger will result in higher percentages of decay and stain, but this may well be compensated for by the increased value of the trees and their products.

The 1,418 yellow birch were sampled in what Halliday (1937) classified as the Algoma and Algonquin forest ecological sections of Ontario. The 241 trees sampled in the Algoma section grew much more slowly than those in the Algonquin section; trees of the same diameter were as much as 30 to 40 years older in Algoma (Morawski et al. 1958). At comparable ages, yellow birch in the Algoma section were more defective than those in the Algonquin section. For example, trees sampled in the Algoma section at age 150 years averaged 34 cm (13.4 in.) DBH and 44% of their merchantable stem volume was defective, in comparison with 40 cm (15.7 in) DBH and 35% of stem volume defective in the Algonquin section.

Replies to a questionnaire were received from 27 hardwood industries that process yellow birch south of the Canadian Shield; these indicated that stem decay and stain in this region of Ontario were not serious problems (Basham 1973a).

The influence of site (soil moisture regime) on the extent of stem decay and stain in yellow birch was examined in both the Algoma and the Algonquin ecological sections. Trees were separated on the basis of dry, fresh, and moist moisture regimes. In neither section was there any clear correlation between site and stem defect (Morawski et al. 1958).

When the 241 yellow birch in the Algoma section and the 1,177 trees in the Algonquin section were analyzed separately, there was a strong correlation between tree age and diameter. Consequently, it is not surprising that there was a good positive correlation for each section between tree diameter and the extent of stem defect (Morawski et al. 1958).

In the 1,418 yellow birch examined for stem defect in the Great Lakes–St. Lawrence Forest Region, 70% of the defect was stain and the remainder was decay. About 71% of the decay was in the advanced stage, and just over 23% of the decay was in the butt region of the stem. About 25% of the stain was in the butt region.

The stained wood in yellow birch was brown or reddish-brown. Almost all trees more than 60 years old had some stain at a height of 30 cm, the stump height used in the survey. In trees more than 100 years old the cross-sectional stained area at stump height was frequently quite extensive. In trees with decay columns, the columns were almost invariably surrounded by narrow stain zones. Much of the stain in yellow birch is believed to be of physiological-biochemical origin, and to require no microorganisms for its initiation and development. However, the frequency with which the decay fungus *Stereum murraii* (renamed *Cystostereum murraii*) was isolated from the stained wood (Basham and Morawski 1964) suggests that an appreciable proportion of yellow birch stain represents early incipient stages of *S. murraii* decay.

The most common form of decay in the 1,418 yellow birch trees was a yellow-brown stringy type that accounted for 71% of the advanced decay. It occurred in both trunk and butt regions. In the trunk region, *S. murraii* (Fig. 18) was the principal cause, distantly followed by *Pholiota aurivella* (often incorrectly identified as *P. adiposa* before 1965). In the butt region, *P. aurivella* was the decay fungus most frequently isolated from yellow-brown stringy decay, closely followed by *Armillaria* sp. (probably *A. ostoyae*) and *Flammula alnicola* (renamed *Pholiota alnicola*). Practically all of the remainder of the advanced decay in yellow birch was of the white spongy type, already described in the section on trembling aspen. This was caused primarily by two very closely related fungi, *Fomes igniarius* (renamed *Phellinus igniarus* [Fig. 18]), and *Fomes igniarius* var. *laevigatus* (renamed *Phellinus laevigatus*); a small amount of this decay was caused by *Fomes fomentarius*. *Fomes igniarius* occurred in both butt and trunk regions, *F. igniarius* var. *laevigatus* occurred primarily in the trunk region, and *F. fomentarius* was limited to the trunk region. A very small amount of brown cubical butt rot was found; of the four identifiable isolations made from this defect, three were *Coniophora puteana* and the other was *Poria cocos* (renamed *Wolfiporia extensa*). The latter fungus was the most common cause of butt decay in a study of yellow birch stem decay in Nova Scotia (Stillwell 1955). Almost all of the incipient decay in the 1,418 yellow birch examined in Ontario was yellowish. The only decay fungus consistently associated with incipient decay was *S. murraii*.

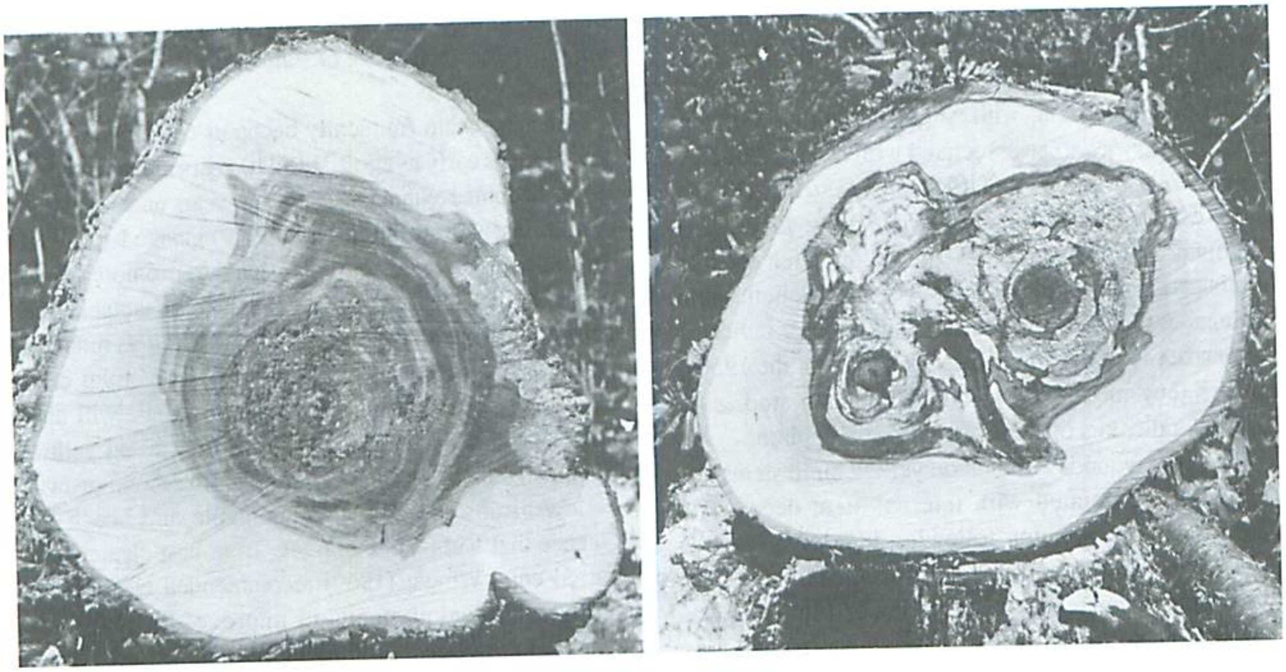


Figure 18. Yellow birch stem decays, (left) transverse view of advanced decay caused by Stereum murraii (Cystostereum murraii), *associated with a severe stem wound, (right) transverse view of advanced decay caused by* Fomes igniarius (Phellinus igniarius).

Several studies conducted outside of Ontario have shed some light on the means by which decay fungi enter the stems of yellow birch. Shigo (1966) examined defective stem wood associated with logging wounds in 116 yellow birch in New Hampshire. He found the most common decay fungus in these associations to be "*Pholiota squarrosa-adiposa*"; there can be little doubt that this was the fungus mycologists now call *Pholiota aurivella*. Davidson and Lortie (1970) examined defective stem wood associated with stem wounds in eight yellow birch trees in Quebec. They found *P. aurivella* to be the only decay fungus consistently associated with decay and stain. From these results it appears likely that most *P. aurivella* infections in yellow birch originate from stem wounds. The two other major causes of stem decay in yellow birch, *S. murraii* and *F. igniarius*, were not found in yellow birch by Davidson and Lortie (1970) and were isolated only once each by Shigo (1966) from 116 wounded yellow birch. These results support the generally held view that, whereas *S. murraii* and *F. igniarius* can invade stems through stem wounds if conditions are suitable, their usual mode of entry is through dead branch stubs. In Nova Scotia, Stillwell (1954) found considerable decay caused by *F. fomentarius* in large yellow birch branches killed by the "birch dieback" syndrome. The fact that *F. fomentarius* decay was found only in the trunk region and never in the butt region of the stems of yellow birch in Ontario suggests that many stem infections by this fungus originate in large dead branches.

Probably because of the relatively high value of yellow birch and its high incidence of stem decay and stain, several studies on the relationships between the extent of stem defect and external signs of defect in living trees have been carried out. The decay-causing fungi seldom produce easily visible sporophores (fruiting bodies) on living yellow birch trees. *Stereum murraii* sporophores are small, flat, and difficult to detect, particularly when they occur high up in the trunk, which is their usual location. Furthermore, they are not common on living trees. Sporophores of *P. aurivella* occasionally appear on living yellow birch, but they are fleshy, annual organs that are present for a relatively brief period in late summer or fall. The tough, perennial sporophores of the *F. igniarius* group seldom occur on living yellow birch, and when they do they are generally flattened against the trunk, unlike the more visible shelf-like sporophores on trembling aspen.

In various parts of the northeastern and north-central United States, yellow birch stem cankers have been frequently associated with stem decay. The cankers are generally described as sunken areas with the bark firmly attached, often impregnated with dark, hardened fungal material, and with slightly swollen borders. They are reported to be associated with decay caused by *S. murraii* (Davidson et al. 1941), *F. igniarius* (Ohman and Kessler 1964), and *F. igniarius* var. *laevigatus* (Campbell and Davidson 1941b). Yellow birch cankers of this nature appear to be far less common or noticeable in Canada; they were not observed as a major indicator of stem decay in the Ontario decay survey of the 1950s, nor are they mentioned in other Canadian studies of external indicators of stem decay in yellow birch.

Logging wounds inflicted on yellow birch stems are frequently associated with internal stem decay, but "decay and discoloration following logging wounds... definitely cannot be explained or predicted on the basis of external characters or features alone" (Shigo 1966). Appreciable decay was associated with large basal logging scars 4 years after they were inflicted (Benzie et al. 1963). Felling scars or other mechanical injuries that involve death of the cambium would likely have similar effects. Lavallée and Lortie (1968), in a study of external features and stem decay in living yellow birch in Quebec, concluded that mechanical injuries are more reliable indicators of stem decay than are the more frequently occurring branch stubs and broken branches. They found that, in general, the larger the wound surface area, the more decay, and that besides mechanical injuries, frost cracks and large holes were also frequently associated with stem decay. Poorly healed branch stubs more than 6.3 cm (2.5 in.) in diameter or dead branches in that size class were usually associated with some stem decay; however, stubs or dead branches 3.8 cm (1.5 in.) in diameter or less were seldom associated with stem decay (Lavallée and Lortie 1968).

Shigo (1965a) and Lavallée and Lortie (1968) suggested that the abundance, size and distribution of branch stubs on individual trees is the most reliable external indication of the amount of stain in the central core of yellow birch stems. Extensive stain columns were frequently associated with several branch stubs that were fairly close together (Lavallée and Lortie 1968), or with relatively large-diameter branches that died late in the life of the tree (Shigo 1965a). In both of these studies it was observed that trees with little stem stain were generally those that self-pruned their branches at a relatively early age, when the branches were small. Hence, any practice that results in young stands in which yellow birch are sufficiently close to their neighbors that self-pruning takes place should minimize the occurrence of stain in the stems of mature, crop-size trees.

Because stain frequently becomes extensive in yellow birch as early as age 101 to 110 years in Ontario, and decay becomes extensive at age 140 years under average conditions, yellow birch should be managed to avoid serious stain and decay problems and to promote vigorous, fast-growing trees that will attain merchantable size before they reach these ages. Clearly, doing as much as possible to prevent stem wounding of potential crop trees, particularly during logging operations, will also help to minimize the impact of stem decay on yellow birch. On the basis of defect indicators in second-growth yellow birch (as well as sugar maple and beech) in Quebec that had resulted largely from past clearcuts or partial cuts, Winget (1969) recommended clearcutting tolerant hardwood stands to improve the quality of potential crop trees. Skilling (1959) studied the effects of pruning 20-year-old yellow birch on tree growth rate and quality. He found that pruning had no adverse effects on tree growth rate 10 years after treatment, and that as long as branches were less than 5 cm (2 in.) in diameter and were pruned flush with the bark, "lumber defects" commonly associated with natural pruning (unsound stubs, ingrown bark, loose knots and pockets of decay) did not occur.

Sugar Maple

Of the fourteen major commercial tree species examined for the existence of stem-defect/age relationships in the Ontario decay survey (Basham and Morawski 1964), sugar maple was unique in its relatively high incidence of defect in immature trees. Table 13 shows that in trees 21 to 60 years of age, an average of 14.8% of the merchantable stem volume was defective, much higher than in any other species at comparable stages of maturity. However, Table 13 also shows that, above age 100 years, the increase in extent of defect levelled off; defect accounted for 26.2% of the merchantable stem volume in age class 81–100 years and increased only to 32.3% by age class 221–240 years. In the 3,922 sugar maple trees sampled, 80% of the defect was in the form of stain, a figure exceeded only by that for black ash (84%). Most of the defect in sugar maple less than 60 years old was stain; very little was decay. Because sugar maple and yellow birch occur so frequently together, comparisons of the extent of defect

Table 13. Occurrence of decay and stain in the stems of 3,922 sugar maple sampled in the Great Lakes–St. Lawrence Forest Region of Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. defective (decay and stain) vol. (dm^3)	Merch. vol. decayed (%)	Merch. vol. defective (%)
21–60	408	38.9	5.75	1.3	14.8
61–80	696	90.4	18.81	2.3	20.8
81–100	858	218.7	57.29	3.5	26.2
101–120	537	453.2	111.96	2.7	24.7
121–140	399	532.0	145.25	4.5	27.3
141–160	290	881.9	268.95	6.9	30.5
161–180	252	920.7	267.91	7.0	29.1
181–200	172	1,026.5	318.23	8.8	31.0
201–220	143	1,087.2	352.25	7.6	32.4
221–240	91	1,284.7	414.94	7.9	32.3
241+	76	1,554.1	559.50	10.1	36.0

in stems of the two species are of interest. The decay survey data indicate that stem decay and stain are more extensive in sugar maple up to age 80, but in trees more than 100 years old, they are less extensive than in yellow birch. When only stem decay is considered, there is little difference in the extent of decay (on the basis of percentage of stem volume) in the two species before age 90 years (Fig. 19). However, as trees pass that age, yellow birch quickly develops more decay than sugar maple, and after 180 years, yellow birch has almost twice as much stem decay as sugar maple.

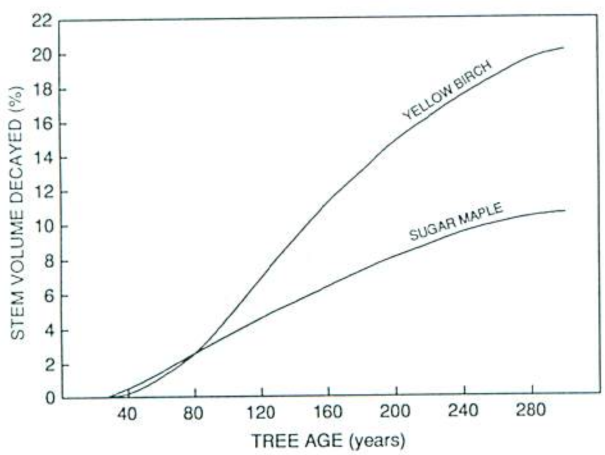


Figure 19. Comparison of the extent of decay in the merchantable stem portions of yellow birch and sugar maple trees at similar ages. Decay-age data obtained from curves in Basham and Morawski's (1964) figure 27.

Beyond age class 81–100 years, the extent of stain in sugar maple stems remained at between 22 and 25% of the merchantable stem volume, whereas the percentage of decay continued to increase slowly. The result was that there was less stem defect in mature and overmature sugar maple than in most of the other deciduous species included in the decay survey (Basham and Morawski 1964). With less than 6% of the merchantable stem volume decayed in trees under age 140, and only about 8% at 240 years (Table 13), it is clear that stem decay will generally have little impact, regardless of the age at which sugar maple stands are harvested, and that considerations other than the development of decay will generally determine cutting ages. Furthermore, the average extent of stain is 22.5% in trees more than 80 years old, regardless of age (Table 13). In most cases, therefore, there is no such thing as a pathological rotation age for sugar maple.

Nordin (1954) carried out a major study of sugar maple decay in Ontario in basically the same regions as the federal-provincial decay survey of the 1950s. He examined 606 trees, and although he described stem stains and the microorganisms isolated from them, he did not include stained wood in his measurements of stem defect. In comparable age classes, he reported stem decay at roughly double the percentages of stem volume that were reported in the provincial decay survey. Although his sample size was much smaller than that of Morawski et al. (1958), it is highly unlikely that the actual difference in the extent of decay was of that magnitude. A more reasonable explanation is that, because of the subjectivity involved in distinguishing between stain and early incipient decay, Nordin categorized some of the defect that Morawski et al. classified as stain under incipient decay. In any case, Nordin's results were similar to those of Morawski et al. in that he found the extent of "decay" surprisingly high in his youngest age class, which he gives as 40 years; from that point on, the extent of decay increased at a relatively slow rate until about age 220 years. Nordin examined 21 trees more than 300 years old, and reported a relatively rapid increase in the extent of decay from age 220 years to age 320 years. In the decay survey, only one tree more than 275 years old was sampled and, consequently, only the beginning of this trend at about age 240 years was detected.

The decay survey of sugar maple in the federal-provincial study of the 1950s was carried out in the Algoma and Algonquin ecological sections (Halliday 1937) of the Great Lakes–St. Lawrence Forest Region. The 784 trees sampled in the Algoma section exhibited appreciably lower average growth rates than the 3,138 trees sampled in the Algonquin section. For example, sugar maple sampled in the Algoma section at age 140 years averaged 22.5 cm (8.9 in.) DBH in comparison with 141.5 cm (15.9 in.) for trees in the Algonquin section. Attempts to relate the development of stem decay in sugar maple to site characteristics were made separately in each ecological section; however, no relationships of any practical importance were evident (Morawski et al. 1958).

The sample of 3,922 sugar maple was also divided by land type. All 784 trees sampled in the Algoma ecological section, and 2,831 of the 3,138 trees sampled in the Algonquin section, grew on land of the Sherborne type. The remaining 317 trees of the Algonquin section grew on land of the Limerick type. These land types are based on parent soil material and are defined by Hills (1952) as silty-sand till derived from granitic bedrock (Sherborne) and sandy till derived from basic igneous rock or schists in which limestone may or may not be present (Limerick). Practically all of the Limerick sample was located in the easternmost sample plots, near where the three counties of Renfrew, Frontenac and Lennox–Addington meet. The Limerick land type has somewhat richer soils than the Sherborne land type. Within the Algonquin ecological section, the sugar maple sampled on the Limerick land type, in comparable diameter classes, had somewhat better height growth and a corresponding slightly greater volume than those on the Sherborne land type (Morawski et al. 1958). The Limerick trees also had a slightly lower incidence of stem decay. A comparison of maple of similar diameters on the Sherborne land type indicated that trees in the Algoma section were somewhat more defective than trees in the Algonquin section.

The two studies of sugar maple decay in the 1950s, those by Nordin and the federal-provincial decay survey, were carried out in Ontario on the Canadian Shield. Because of the deeper, richer soils south of the Shield it was generally believed the sugar maple there were faster growing and less defective than trees growing on the Shield. An opportunity to test this belief arose in the early 1970s in connection with a thinning and fertilization study carried out by the Great Lakes Forestry Centre (Sault Ste. Marie) in two typical sugar maple stands in Sydenham Township, Grey County. The thinning involved the felling of 300 sugar maple trees ranging in DBH from 8.9 to 45.7 cm (3.5 to 18 in.), and subsequent bucking into lengths that corresponded as closely as possible to those in a commercial operation. The average age of the 300 trees was 65 years, the average DBH was 21.6 cm (8.5 in.), and an average of 4.5% of the merchantable stem volume was decayed or stained (Basham 1973a). At a comparable age (65 years) in the federal-provincial decay survey, sugar maple on the Shield had an average DBH of 14 cm (5.5 in.) and approximately 20% of their merchantable stem volume was defective. These results confirm the belief that sugar maple south of the Canadian Shield in Ontario tends to be much faster growing and less defective than sugar maple on the Shield.

Most of the respondents to the questionnaire sent to hardwood-processing industries in southern Ontario, 70 out of 95, handled sugar maple (Basham 1973a). Twenty-eight of these (35.4%) reported that stain and decay in this species were serious problems. However, this includes 11 who indicated that problems were encountered only in sugar maple that was grown "to the north", presumably on the Canadian Shield. Some of the remainder could well have experienced the same situation but did not indicate this in their replies. Indeed, in view of the distances between logging sites and manufacturing plants, it is quite possible that in all problem cases in the three districts bordering the Canadian Shield (i.e., Lake Simcoe, Lindsay, and Tweed), much of the defective hard maple was cut on the Shield. Replies from the Lake Huron District suggest a higher-than-average incidence of stain and decay in hard maple growing on lowland sites in the Bruce and northern Grey counties. Only two of the 31 respondents who dealt with hard maple in Lake Erie District regarded stain and decay as serious problems in this species.

Nordin (1954) reported a good correlation between sugar maple tree diameter and the loss of recoverable stem volume attributable to decay and other natural defects. The percentage of merchantable stem volume decayed increased from 5.6% in the 5-in. (13 cm) diameter class to 18.4% at 26 in. (66 cm). The increase in diameter was accompanied by a gradual, progressive increase in the percentage of stem volume decayed (Nordin 1954). A similar relationship between sugar maple diameter and the extent of stem defect was found in the federal-provincial decay survey (Morawski et al. 1958).

As has already been pointed out, 80% of the stem defect in the 3,922 sugar maple trees studied in the federal-provincial decay survey was in the form of stain. Approximately 88.5% of the decay was in the advanced stage and roughly 20% of the decay was in the butt region. Just under 25% of the stain was in the butt region.

Stained (discolored) sugar maple stem wood frequently occurs in the central portion of the bole where there is no decay (Fig. 20a). This is not true heartwood in that it is almost invariably the result of a disturbance such as a dead branch, mechanical wound or fungal invasion. Where fungal decay occurs, it is surrounded by a collar of stained wood radially and by tapered, stained columns vertically. Most sugar maple stain is brown, ranging from pale yellowish-brown to dark chocolate brown, but it may also be greenish-brown, olive green, dark green, or almost black. The term "blackheart" is sometimes used to describe the chocolate-brown to black stains. All stains, but more particularly those with a greenish hue, are sometimes called mineral stain. Since the darker stained wood frequently has a higher mineral (calcium, potassium and magnesium carbonate) content than clear wood and is harder than clear wood (Scheffer 1954), the term mineral stain is not entirely inappropriate.

The development of stain in sugar maple trees in response to an injury or infection can be regarded as a defence mechanism on the part of the tree, a modification of the affected tissue to make it less suitable for, and therefore more resistant to, invasion by microorganisms, particularly decay fungi; for this reason, it is sometimes referred to as protection wood. Much of the stain is apparently sterile; in another study, 948 isolation attempts were made in 209 sugar maple trees from stained wood containing no decay, and 62.3% proved to be sterile (Basham and Taylor 1965). Fungi were isolated in 30.8% and bacteria in 6.9% of the cases. In the same sample of 209 trees, 83 isolation attempts were made from stained wood associated with decay; 47% of these were sterile, 49.4% yielded fungi and 3.6% yielded bacteria. Most of the fungi were non-decay fungi that are not believed to be capable of causing discoloration. Clearly, stain in sugar maple is primarily of physiological, not pathological, origin in most cases. In some cases stain does harbor decay-causing fungi; approximately 25% of the isolations of the decay fungus *Polyporus glomeratus* (renamed *Inonotus glomeratus*) from the 3,922 sugar maple sampled in the decay survey were obtained from stained wood. Although some of those stains may have developed as early incipient *P. glomeratus* decay, it seems likely that in most cases the stain was present before it was invaded by the fungus.

Roughly 70% of the decay encountered in the 3,922 sugar maple examined in the federal-provincial decay survey was a yellow-brown stringy type that occurred in both trunk and butt regions. In the trunk, the main causal organism was *P. glomeratus* (Fig. 20b,c), followed by *Pholiota spectabilis* (renamed *Gymnopilus spectabilis* [Fig. 20d]). In the butt region, yellow-brown stringy decay was caused mainly by *Armillaria* sp. (probably *A. ostoyae*) and *P. spectabilis*. About 20% of the stem decay was a white spongy type in both the trunk and butt regions. This decay was caused by *Fomes igniarius* (renamed *Phellinus igniarius* [Fig. 20e,f]) and *Fomes connatus* (renamed *Oxyporus populinus*). The appearance of *F. igniarius* decay has been described in the section on trembling aspen. Decay caused by *F. connatus* is similar in appearance, but is more greyish-white and does not have black zone lines. Incipient yellow decay accounted for most of the remaining 10% of the stem decay in the 3,922 sugar maple, from which several fungi were isolated; the most common of these was *P. glomeratus*. A very small amount of brown cubical butt decay, caused by *Coprinus micaceus* and *Poria cocos* (renamed *Wolfiporia extensa*), was encountered.

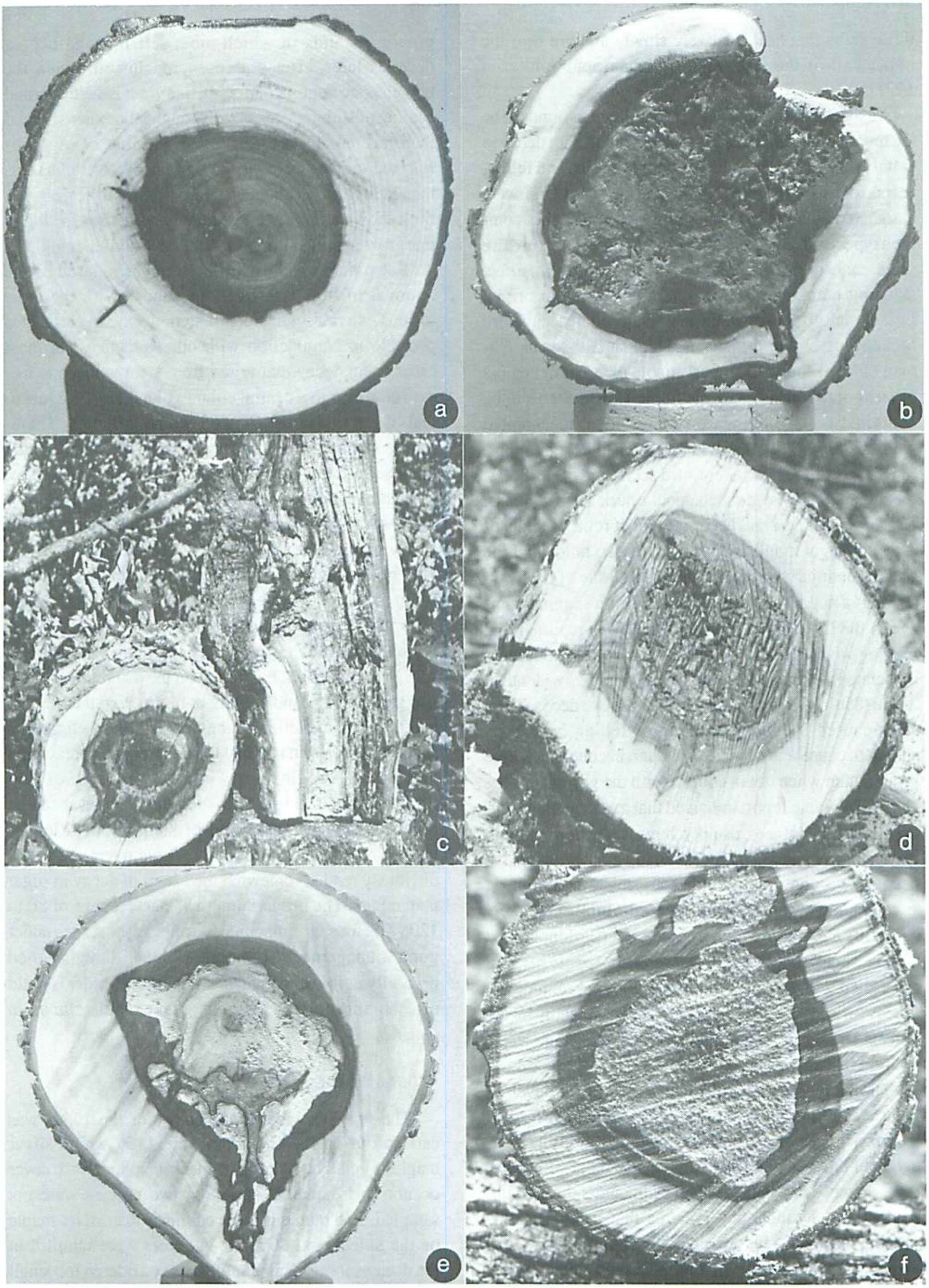
In both the federal-provincial decay survey, in which 3,922 sugar maple were examined (Basham and Morawski 1964), and in Nordin's (1954) study, in which 606 sugar maple were examined, *P. glomeratus* was isolated from stem decay with far greater frequency than any other decay fungus. It accounted for 34% of the isolations of decay fungi in the former study and 25% of such isolations in the latter. In both studies, the fungus that ranked second in frequency of isolation was *Corticium vellereum* (renamed *Hypochnicium vellereum*). Unlike other decay fungi, which gain entrance to the stem almost exclusively through stem wounds or broken tops, *C. vellereum* also enters through branch stubs, where it causes decay and is an inhabitant of the stained wood that develops in the stem from branch stubs (Basham and Anderson 1977). *Corticium vellereum* was isolated repeatedly from stain and from decay of all types in sugar maple, with the exception of brown cubical decay. It is generally believed that *C. vellereum*, though a member of the class Basidiomycetes, to which 99% of stem and root decay fungi belong, is incapable of causing advanced decay in sugar maple stems. Its presence in decays and stains of all types probably reflects its ability to invade stained wood or wood already decayed by other fungi.

In his study of stem decay in 606 sugar maple trees in south-central Ontario, Nordin (1954) attempted to identify the entry point for each decay column or pocket. He concluded that the most common entry points, in order of frequency, were frost cracks, dead branches and stubs, stem scars (felling, lightning, fire, etc.) and root systems. More than 90% of decay infections could be traced to those sources. Other entry points included damaged tops, cankers, burls and parent stumps. Nordin did point out that, whereas branch stubs were frequent entry points, the volume of decay associated with each stub was relatively small. In a study of 1,024 sugar maple branch stubs on 275 second-growth trees, Basham and Anderson (1977) concluded that branch stubs were an insignificant source of stem decay. However, although the upper age limit of the trees was 114 years, no stubs with diameters larger than 5.1 cm (2 in.) were available for sampling. Six of the 1,024 stubs yielded isolates of *P. glomeratus* and one yielded *F. igniarius*. When seven larger stubs (average diameter 7.4 cm) on four larger trees were subsequently examined, decay pockets caused by *P. spectabilis* were found in three of them. In yet another study in south-central Ontario, Vasiloff and Basham (1963) examined 455 second-growth sugar maple and concluded that decay fungi entered stems through stem wounds rather than through branch stubs, with very rare exceptions. From careful examination of what appeared to be frost cracks, they concluded that the majority were originally "felling scars or sun scald injuries that were followed by repeated separation of the callus, presumably due to sudden temperature changes, resulting in frost ribs" (Vasiloff and Basham 1963). Shigo (1966) found that decay in sugar maple stems entered through logging wounds, and that *F. connatus*, the most common decay fungus in this association, was present in four of the 48 trees studied.

Although a few of the fungi that decay sugar maple produce sporophores on the stems of living trees or nearby on the ground, the sporophores are either inconspicuous, short-lived, or both. An exception is *Fomes igniarius*, whose sporophores are long-lived and very conspicuous; however, they are rare on living trees. These fruiting bodies have been described in the section on trembling aspen. When they do occur on living sugar maple, decay generally extends at least 2 m above and below the sporophores. *Fomes connatus* sporophores are sometimes produced on the edges of basal stem wounds. They are small, generally less than 3 cm wide, soft, and yellowish-white, and frequently have green moss growing on their tops. The volume of internal decay associated with *F. connatus* sporophores is usually quite small. *Armillaria* sp. sporophores have been described in the section on trembling aspen. They form on the base of stems or on the ground nearby, but are short-lived and occur only in late summer or early fall. *Polyporus glomeratus* very seldom produces sporophores on living trees, but the presence of stem decay is sometimes indicated by swollen, punky knots or linear black seams formed by the fungus. A small proportion of the white spongy trunk decay in sugar maple is caused by the fungus *Hydnum septentrionale*. This fungus is mentioned here because its few occurrences are generally revealed by prominent clusters of creamy-white, fleshy, shelf-like sporophores with the undersurface covered with white spines. Their presence usually indicates extensive stem decay.

The most reliable external indicators of stem decay in sugar maple are stem wounds or other abnormalities, and the size and age of those abnormalities. Branch stubs or dead branches more than 5 cm (Basham and Anderson 1977) or 10 cm (Hesterberg 1957) in diameter are likely entry courts for stem decay. Little defect is associated with branch stubs less than 2.7 cm (0.5 in.) in diameter. Stubs between these sizes, though associated with little or no decay, can be responsible for the introduction of considerable stain into the core of the stem, particularly

Figure 20 (facing page). Sugar maple stem defects. (a) transverse section of central core of stained wood, (b) transverse section of advanced decay caused by Polyporus glomeratus, *(c) transverse and radial sections of decay caused by P. glomeratus, (d) transverse section of advanced decay caused by* Pholiota spectabilis (Gymnopilus spectabilis), *(e,f) transverse sections of advanced decay caused by* Fomes igniarius (Phellinus igniarius).


a
b
c
d
e
f

those stubs that heal relatively slowly and are near the upper end of the size range (Basham and Anderson 1977).

Vasiloff and Basham (1963) found stem wounds to be the most reliable indicators of the extent of stem decay in Ontario. They reported that sunscald injuries and felling scars, followed by frost cracks and dead leaders, were associated with the largest volume of decay. Other common types of wound associated with stem decay were fire scars, cankers caused by the fungus *Eutypella parasitica*, skidding scars, and narrow seams of uncertain origin. Less common types of wound associated with decay were broken tops, broken crotches and branch-stub seams. Ohman (1968a) found the most reliable external indicators of stem decay in sugar maple in the United States to be abnormal bole swellings or depressions, mechanical wounds, cracks, seams, holes, unhealed branch stubs, fungal sporophores, cankers, bird pecks and insect holes. Lavallée (1968) listed mechanical injuries, frost cracks, and large broken branches as the most reliable signs of decay in sugar maple in Quebec. He also noted that the size of the injury was related to the volume of decay. In a study of sugar maple deterioration after logging damage in the Lake States, Hesterberg (1957) reported that logging wounds narrower then 10 cm (4 in.) had far less associated stem decay 20 years later than scars wider than 20 cm (8 in.), which frequently hid extensive decay. Basal scars caused by either skidding or felling have been shown to cause more butt decay when in contact with the ground than when not in contact with the ground (Anon. 1973). The same report indicated that exposed, light-colored wound surfaces usually have very limited stem decay, whereas darker surfaces usually indicate extensive decay. Two abnormalities that are fairly common on sugar maple stems in south-central Ontario, cankers caused by *E. parasitica* and irregular, deep lesions caused by the sugar maple borer, *Glycobius speciosus*, are associated with a limited amount of internal stem defect (decay in the former case, but primarily stain in the latter). They also signal a risk of stem breakage at the point of disfigurement.

The many research studies carried out on the development of stain and decay in sugar maple stems have formed the basis for several recommended silvicultural and management practices that can appreciably reduce their impact. Because much of the stem stain enters through unhealed branch stubs, any practice that promotes self-pruning when the trees are relatively young and vigorous and the branches small will minimize stain development. Clearly, this is preferable to young, relatively open-growing stands in which most self-pruning occurs decades later, after crown encroachment, when the branches are large; at this point, tree vigor is declining and healing of stubs is very slow. Though labor intensive and therefore costly, artificial flush pruning of vigorous selected crop trees, concentrated on live branches less than 5 cm (2 in.) in diameter to promote rapid healing, has been shown to improve tree quality with no reduction in tree growth rate (Skilling 1958; Zeedyk and Hough 1958).

Sugar maple stand decadence can be reduced by the removal of high-risk trees, i.e., those with the most serious external indicators of stem decay, as early as is possible in conjunction with other practices. In most cases, stem decay that arises from stem wounds is forever confined to a central column of a diameter equal to that of the tree at the time of wound infliction. Therefore, a stem wound on a large tree is potentially much more serious than a wound on a small tree. In the latter case, prevention of further injury and promotion of a satisfactory growth rate should result in a crop tree with a very small proportion of defective stem wood.

The incidence of many stem wounds of the type that result in the most stem decay can, to a great extent, be minimized by modifying management procedures. Sunscald wounds are caused by frost injury induced by warming of the bark by the sun on the southwestern side and subsequent rapid cooling at night. Partial cutting to avoid drastic reductions in basal area largely eliminates sunscald hazards in residual trees. Forest-fire prevention and careful logging supervision to reduce logging damage to the residual trees are other steps that can be taken to reduce the impact of stem decay. Finally, harvesting stands before they become overmature will obviously reduce somewhat the extent of decay in sugar maple logs. The observation that "harvest ages of 80 to 120 years for saw-timber are feasible on most sites under good management" (Ohman 1968b), though aimed primarily at forest managers south of the border, should also be appropriate for most sugar maple stands in Ontario.

Other Maples

The provincewide decay survey of the 1950s was carried out on the Canadian Shield, on which silver maple is relatively rare and black maple almost never occurs; this explains why these two species were not sampled. Red maple is more common than silver maple on the Shield, and 66 red maple trees were sampled in the decay survey. This sample was considered too small to provide meaningful stem-decay relationships, and it was not included in the two publications that dealt with the survey (Morawski et al. 1958; Basham and Morawski 1964). However, because of the scarcity of information on red maple stem decay, results obtained from the 66 trees are presented herein.

The 66 red maple were widely scattered throughout the Algoma and Algonquin ecological sections. Usually only one or two trees larger than the minimum sampling size grew in each plot, and for the most part red maple was a minor component of stands composed mainly of sugar maple, yellow birch, beech and hemlock. Table 14 shows that, at comparable ages, red maple stems were considerably more defective than those of sugar maple, and somewhat more defective than those of yellow birch. In age class 101–120 years, the average merchantable volumes for red maple, sugar maple, and yellow birch were 348, 453 and 464 dm^3, respectively; the approximate average percentages of those volumes that were defective were 40, 25 and 30%, respectively.

Although the sample was small, the data in Table 14 show that, in red maple, the percentage of merchantable stem volume affected by decay and stain increased with age, and averaged more than 40% after age 80 years. Decay accounted for 31% of the defect in red maple in comparison with 20% in sugar maple. Stem decay apparently begins at a relatively early age in red maple. Table 14 shows that 7.2% of stem volume was decayed in the 18 trees in age class 61–80 years, in comparison with only 1.6% in yellow birch (Table 12) and 2.3% in sugar maple (Table 13) in the same age class.

Stained wood in red maple stems was medium- to dark-brown and occurred alone in the central core or at the boundaries of decay columns. Most of the decay (88.5%) was of the advanced yellow-brown stringy type, mainly in the trunk but also fairly common in the butt region. Smaller amounts of white spongy decay, virtually limited to the trunk region, and of incipient yellow-brown decay in both trunk and butt regions, were found in the stems of the 66 red maple sampled.

The principal decay fungus in red maple stems in Ontario, as it is in sugar maple, is *Polyporus glomeratus* (renamed *Inonotus glomeratus*). This fungus is associated with most of the yellow-brown stringy trunk decay and occasionally with the same type of butt decay. Some isolations of *P. glomeratus* were obtained from brown trunk stains, which were most likely early incipient stages of *P. glomeratus* decay. A small proportion of the yellow-brown stringy trunk decay was caused by *Stereum murraii* (renamed *Cystostereum murraii*) and *Pholiota spectabilis* (renamed *Gymnopilus spectabilis).* The yellow-brown stringy butt decay was caused primarily by *Armillaria* sp. (probably *A. ostoyae*), *P. spectabilis* and *Pholiota aurivella.* The relatively small amount of white spongy decay found in red maple was caused by *Fomes igniarius* (renamed *Phellinus igniarius*). Virtually the same fungi have been reported as the causes of most stem decay in red maple in the northeastern United States (Campbell and Spaulding 1942; Shigo 1965b), except that those authors also report that *Fomes connatus* (renamed *Oxyporus populinus*) is a major cause of decay in that region.

Stem decay in silver maple has never, to my knowledge, been intensively studied in Ontario. However, Eslyn (1962) used nondestructive methods (radiation and increment cores) to detect decay and to identify decay-causing fungi in silver maple stands in Iowa. Because of the techniques used, his results were confined to the lower stem regions. The most frequently isolated Basidiomycete was *Corticium vellereum* (renamed *Hypochnicium vellereum*), which Eslyn suspected was not a primary cause of decay. Only one other decay- causing fungus was consistently isolated, *P. aurivella,* which Eslyn described as of major importance in butt decay of silver maple.

Table 14. Occurrence of decay and stain in the stems of 66 red maple sampled in the Great Lakes–St. Lawrence Forest Region of Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. defective (decay and stain) vol. (dm^3)	Merch. vol. decayed (%)	Merch. vol. defective (%)
41–60	15	82.1	16.25	1.0	19.8
61–80	18	144.4	40.69	7.2	28.6
81–100	9	209.5	91.80	18.6	43.8
101–120	11	348.3	140.35	12.3	40.3
121–140	5	444.6	207.14	8.1	46.6
141+	8	767.5	397.61	19.2	51.8

Of the 95 hardwood-processing industries south of the Canadian Shield in Ontario that responded to the stem-defect questionnaire, 66 indicated that they handled soft (red or silver) maple (Basham 1973a). Of those, 30 (45.5%) indicated that they had serious decay and stain problems with those species, which made soft maple the number-one problem in that respect. The major problem with soft maple, according to the questionnaire respondents, was "wormy wood" or "worm holes". Follow-up visits to sawmills revealed that the "worm holes" were small tunnels 1 to 2 mm in diameter that appeared to occur anywhere throughout the xylem, from the pith to the cambium. These were invariably surrounded by a fairly extensive greenish-brown stain that formed a more-or-less star-shaped pattern on the faces of cut logs. One or more species of ambrosia beetle, probably including the genera *Xyloterinus* and *Corthylus*, are responsible for the tunnels. Apparently the insects can invade and damage healthy, vigorous trees. The stain is probably caused by the fungi carried into the tree and used as food by the beetles.

Although "wormy" soft maple was by far the most frequently noted defect in this species group, some respondents reported the occurrence of butt decay. However, from comments on the questionnaire replies and from visits to southern Ontario mills, it was concluded that this is seldom a serious problem except in overmature trees or stands.

A study of decay in 324 red maple connected to 72 clumps of sprouts in New Hampshire revealed that branch stubs were far more important as entry points for decay fungi than were parent stumps (Shigo 1965b). The principal decay fungus that infected trees through branch stubs was *Polyporus glomeratus*. Logging wounds in red maple have been shown to serve as points of entry to the stem for *Fomes igniarius*, *Fomes connatus* and *Corticium vellereum* (Shigo 1966).

Sound, or relatively sound, red maple trees are valuable. However, because they are subject to considerable stem stain and decay at a relatively early age (Table 14), early pruning (natural or artificial) followed by rapid growth and harvesting well before age 100 years should help to prevent stem decay from having a serious economic impact.

Beech

One of the principal reasons beech is generally considered a low-value tree species is because it is thought to be highly defective. In the federal-provincial decay survey of the 1950s, 393 beech were sampled, all in the Algonquin ecological section. The percentages of merchantable stem volume affected by decay and stain are shown, by age class, in Table 15. The beech sample was about as defective as the sugar maple sampled in the survey (Table 13), and less defective than yellow birch (Table 12) and red maple (Table 14). Hence, on the basis of the decay survey, beech is certainly no worse than average in comparison with other tolerant hardwood species of south-central Ontario as far as stem defectiveness is concerned.

Roughly 10% of beech stem volume was decayed after trees reached approximately 70 years of age (Table 15). The extent of defect increased gradually with age until trees reached 140 years; from this age onward, between 10 and 20% of the stem volume was decayed and close to 40% of the volume was defective.

Replies to a questionnaire were received from 63 hardwood industries that processed beech in Ontario south of the Canadian Shield; of these, 23 (36.5%) indicated that stem decay and stain were serious problems

Table 15. Occurrence of decay and stain in the stems of 393 beech sampled in the Great Lakes–St. Lawrence Forest Region of Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. defective (decay and stain) vol. (dm^3)	Merch. vol. decayed (%)	Merch. vol. defective (%)
41–60	19	23.5	3.31	0.9	14.1
61–80	80	61.7	12.90	7.1	20.9
81–100	99	110.9	31.47	10.0	28.4
101–120	69	298.2	63.79	6.7	21.4
121–140	57	663.4	222.92	9.3	33.6
141–160	38	1,007.0	368.53	13.0	36.6
161+	31	1,671.3	655.09	18.9	39.2

(Basham 1973a). Soft maples were the only species for which a higher percentage of respondents showed concern. In beech, decay alone was considered a serious problem by 33% of the respondents, by far the highest percentage of any species. The decay was frequently described by respondents as butt decay, and occasionally as a trunk decay associated with rough, swollen bark or with numerous branch stubs.

The percentage of merchantable stem volume that was defective in the 393 beech sampled increased consistently with tree diameter (Morawski et al. 1958). Most of the trees grew as patchy admixtures in sugar maple/yellow birch stands on dry and fresh sites, primarily on upper slopes. The sample was too small for an analysis of the relationship between site and stem defect. However, it was observed that most defect tended to occur in beech growing on dry, shallow soils (Morawski et al. 1958).

Beech grown in Ontario south of the Shield is generally of poor quality and is utilized only sparingly by the wood-using industries of that region. Besides the fact that there is a reluctance to use beech for many products, once a tree is cut the logs are susceptible to relatively rapid development of sap stain. In addition, the lumber has a tendency to shrink, check, and warp unless dried very carefully. Nevertheless, beech is present in most stands and woodlots in southern Ontario, often as a major stand component. It is perhaps significant that one-third of those respondents who processed or dealt with beech felt that stain and/or decay were serious problems. This suggests that those respondents, at least, believe that beech is potentially of some commercial value.

The stained stem wood in the 393 beech sampled in the federal-provincial decay survey was brownish and accounted for 63.6% of the defect in this species. This is a comparatively low figure for tolerant hardwoods in the Great Lakes–St. Lawrence Forest Region of Ontario. Fully one-quarter of the stain occurred in the butt region. Stained wood was occasionally the only stem defect, particularly in the younger trees. More commonly, it surrounded decay pockets or columns in narrow bands radially and in tapered extensions vertically.

About 84% of the decay was in the advanced stage, and the most common type of advanced decay was a yellow-brown stringy type that occurred in both trunk and butt regions of the stems. Most of the remaining advanced decay was white and spongy, and was found in both trunk and butt regions. A very small amount of brown cubical butt decay was found. The remaining decay was an incipient yellow type that occurred almost entirely in the trunk region.

Polyporus glomeratus (renamed *Inonotus glomeratus*) was the principal cause of stem decay (usually a yellow-brown stringy trunk type) in beech. Yellow-brown stringy butt decay was caused by *Armillaria* sp. (probably *A. ostoyae*) and by *Pholiota aurivella* (often incorrectly identified as *P. adiposa* before 1965). Most of the white spongy trunk and butt decay was caused by *Fomes igniarius* (renamed *Phellinus igniarius*). *Corticium vellereum* (renamed *Hypochnicium vellereum*) and *P. glomeratus* were the fungi most frequently isolated from the incipient yellow decay and from brown stain.

In New Hampshire, Campbell and Davidson (1939) observed that *P. glomeratus* infected beech primarily through dead branch stubs, but also occasionally through stem wounds. Logging wounds have been shown to serve as entry points to beech stems for *F. igniarius*, *P. aurivella*, *Armillaria* sp. and several other decay fungi (Shigo 1966). The size of the logging wound was a fairly accurate indicator of the extent of internal defect in this species. Extensive *P. glomeratus* trunk decay in beech frequently results in bark swellings or cankers, and at branch stubs black, roughened fungal material that protrudes as much as 7.5 cm (3 in.), frequently called "sterile conks", may appear (Campbell and Davidson 1939).

The results of the federal-provincial decay survey of the 1950s indicated that, at least on the Canadian Shield, the reputation of beech as a relatively defective species is largely undeserved. Because beech was almost always bypassed in logging operations in the past, many overmature or wounded, and therefore defective, beech are growing in our forests today. If care is taken to avoid wounding young beech during logging operations and if the trees are harvested before the age of 130 years, two-thirds of the stem, on average, should be free of decay and stain (Table 15).

Basswood

Only 140 basswood of merchantable size were present in the sample plots established in the federal-provincial decay survey of the 1950s. This relatively small sample formed the basis for Table 16, which indicates that basswood is one of the least defective deciduous tree species in Ontario. Table 16 indicates that very little decay or stain is present in basswood stems until age 120 years, and although the conclusion is based on relatively few sample trees, it is probably safe to assume that basswood harvested before age 120 years will not have extensive stem defect. The few (29) trees sampled that were older than 120 years, on the other hand, were quite defective.

Table 16. Occurrence of decay and stain in the stems of 140 basswood sampled in the Great Lakes–St. Lawrence Forest Region of Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. defective (decay and stain) vol. (dm^3)	Merch. vol. decayed (%)	Merch. vol. defective (%)
21–40	9	30.4	0.66	0.0	2.2
41–60	33	89.9	2.70	0.4	3.0
61–80	37	490.3	19.10	1.8	3.9
81–100	22	776.8	36.52	3.5	4.7
101–120	10	1,128.5	50.78	2.8	4.5
121–140	12	1,883.2	374.78	15.6	19.9
141–180	11	2,349.4	540.33	10.0	23.0
181+	6	2,896.6	915.34	23.9	31.6

The majority of the 140 sampled basswood occurred in sugar maple/yellow birch stands in the southern portion of the Algonquin ecological section, on good sites with deep, loamy soils and fresh-to-moist moisture regimes. There was insufficient variation in site among the trees sampled for an analysis of the relationship between site and the extent of stem defect.

Replies to a questionnaire were received from 63 hardwood industries that processed basswood south of the Canadian Shield in Ontario. When the apparent relative soundness of basswood on the Shield is considered, it came as a surprise that 16 of the respondents (25.4%) indicated serious basswood decay and stain problems (Basham 1973a). In terms of defects, this ranked basswood fourth among the 12 hardwood species covered in the questionnaire. Stem stain was identified as the problem by six of the respondents, whereas the other 10 reported that both stain and decay were cause for serious concern.

Basswood had the lowest (25.4%) percentage of stem defect in the form of stain of all the deciduous trees in Ontario that were sampled in the federal-provincial decay survey. The stain was generally brownish, occasionally with a green hue. All of the decay was either yellow-brown stringy advanced decay or incipient yellow decay. Yellow-brown stringy advanced decay made up two-thirds of the total defect volume in basswood and was present in both butt and trunk regions.

Pholiota aurivella (often incorrectly identified as *P. adiposa* before 1965) caused much of the decay in the 140 basswood sampled (Basham and Morawski 1964). It, along with *Pholiota spectabilis* (renamed *Gymnopilus spectabilis*), caused practically all of the trunk defect. *Armillaria* sp. (probably *A. ostoyae*) was the cause of most of the yellow-brown stringy butt decay; *P. aurivella* was also responsible for some of the butt defect.

There are virtually no reliable external indicators of stem defect in basswood except in late summer and early fall, when the short-lived fruiting bodies of *Armillaria, P. aurivella*, and *P. spectabilis* may appear. Little is known about the entry of these decay fungi into basswood stems; however, it appears likely that some of the stem decay can be attributed to the fact that basswood regenerates by producing sprouts from the base of old stumps. The evidence in Table 16 indicates that the only procedure necessary to ensure that stem decay and stain do not become serious is to harvest basswood before, or soon after, it reaches age 120 years.

Black Ash

Table 17 shows the occurrence, by age class, of decay and stain in the relatively small sample of 103 black ash trees sampled in the federal-provincial decay survey of the 1950s. The fact that a very high percentage (62 to 75%) of stem volume is affected by decay and stain in trees more than 100 years old is tempered somewhat by the fact that most of this defect is in the form of stain. Indeed, the presence of stain almost throughout the merchantable length of the oldest trees suggests that much of the stain is true heartwood, and is a result of the normal process and death of cells rather than a result of wounding (branch death, etc.) or trauma such as invasion by fungi or insects. Nevertheless, the very extensive stain in the stems of the 35 black ash that were more than 100 years old suggests that, where discolored wood is objectionable, this species should be harvested by, or soon after, age 100 years. The incidence of decay, as shown in the second-last column of Table 17, is comparable with that in other tolerant hardwood species of Ontario.

Table 17. Occurrence of decay and stain in the stems of 103 black ash sampled in the Great Lakes–St. Lawrence Forest Region of Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. defective (decay and stain) vol. (dm^3)	Merch. vol. decayed (%)	Merch. vol. defective (%)
41–60	24	50.8	2.23	3.8	4.4
61–80	30	151.5	28.18	6.0	18.6
81–100	14	295.8	67.12	3.6	22.7
101–120	9	402.7	249.24	2.3	61.9
121–140	12	810.4	605.39	14.9	74.7
141+	14	1,395.3	1,046.47	11.3	75.0

Black ash sampled in the decay survey was confined largely to moist and wet sites (Morawski et al. 1958) in the Algonquin and Algoma ecological sections. Replies to a questionnaire were received from 70 hardwood industries in southern Ontario south of the Canadian Shield that process ash (Basham 1973a). These indicated that stem decay and stain in ash were not serious problems in that region.

About 84% of the defect encountered in stems of black ash was in the form of stain. All stain in ash was medium to dark brown; it was present in both butt and trunk regions, and was particularly extensive in older trees. Most of the advanced decay was a yellow-brown stringy type, and occurred mainly in the trunk region; the remainder was white, spongy decay in both branch and butt regions. A small amount of incipient yellow decay was also encountered in the stems of black ash.

Unlike in most other tree species in Ontario, no single fungus stood out as the most common cause of stem decay in black ash. *Stereum murraii* (renamed *Cystostereum murraii*) and *Polyporus glomeratus* (renamed *Inonotus glomeratus*) caused most of the yellow-brown stringy trunk decay, and *Armillaria* sp. (probably *A. ostoyae*) caused most of the yellow-brown stringy butt decay. White spongy decay was caused mainly by *Fomes igniarius* (renamed *Phellinus igniarius*) and *Fomes conchatus* (renamed *Phellinus conchatus*).

Red Oak

Red oak is far more abundant, and therefore a far more valuable resource, in the United States than in Ontario, or in Canada for that matter. Hence, practically all of the research and literature on red oak stem decay and stain originates in the United States. Only 42 red oak were present on sample plots of the federal-provincial decay survey of the 1950s. The extent of stem decay and stain in the stems of these trees, by age class, is shown in Table 18. Though a relatively small sample, it nevertheless indicates that stem defect in red oak is not a serious problem. Minor amounts of decay and stain were present in the 34 trees between the ages of 40 and 140 years that were sampled. Decay was moderately extensive in the eight sampled trees more than 140 years old, but stain was relatively sparse. The red to reddish-brown normal heartwood of red oak was quite distinct from the wound-initiated brown stain, and was not included in Table 18.

Replies to a questionnaire were received from 55 hardwood industries that processed red oak south of the Canadian Shield in Ontario. Only six of the respondents

Table 18. Occurrence of decay and stain in the stems of 42 red oak sampled in the Great Lakes–St. Lawrence Forest Region of Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. defective (decay and stain) vol. (dm^3)	Merch. vol. decayed (%)	Merch. vol. defective (%)
41–60	9	144.4	2.87	0.0	2.0
61–80	22	232.3	8.83	0.7	3.8
81–140	3	947.1	63.44	2.0	6.7
141+	8	1,500.9	199.60	8.4	13.3

reported serious decay or stain problems, an indication that stem decay and stain in red oak are not serious problems in southern Ontario (Basham 1973a).

From American reports it appears that red oak stem decay is not a serious problem south of the border either. In fact, the title of one United States Forest Service paper published in Pennsylvania is "Decay not serious in northern red oak" (Berry and Beaton 1971). In a study of stem decay in five oak species in Kentucky, Berry (1969) found that only 0.65% of the volume of red oak stems was decayed. The percentages of stem volume that were decayed in three of the species of oak were 2.66, 2.35 and 1.84%. Only white oak, with 0.75% decayed, was less defective than red oak.

The brown stain in the 42 red oak sampled in the federal-provincial decay survey appeared to originate in branch stubs, and comprised only 13% of the total defect volume. All of the decay was in the advanced stage, and fully 98% was the advanced yellow-brown stringy type, which occurred in both butt and trunk regions. Small amounts of white spongy trunk decay and brown cubical butt decay were also encountered. Decay and stain together amounted to only 6.3% of the total merchantable volume of the 42 sample trees.

Data from the decay survey on the identity of the fungi causing decay in the sample of 42 red oak in Ontario were insufficient to justify their inclusion in this report. In several American studies, fungi that cause decay in red oak have been identified. From those reports it is clear that several different fungi are responsible for roughly equal proportions of stem decay. Since the majority of them cause little or no stem decay in other tree species in Ontario, there is no need to name them in this report. In one other study carried out in Ontario, near Petawawa, Riley (1947) reported that *Polyporus obtusis* (renamed *Spongipellis unicolor*) caused considerable stem decay of red, white and bur oaks in some areas. This fungus was not isolated from the 42 red oak sampled in Ontario in the 1950s, and is rarely mentioned in reports from the United States that deal with stem decay in oak.

In American studies of stem decay in red oak and other oaks, the two major points of entry for decay-causing fungi appear to be basal fire scars and dead branch stubs.

White Elm

In the federal-provincial decay survey carried out in the 1950s, 62 white elm were sampled; it was felt that this sample was too small to provide meaningful stem-decay relationships and this species was not included in the two publications that dealt with that survey (Morawski et al. 1958; Basham and Morawski 1964). The data on stem decay and stain collected from those 62 trees are presented in Table 19. From this table it is clear that neither decay nor stain is a serious problem in white elm until trees are well over 100 years old.

Most of the stem defect (84.6%) in the 62 white elm was a brown stain. An advanced yellow-brown stringy decay, which occurred mostly in the butt region, accounted for more than half of the decay volume. A white, spongy trunk decay and an incipient yellow trunk decay were also encountered in white elm. The major cause of decay was *Pholiota aurivella* (often incorrectly identified as *P. adiposa* before 1965), which was responsible for most of the yellow-brown stringy decay. Much of the remaining decay was caused by *Pleurotus ulmarius*.

Black Cherry

Because the species is rare on the Canadian Shield in Ontario, only 22 black cherry trees of merchantable size were present in the sample plots established for the federal-provincial decay survey of the 1950s. Of course, no relationships between the extent of stem decay and stain in these trees and age, diameter, site, etc., can be assessed from such a small sample. Nevertheless,

Table 19. Occurrence of decay and stain in the stems of 62 white elm sampled in the Great Lakes–St. Lawrence Forest Region of Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. defective (decay and stain) vol. (dm^3)	Merch. vol. decayed (%)	Merch. vol. defective (%)
41–60	26	59.5	3.68	0.9	6.2
61–80	13	107.6	13.87	1.0	12.9
81–100	10	478.6	67.98	1.9	14.2
121+	13	1,612.8	688.68	5.6	42.7

because black cherry is a valuable species commercially, the information obtained from the 22 trees is presented as an indication of how much, and what types of, defect can be expected in black cherry stems in south-central Ontario.

Of the 22 trees, three were in the 21- to 40-year age class and one was in the 161- to 180-year class. With the largest age class (101–120 years) represented by only six trees, it was felt that breaking down the extent of stem decay and stain by age class in the form of a table would be virtually meaningless. However, there was the usual trend of increasing stem defect, as a percentage of merchantable volume, with increasing age. The extent of stem decay in the 22 black cherry was greater than the average for tolerant hardwood species in south-central Ontario. The three trees in the 21- to 40-year age class had an average of 7% of their stem volume decayed, much more than for trees of any of the other tolerant hardwood species in the 41- to 60-year age class. The eight trees sampled that were more than 100 years old had an average of 21% of their merchantable stem volume decayed. Because of the normal reddish-brown heartwood of black cherry, it is difficult to detect pathological or wound-initiated stain with certainty. It was felt that dark brown stains surrounding decay pockets or associated with dead branch stubs were not normal heartwood. These comprised roughly 15% of the merchantable stem volume, on average, with very slight increases with increasing age class.

Replies to a questionnaire were received from 40 hardwood industries that processed black cherry south of the Canadian Shield in Ontario; only six of those indicated that stem decay was a serious problem (Basham 1973a). This suggests that black cherry south of the Shield in Ontario may be less defective than black cherry growing on the Shield.

Decay in the stems of black cherry differed from that in other tolerant hardwoods not only by its presence at a relatively early age, but in its appearance as well. The greatest volume loss was caused by a reddish-brown trunk decay that contained scattered, soft white pockets. Brown cubical decay accounted for much of the remaining decay; it was present in both butt and trunk regions. A limited amount of advanced yellow-brown stringy decay occurred in both trunk and butt regions of the stem. Little information was obtained on the identity of the major decay-causing fungi in black cherry from the 22-tree sample. From the few identified isolates, and from the intensive study of black cherry stem decay carried out in Pennsylvania by Davidson and Campbell (1943), it appears that no single fungus is the major cause of stem decay in this species. Furthermore, the many fungi that do cause decay are, for the most part, different from those that cause serious decay problems in the stems of the other commercially important tree species of Ontario.

Dead branch stubs of relatively large diameter were found to be the main points of entry for decay-causing fungi of black cherry in Pennsylvania (Davidson and Campbell 1943). To reduce the development of stem decay on a stand basis, they recommended the removal of forked trees and the elimination of multiple-sprout clumps. In another Pennsylvania study, Grisez (1978) concluded that pruning young black cherry trees up to about 50% of their total height can increase the quality and value of the trees thereafter.

Ironwood

Although it is of relatively little commercial value, mainly because of its small size at maturity, ironwood is widely scattered throughout the Algonquin ecological section of south-central Ontario, and 157 trees of merchantable size were present in the sample plots of the federal-provincial decay survey of the 1950s. This sample was large enough to yield meaningful decay relationships for this species.

Table 20 reveals that, on the basis of the 157-tree sample, ironwood is a relatively defective species as far as stem decay and stain are concerned. Of all the species covered in this report, only red maple had as high a percentage of merchantable stem volume affected by decay as ironwood, in all age classes sampled. Stained wood, which varied from medium to dark brown, accounted for 62.3% of the defect volume. The most common type of advanced decay was the yellow-brown, stringy type, which occurred more in the butt than in the trunk region. White, spongy decay was also present, primarily in the trunk region. Some brown cubical butt decay was found. An incipient yellow decay was sometimes encountered in the trunk region, but rarely in the butt region.

The major causes of stem decay in ironwood were *Stereum murraii* (renamed *Cystostereum murraii*), mainly as a yellow-brown stringy trunk decay; *Pholiota aurivella* (often incorrectly identified as *P. adiposa* before 1965), which caused most of the yellow-brown stringy butt decay; and *Fomes igniarius* (renamed *Phellinus igniarius*), the cause of most of the white spongy decay.

Table 20. Occurrence of decay and stain in the stems of 157 ironwood sampled in the Great Lakes–St. Lawrence Forest Region of Ontario. Based on trees examined as part of the federal-provincial decay survey of the 1950s.

Age class (years)	No. of trees	Avg. merch. vol. (dm^3)	Avg. defective (decay and stain) vol. (dm^3)	Merch. vol. decayed (%)	Merch. vol. defective (%)
21–60	51	19.8	1.91	1.0	9.7
61–80	46	48.4	14.83	9.3	30.6
81–100	24	95.2	38.54	12.7	40.5
101–120	18	149.5	52.94	14.3	35.4
121+	18	237.3	101.43	19.7	37.1

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APPENDIX A. Common and scientific names for tree species referred to in the text[a]

Common name	Scientific name
Ash, black	*Fraxinus nigra* Marsh.
Aspen, largetooth	*Populus grandidentata* Michx.
Aspen, trembling	*Populus tremuloides* Michx.
Basswood	*Tilia americana* L.
Beech	*Fagus grandifolia* Ehrh.
Birch, white	*Betula papyrifera* Marsh.
Birch, yellow	*Betula alleghaniensis* Britton
Cedar, eastern white	*Thuja occidentalis* L.
Cherry, black	*Prunus serotina* Ehrh.
Cottonwood, eastern	*Populus deltoides* Bartr.
Elm, white	*Ulmus americana* L.
Fir, balsam	*Abies balsamea* (L.) Mill.
Hemlock, eastern	*Tsuga canadensis* (L.) Carr.
Ironwood	*Ostrya virginiana* (Mill.) K. Koch
Larch, eastern (tamarack)	*Larix laricina* (Du Roi) K. Koch
Maple, black	*Acer nigrum* Michx. f.
Maple, red	*Acer rubrum* L.
Maple, silver	*Acer saccharinum* L.
Maple, sugar	*Acer saccharum* Marsh.
Oak, bur	*Quercus macrocarpa* Michx.
Oak, red	*Quercus rubra* L.
Oak, white	*Quercus alba* L.
Pine, eastern white	*Pinus strobus* L.
Pine, jack	*Pinus banksiana* Lamb.
Pine, red	*Pinus resinosa* Ait.
Poplar, balsam	*Populus balsamifera* L.
Spruce, black	*Picea mariana* (Mill.) B.S.P.
Spruce, white	*Picea glauca* (Moench) Voss

[a] Nomenclature is after Hosie (1979).

APPENDIX B. Decay-causing fungi referred to in the text, with proposed or accepted new nomenclature

Name generally used between World War II and the early 1960s	Proposed or accepted new name
Corticium galactinum	*Scytinostroma galactinum*
Corticium polygonium	*Peniophora polygonia*
Corticium vellereum	*Hypochnicium vellereum*
Flammula alnicola	*Pholiota alnicola*
Fomes conchatus	*Phellinus conchatus*
Fomes connatus	*Oxyporus populinus*
Fomes igniarius	*Phellinus igniarius*
Fomes igniarius var. *laevigatus*	*Phellinus laevigatus*
Fomes igniarius var. *populinus*	*Phellinus tremulae*
Fomes pini	*Phellinus pini*
Odontia bicolor	*Resinicium bicolor*
Merulius himantioides	*Serpula himantioides*
Pholiota adiposa[a]	*Pholiota aurivella*[a]
Pholiota spectabilis	*Gymnopilus spectabilis*
Polyporus balsameus	*Tyromyces balsameus*
Polyporus glomeratus	*Inonotus glomeratus*
Polyporus obtusis	*Spongipellus unicolor*
Polyporus schweinitzii	*Phaeolus schweinitzii*
Polyporus tomentosus	*Inonotus pseudopini*
Poria cocos	*Wolfiporia extensa*
Stereum murraii	*Cystostereum murraii*
Stereum pini	*Peniophora pseudopini*
Stereum sanguinolentum	*Haematostereum sanguinolentum*

[a] *P. adiposa* and *P. aurivella* are probably two different fungi. Prior to the mid-1960s, *P. aurivella* was frequently misidentified as *P. adiposa*.

APPENDIX C. Calculations used by Basham and Morawski (1964) to estimate timber and revenue losses in Ontario as a result of stem decay.[a]

Tables 76 and 77 present the results of calculations designed to give some indication of the economic importance of heartwood defects of fungal origin to the forest industry of Ontario. They are based on the three most recent Annual Reports of the Minister of Lands and Forests of the Province of Ontario (13, 14, 15). These reports contain summaries of the volume of each species cut annually, based on measurements of the timber following deductions for defect made in accordance with the Ontario scaling regulations. Measurements are recorded in different units depending upon the product, and all units are converted into equivalent cubic feet. Table 76 shows the average annual net volume of timber cut, in cubic measure calculated in this way, for the twelve major commercial tree species of Ontario in this period (April 1, 1958 to March 31, 1961). Although arbitrary measurements based on scaling regulations frequently do not coincide with various utilization practices or with manufactured volumes, they represent a universally recognized standard with which other yields can be compared.

The annual revenue from Crown stumpage charges, by species and product, is also summarized in these reports. The average annual revenue for each of the twelve principal tree species is shown in Table 76. Stumpage charges vary among different species, and within species according to the product and location. Of course, they are much less than market values, but are directly related to them. Hence, the revenue values for each species shown in Table 76 bear roughly the same relationship to one another as do the market values of the annual cut of each species in Ontario.

Table 77 shows the theoretical annual loss of revenue in Crown stumpage charges due to heartwood defects of fungal origin in the twelve major commercial tree species of Ontario. In this table for each species ages were selected that were considered most likely to approximate average harvest ages. For each species the percentage of the total merchantable volume defective at these ages has been ascertained from balanced curves prepared from the final columns in the series "B" tables. These percentages were then converted to percentages representing volumes culled according to the Ontario scaling regulations. A conversion factor of 1.606 for white pine was obtained from the data presented by White (16), and, since red pine has such similar defects and uses, the same factor was applied to both species. For the remaining species, cull volumes for the same samples had been calculated (10), so that conversion factors were easily computed.

For each species, the average annual net volume cut (Table 76) and the percentage of the volume culled at the estimated harvest ages were now available. From these, it was a simple matter to compute the annual gross volume cut, and the annual volume culled due to defect. The latter amounted to approximately 22 million cubic feet, or 6.3 per cent of the former.

The revenue value per thousand cubic feet of timber for each species was derived from Table 76. By multiplying these values by the annual volumes culled, figures were obtained which represent additional revenue that theoretically could have been obtained from each species had these culled volumes been free of defect. This amounted to $880,000 annually for the twelve major species, of which three-fourths was attributable to only three species, namely, yellow birch, black spruce, and white pine.

[a] Text has been reproduced exactly from the earlier report, but tables have been modified slightly for purposes of presentation.

Table 76. The average annual volume cut and revenue from crown stumpage charges for the 12 major commercial tree species of Ontario from 1 April 1958 to 31 March 1961.

Species	Average annual net volume cut[a] (thousand ft^3)	Percentage of total annual net volume cut	Average annual revenue[a] (thousand $)	Percentage of total annual revenue
Black spruce[b]	137,066	41.5	5,137	44.3
Jack pine	74,505	22.6	2,118	18.3
White spruce[b]	41,438	12.5	1,593	13.7
White pine	19,825	6.0	1,121	9.7
Yellow birch	6,845	2.1	514	4.4
Balsam fir	12,935	3.9	284	2.5
Red pine	4,935	1.5	269	2.3
Sugar maple[c]	4,759	1.4	183	1.6
Trembling aspen[d]	18,619	5.6	182	1.6
Hemlock	3,198	1.0	81	0.7
White birch	1,516	0.5	26	0.2
Basswood	384	0.1	22	0.2
Other species and fuelwood	4,262	1.3	57	0.5
Total	330,287	100.0	11,587	100.0

[a] Figures from Annual Reports of the Minister of Lands and Forests of the province of Ontario.
[b] 90% of spruce pulpwood designated black spruce, all other spruce designated white spruce.
[c] Recorded as maple, probably includes some red maple.
[d] Recorded as poplar, probably includes some largetooth aspen and balsam poplar.

Table 77. Theoretical annual loss of revenue in Crown stumpage charges as a result of heartwood defects of fungal origin in the 12 major commercial tree species of Ontario.

Species	Selected felling age (years)[a]	A, Percentage of volume defective at felling age (curved values)	Factor for converting from A to B[b]	B, Percentage of volume culled at felling age	Average annual net volume cut (thousand ft^3)	Estimated annual gross volume cut (thousand ft^3)	Estimated annual volume culled as a result of defect (thousand ft^3)	Revenue value[c] per thousand ft^3 ($)	Theoretical annual revenue lost as a result of defect (thousand $)
Yellow birch	140	35.4	0.845	29.9	6,845	9,765	2,920	75	219
White pine	120	9.8	1.606	15.7	19,825	23,517	3,692	57	210
Black spruce	120	2.9	1.238	3.6	137,066	142,185	5,119	37	189
White spruce	110	3.5	1.300	4.6	41,438	43,436	1,998	38	76
Jack pine	90	2.4	1.270	3.1	74,505	76,889	2,384	28	67
Sugar maple	140	28.5	0.744	21.2	4,759	6,039	1,280	38	49
Balsam fir	80	7.0	1.259	8.8	12,935	14,183	1,248	22	27
Trembling aspen	70	16.4	0.731	12.0	18,619	21,158	2,539	10	25
Hemlock	140	5.5	2.146	11.8	3,198	3,626	428	25	11
Red pine	100	1.0	1.606	1.6	4,935	5,015	80	55	4
Basswood	110	5.0	1.289	6.4	384	410	26	57	2
White birch	80	6.5	0.400	2.6	1,516	1,556	40	17	1
Average	–	–	–	6.3	–	–	–	–	–
Total	–	–	–	–	326,025	347,779	21,754	–	880

[a] Ages chosen to approximate average ages at which the different species were harvested. These should not be interpreted as recommended rotation ages.

[b] For white pine, calculated from White (1953) and assumed to be the same for red pine. For the remaining species, calculated from Morawski et al. (1958).

[c] Calculated from Table 76.