TREMBLING ASPEN QUALITY IN NORTHERN ONTARIO—VARIOUS ASPECTS OF DECAY AND STAIN STUDIES AND THEIR MANAGEMENT IMPLICATIONS

J.T. Basham

Forestry Canada
Ontario Region
Great Lakes Forestry Centre

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ABSTRACT

Trembling aspen (*Populus tremuloides* Michx.) continues to increase in importance in relation to other forest species in Ontario, despite its frequent high incidence of stem decay and stain. These defects can have a serious impact on harvesting efficiency and costs, and on product values. Since the mid-1970s, Forestry Canada and the Ontario Ministry of Natural Resources have conducted several joint investigations of trembling aspen quality in northern Ontario. Without burdening the reader with unnecessary scientific and technical details, this report outlines the principal results of these studies, some hitherto unpublished, with the emphasis on decay and stain aspects. Results from other work carried out by the author on aspen decay in Ontario are included. Subjects covered include stem defects in young aspen, whether aspen originating from cutovers are more defective than their parent stands, insects and decay problems in aspen root systems, the effects of scarifying or spraying young aspen sucker stands (to enhance the establishment of planted conifers) on the quality of the surviving aspen, the effects of scarifying to promote aspen sucker development on the growth and quality of those suckers, stem decay in mature aspen and estimation of its extent, clonal variations in stem defectiveness and growth rate, and the relationship between site and aspen quality. Recommended management procedures to minimize the impact of decay and stain on trembling aspen are presented.

RÉSUMÉ

L'importance du peuplier faux-tremble (*Populus tremuloides* Michx.) par rapport aux autres essences forestières en Ontario ne cesse de croître, malgré la forte incidence de carie de la tige et de taches colorées. Ces défauts peuvent avoir des incidences graves sur le rendement et les coûts de la récolte et sur la valeur du produit. Depuis le milieu des années 70, Forêts Canada et le ministère des Richesses naturelles de l'Ontario ont effectué plusieurs études conjointes sur la qualité du peuplier faux-tremble dans le nord de l'Ontario. Ce rapport, sans accabler le lecteur de détails scientifiques et techniques superflus, expose les grandes lignes des principaux résultats de ces études, dont certaines sont encore inédites, en mettant l'accent sur les problèmes de carie et de coloration. Il présente également les résultats d'autres travaux effectués par l'auteur sur la carie du bois de peuplier faux-tremble en Ontario. Parmi les sujets abordés, mentionnons les défauts des tiges des jeunes peupliers faux-trembles; la fréquence de défauts chez les peupliers faux-trembles provenant de parterres de coupe rase par rapport à ceux des peuplements d'origine; les insectes ravageurs et les caries dont sont victimes les systèmes racinaires des peupliers faux-trembles; les effets du scarifiage ou de l'arrosage des jeunes peuplements constitués de drageons de peupliers faux-trembles (afin de favoriser l'établissement des conifères plantés) sur la qualité des peupliers faux-trembles survivants; les effets du scarifiage destiné à favoriser le développement des drageons racinaires sur la croissance et la qualité de ces drageons; la carie des tiges de peupliers faux-trembles mûrs et l'estimation de l'ampleur du phénomène; les variations observées au niveau des défauts des tiges et du taux de croissance entre les différents clones; et la relation entre la station et la qualité du bois de peuplier faux-tremble. L'auteur recommande également des méthodes d'aménagement destinées à minimiser l'impact des caries et des colorations sur le bois de peuplier faux-tremble.

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INTRODUCTION

In the late 1940s, when I started my career with what is now Forestry Canada, trembling aspen (*Populus tremuloides* Michx.) was largely regarded as a weed species by the forestry community in Ontario. Except for two or three pulp mills that mixed a little aspen with their conifers, trembling aspen was looked upon as a nuisance because of its prolific and vigorous sucker regeneration process, its widespread occurrence on many sites, and its relatively fast growth rate in mixedwood stands. The perceived drawbacks of trembling aspen (hereafter referred to as aspen) were low pulp strength because of its shorter fiber length, problems with machining and drying timber, and a relatively high incidence of stem decay and stain.

Despite this, there was a flurry of activity in the 1950s in investigating aspen decay and stain. In response to a request from one of the pulp mills then utilizing aspen, the Marathon Paper Mills of Canada Ltd., a study (Basham 1958) was started in 1950 on their limits south and east of Caramat, Ontario; 1,754 aspen of commercial size were felled and the stems dissected. In addition, 2,458 aspen of merchantable size were examined between 1952 and 1955 throughout the forest regions of Ontario as part of the federal–provincial "cull survey" of decay and stain in most of the commercially important species in the province (Basham and Morawski 1964).

Despite the construction of several veneer mills in the 1960s to satisfy the demand for aspen plywood in the construction industry, aspen was still greatly underutilized, largely because of the reluctance of pulp mills to use it. However, Ontario's pulp industry realized that their traditional reliance on conifers would very likely have to be reduced in the future because of the depletion of accessible mature coniferous stands, and because the rate of coniferous regeneration appeared inadequate to meet the demand for fiber. Ontario's forestry community began to look at the long underutilized but ubiquitous aspen as one possible long-term solution to perceived threats of losing the industry's position as a major supplier of wood fiber and of having a much less viable forest industry in many parts of northern Ontario.

Developments over the past two decades or so have led to a substantial increase in the utilization of aspen. Because of their low cost and abundant supply, small-diameter aspen logs are being used in increasing amounts in the production of waferboard for many construction uses. There is increasing market acceptance of short-fiber pulps, and recently developed techniques favor the use of aspen in chemimechanical pulp. According to Jackson et al. (1985), chemithermomechanical pulp from aspen is "... comparable in optical properties and in most strength properties to [thermomechanical pulp] produced from softwood chips to an equivalent level of drainage". However, they pointed out that decayed aspen wood results in "pulps of inferior strengths and poor brightness", and that "these deficiencies cannot be compensated for in a subsequent bleaching process". Hunt et al. (1978) have shown that kraft pulp from decayed aspen wood had a substantially lower yield and reduced strength (particularly tear factor) compared with pulp made from sound aspen wood.

From the late 1950s to the early 1970s, the Ontario forest pathology unit of Forestry Canada carried out no research on aspen decays and stains. In 1973 we received a request for assistance from the Ontario Ministry of Natural Resources (OMNR) and the successor to the Marathon Paper Company, American Can of Canada. They had begun a study of aspen quality on the company's limits north of Manitouwadge. The request was to assist them by studying the development of stain and decay in the aspen sucker stands that had originated from widespread aspen harvesting carried out since 1945. This led to a series of cooperative studies on aspen quality from 1974 until my retirement as a full-time Forestry Canada employee in 1988.

Although the situation has been improving over the past decade, there is still a scarcity of published information and a shortage of experience dealing with the management and ecology of aspen in the boreal forest of central-eastern Canada. Because the utilization of aspen will very likely increase in the future, this situation must be rectified as soon as possible. Thus, I believe that all those who have hitherto unpublished information on aspen, whether it be the results of research or of careful and repeated observations, should make that information available to potential users with as little delay as possible.

This report ties together many loose ends connected with the variety of aspen quality studies I have carried out since 1974, many in cooperation with OMNR and American Can personnel. I have attempted to include all pertinent hitherto unpublished results, or to present previously published data in a form that is less technical and hopefully more meaningful to the potential user. Some new conclusions and management recommendations are included, made possible by recent data analyses, additional data collected on studies already reported, and by reviewing the results of two or more studies and analyzing their interrelationships.

Much of the data upon which the results presented in this report are based were collected in the region north of Manitouwadge and southeast of Caramat, in north-central Ontario. Readers should bear in mind that although the results should apply to most regions of the boreal forest in Ontario, different results could occur in aspen or mixedwood stands in other regions of the province and elsewhere in North America. The optimum growth of aspen occurs north of the "height of land" in Ontario (Maini 1972) and the Caramat–Manitouwadge areas are close to this

region. Further south, the potential longevity of aspen clones is reduced, early growth rates are faster but stand deterioration generally begins at a younger age (Shields and Bockheim 1981). Thus, for aspen in regions such as Thunder Bay, Sudbury or Ottawa, results should be modified to take this into account.

Some sections of this report, in particular that dealing with the extent of stem decay and stain associated with several aspen clones and individual trees within those clones, are somewhat lengthy and detailed; for this reason, perhaps they will be less meaningful for many readers. They are included in this form so that the information they contain will be available to those readers who may find the detailed results interesting and useful. Readers less interested in technical details may wish to turn forthwith to the final section, which summarizes all topics, and thereafter read those sections of the report that reflect their particular interests.

DEVELOPMENT OF STAIN AND DECAY IN YOUNG ASPEN STEMS

Many of the studies in this report deal with defect in the stems and root systems of young, immature aspen stands. When the defectiveness of aspen stands originating from cutovers as opposed to fire were compared in the early 1970s, the oldest stands of cutover origin available for study in northern Ontario were barely more than 25 years old. To examine the effects of scarification and herbicide spraying on surviving aspen, studies were initiated in even younger stands because these treatments are usually carried out in sucker stands less than 10 years old. To assist in the interpretation of the results from these and other studies, it is helpful to know the usual pattern of development of stain and decay in very young aspen stands undisturbed by human activities.

Most tree species have acceptable levels of stem stain and decay when they first reach commercial size. As trees grow older, age is usually the single factor most closely related to the extent of internal defect. Besides becoming less vigorous as they age, the chances increase that trees will sustain severe stem wounds, dead tops, or large branch stubs, the principal entry points for stem decay and stain in most species (Basham 1991). At maturity, aspen is one of the most decadent tree species in Ontario's forests (Basham and Morawski 1964). Until the 1970s, little was known concerning stain and decay in the stems of young aspen of less than commercial size.

Table 1 shows the average extent of stain and decay in the stems of aspen ranging in age from 3 to 107 years. The trees represented in this table were not subjected to any treatment such as scarification or herbicide spraying, although some served as controls in studies on the effects of those treatments. They were, for the most part, undisturbed by human activities, and were sampled during studies that I was involved in.

Decay can be defined as wood that is noticeably softer and weaker than clear, sound wood. The data in Table 1 indicate that stem decay was of negligible importance in aspen under 50 years of age. However, when stain is considered as well as decay, defective wood accounted for between 6.5 and 10% of the total stem volume in young suckers up to 13 years old. As tree growth accelerated, this

Table 1. Changes in average stem volume and defectiveness with increasing age in undisturbed aspen. (Data from several different studies carried out over many years in the Boreal Forest Region of Ontario. Dominant or codominant trees only.)

Avg. tree age	Data from table no.[a]	Number of trees	Average tree dimensions: Height (m)	DBH (cm)	Volume (dm^3)	Average % of total stem volume: with decay[b]	defective (decay plus stain)
3	–	15	2.4	1.5	0.5	trace	6.6
5	10	51	2.9	1.8	0.8	0.4	7.7
7	4, 5	20	3.9	2.8	2	trace	6.4
9	4, 5	10	4.6	4.1	3.5	0.1	9.8
13	4, 5	20	5.9	6.7	11	1.8	7.6
14	11, 12	20	6.6	5.0	6	trace	5.4
17	11, 12	20	8.3	6.9	15	0.2	4.4
18	4, 5	20	8.8	9.5	35	1.6	4.9
27	9	15	12.0	11.9	61	0.7	6.6
30	19	120	13.1	13.5	89	1.1	12.7
37	2	35	14.9	13.2	101	2.6	7.7
39	2	278	15.3	13.7	107	0.7	9.2
48	2	131	–[c]	–[c]	216	1.0	13.6
50	2	600	18.3	16.0	191	5.8	12.2
65	21	90	26.7	25.9	630	3.4	19.9
70	2	637	21.0	20.8	355	8.5	17.0
71	2	271	–[c]	–[c]	417	2.7	17.4
106	22	90	24.1	30.0	710	11.4	31.1

[a] More detailed information is provided in this report in the indicated tables.
[b] Recorded as trace if amount is <0.05%
[c] Data not available

proportion fell to between 4.5 and 5.5%; in trees aged from 27 to 50 years, between 6.5 and 13.5% of the stem volume was defective. Aspen from 65 to 71 years of age had between 17 and 20% of stem volume defective, and beyond this age the percentage increased steadily for the reasons presented earlier.

The 3-year-old aspen in Table 1 were sampled in connection with a cooperative OMNR–Forestry Canada study on the effects of scarifying 1-year-old aspen on potential tree quality. The 75 sample trees were obtained from an unscarified area of the stand that served as a control. In addition to the surprisingly high average proportion (6.6%) of their stem volume in the form of stain, all 15 stems contained some stain (14 of the 15 aspen sampled at age 2 were stained, and six of the 15 aspen sampled at age 1 were stained). The 51 aspen sampled at age 5 had some stained wood in the stems of all but one tree (Table 1). Clearly, stain develops quite early in the stems of young aspen suckers, and in almost all individuals.

A study of 591 aspen suckers in Colorado, ranging in age from 1 to 19, revealed that internal stem stain resulted from bark damage of any kind (Hinds and Shepperd 1987). Only 11 of these suckers, all 2 to 4 years old, were free of external damage and internal defect. In studying the first 7 years of development of aspen sucker stands in Minnesota, Perala (1984) found a high incidence of insect- and disease-induced injury, which he concluded was normal in aspen sucker stands. In another study of young aspen, Millers (1972) found that almost all young suckers he examined had at least one stem injury. The most common type of aspen sucker damage in Colorado was reported to be due to leaf and shoot diseases (Hinds andShepperd 1987); nine other forms of stem damage were observed. In our Ontario studies, more than 98% of the aspen suckers examined before age 10 had some evidence of external injury. The most common type of damage was shoot blight caused by the fungus *Venturia macularis* (Fr.:Fr.) E. Müller & v. Arx, which infects and kills the longer shoots, particularly the leader. Aspen sucker stands throughout much of the Boreal Forest of Ontario appear to be susceptible to shoot blight, and in years when it is severe, stands with almost 100% leader infection are common (Gross and Basham 1981). Few aspen sucker stands escape at least one shoot blight outbreak, and by age 7, many sucker stems in Minnesota had two crooks caused by separate shoot blight infections. In northern Ontario, leaders of young aspen suckers are also frequently killed or severely injured by June frosts, animal browsing, and a variety of insects. The chances of an aspen sucker not sustaining a dead leader during the first 10 or so years of its existence are clearly very poor.

Some stained wood develops in association with all but the smallest aspen sucker injuries that involve the exposure of stem xylem. In the case of killed leaders or branches, stain can spread downwards a metre or more into the stem. In our attempts to isolate microorganisms from stained wood in undisturbed aspen suckers younger than 10 years, 86% of such attempts were sterile, indicating that most of the stained wood in these young trees is probably of physiological rather than fungal origin. After their initial establishment, which is usually quite rapid, physiological stains generally spread very little if at all, unlike some stains of fungal origin. Stain originating from killed leaders spreads downwards and seldom spreads radially into wood formed following the injury.

Most stain in young aspen sucker stems results from dead leaders or branches caused by shoot blight or insects. Perala (1984) found that most shoot blight damage occurred when suckers were about 2.5 m high and 4 or 5 years old. In Ontario, it has been observed that suckers taller than 3 or 4 m have some resistance to shoot blight infection, and those above 7 m are rarely affected (Gross and Basham 1981). Many insects that affect leaders and branch tips only attack relatively young aspen; tent caterpillars are a major exception. Most potential crop-tree suckers attain a height of at least 8 m by age 10 to 12. At that point, the rate of increase in stain volume is therefore considerably reduced. Meanwhile, total stem volume increment begins to increase dramatically. The annual addition of considerably more sound wood than stain wood volume accounts for the decrease in the percentage of the total stem volume affected by stain and decay during the decade or so after age 12. Eventually, as aspen reaches 25 or 30 years of age, many more potential entry points for stain or decay (branch stubs, cankers, felling wounds, etc.) will develop; this has the potential of causing substantial increases in the percentage of defective stem volume.

STEM QUALITY IN ASPEN ORIGINATING NATURALLY AND AFTER HARVESTING

Decay and stain in the stems of mature aspen are much more extensive than in most other commercial species in Ontario, and are one reason why this species has been underutilized. Until recently, clearcutting pure or predominantly aspen stands has been the most common harvesting method. Since aspen reproduces vegetatively by producing root suckers, the aspen stands that develop should have similar genetic compositions to the aspen in the original harvested stands. Thus, at comparable ages one could reasonably expect the same extent of decay and stain in the second-growth stand as in the parent stand. However, the conditions under which the parent stands developed initially, presumably following fires in most cases, were quite different ecologically from post-harvest conditions. Considering our natural inclination to fear the worst from the unknown, it is not surprising that when post-harvest aspen sucker stands became widespread in northern Ontario, there was considerable apprehension that they would

develop into mature stands even more decadent than their parent stands.

This question was first addressed by Smith (1973), who examined aspen sucker stands in northern Ontario that had originated from cutovers 5, 10, 15 and 20 years earlier. His conclusion that there was a quality problem in aspen suckers of cutover origin was based on the fact that, for all age classes, an average of between 5 and 7% of the total stem volume was in the form of stain or decay (mostly stain); Smith believed this was much higher than normal. He expressed concern that 100% of the 15- and 20-year-old stems contained some stain, as he was uncertain as to whether the stains were of fungal or of physiological origin. It is of interest to note that the highest percentage of stem volume in the form of stain or decay was in the 10-year-old sucker stands. This conforms closely to my data on stands of cutover origin at similar ages (Table 1).

Smith's study was completed by his successor, with Forestry Canada providing identification of microorganisms isolated from stains and decays (Basham and Navratil 1975). Aspen suckers that had originated from cutovers 25 years earlier were added to the sample. As would be expected from the information in the preceding section, these 25-year-old suckers had a smaller percentage of stem volume in the form of stain and decay than the 5- to 20-year-old suckers.

The two surveys of aspen stem decay in mature stands carried out in the 1950s, mentioned in the **Introduction**, were limited to stands of natural (probably fire) origin. Since maximum tree sampling sizes of 9 and 12.8 cm (3.5 and 5 in.) DBH were used in those studies, relatively few of the 4,000 or so aspen were under 50 years of age. Nevertheless, the youngest tree sampled was 33, so that when aspen stands of cutover origin almost 40 years old were available for sampling by the mid 1980s, the first direct comparison of the extent of decay and stain in aspen of cutover and natural (probably fire) origin at similar ages in the Boreal Forest of Ontario could then be made. Table 2 and Figure 1 show the extent of stem decay and stain in fire-origin aspen in the 21–40, 41–60 and 61–80 year age classes from the two studies of the 1950s, and in aspen from 37 to 40 years old sampled in 1986 in two stands of cutover origin. A third aspen stand of cutover origin that was assessed for the extent of stem defect in 1976 in a study of clonal variability, discussed in a later section of this report, was some years older than the two used in this comparison. However, it was not used for this purpose mainly because its location in the Fort Frances area was significantly warmer and drier than was the case in most Boreal Forest regions, and the stand was clearly growing more rapidly and was already showing signs of deterioration. It was obviously not representative of aspen stands growing under conditions typical of Ontario's Boreal Forest. Furthermore, there was some confusion as to the age of the stand; OMNR records indicated that it originated from a harvest operation carried out in the mid-1930s, but dating of sample discs suggested most sucker growth began around 1944.

Table 2 and Figure 1 do not reveal any pronounced differences in the extent of stem stain and decay in aspen of cutover or of fire origin in trees roughly 40 years old. The most direct comparison possible is between the 278 aspen

Table 2. Comparison of the extent of stem decay and stain (defect) in aspen stands of natural (probably fire) and cutover origins in northern Ontario.

Study[a]	Origin of stands sampled	Age class or range	Number of trees sampled[b]	Avg. tree age (years)	Average total stem volume (dm^3)	Average volume of stem decayed and stained (dm^3)	Average % of total stem volume		
							Decayed	Stained	Defective
A	Natural	21–40	35	37	100.6	7.74	2.6	5.1	7.7
		41–60	600	50	190.6	23.23	5.8	6.4	12.2
		61–80	637	70	355.4	60.39	8.5	8.5	17.0
B	Natural	41–60	131	48	216.3	29.50	1.0	12.6	13.6
		61–80	271	71	416.8	71.43	2.7	14.7	17.4
C	Cutover	37–40	278	39	107.3	9.87	0.7	8.5	9.2

[a] A: Federal–provincial survey of stem decay in Ontario during the 1950s, summary of Boreal Forest aspen data. B: Decay study of aspen in the Caramat–Stevens–Manitouwadge region of Ontario, early 1950s. C: Decay study in two aspen stands approximately 25 and 35 km north of Manitouwadge, Ontario, 1986.

[b] Study A sampled all aspen ≥9 cm DBH on square 0.04-ha (0.1-acre) plots. Study B sampled all aspen ≥12.8 cm DBH on plots ranging in size from 0.04 to 0.2 ha (0.1 to 0.5 acres). Study C sampled individual dominant or codominant aspen nearest to preselected points on line plots; the smallest DBH was 9.7 cm.

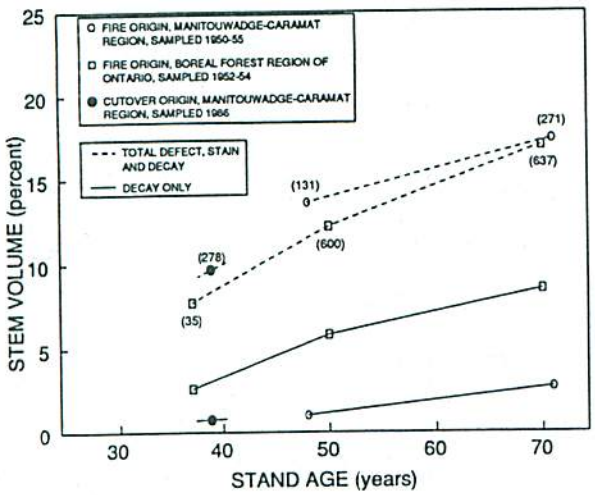

Figure 1. Comparison of the extent of decay, and of decay plus stain, in the stems of aspen of natural (fire) and cutover origin. Numbers in parentheses represent the numbers of trees sampled.

of cutover origin between 37 and 40 years of age and the 35 aspen of fire origin that ranged in age from 33 to 40. Both samples were obtained from the same general region of north-central Ontario. The average proportions of total stem volume affected by stain or decay were 7.7% in the fire-origin trees and 9.2% in the trees of cutover origin. This indicates that the aspen of cutover origin were somewhat more defective than the trees of fire origin. However, Table 2 shows that whereas 2.6% of the stem volume of the fire-origin trees was decayed (more than one-third of the defect), only 0.7% of the stem volume of the aspen of cutover origin was decayed. Decay is a far more serious and economically important defect than stain; stained aspen can be utilized with little loss in yield or value for most products other than chemical pulps, whereas severe losses are usually associated with the use of decayed aspen wood.

In summary, we can conclude that there is no evidence that mature aspen of cutover origin will be noticeably more or less decadent than their parent stands of natural (mostly fire) origin. Although they examined aspen of cutover origin no older than 19 years in Colorado, Hinds and Shepperd (1987) concluded that decay in such stands would probably not exceed the level encountered in stands of natural origin at similar ages.

CHARACTERISTICS AND PESTS OF YOUNG ASPEN ROOT SYSTEMS

Aspen sucker root systems consist of four basic parts. The root collar is the belowground portion of the sucker that adjoins the stem, in which individual roots are indistinguishable. The parent root from which the sucker sprouted can be regarded as two roots attached at roughly 90° angles to the collar–stem axis. The parent root on the far side of the parent stump, called the distal parent root, increases noticeably in diameter after sucker formation, and as a rule is considerably larger than the parent root closest to the parent stump, the proximal parent root, which changes little in size. The fourth part of the root system, adventitious roots, represents new roots formed after the sucker stem is established. Eventually, these will support and nourish the sucker. They differ from the parent roots in that they are usually attached to the collar–stem axis at 110° to 125° angles.

Most suckers originate from the long lateral aspen roots that generally undulate along the upper 40 cm of the soil. Suckering usually occurs at those portions of the roots within 12 cm of the surface, and the distal parent root begins a relatively rapid increase in diameter. The sucker stem relies on this root for water and nutrients for the first few years of its life. The distal parent roots are in a relatively succulent, tender state for that reason, and their expansion in diameter usually brings them closer to the soil surface, making them more vulnerable to injury by scarification or the passage of other machinery. Such injuries can have a serious effect on sucker growth and development.

In our studies of the root systems of aspen suckers and of young aspen, we frequently found that the wood was extensively stained or decayed, far more so than the stem wood. Only dominant or codominant aspen were sampled in all of these studies; in other words, we only assessed individuals that appeared to have the potential to eventually develop into crop trees. At age 5, the youngest aspen root systems we examined, some stained wood was detected in every root system and some decay was present in roughly 40%; by age 12 the proportion of partially decayed root systems had risen to 85%, and had reached 100% at age 27. Several decay-causing fungi were isolated from these decays, but the most prevalent by far was identified as *Armillaria mellea* (now believed to be mostly *A. ostoyae* [Romagn.] Herink and *A. sinapina* sp. nov. [Dumas 1988, Bérubé and Dessureault 1988]). Species of *Armillaria* have been known for some time to cause considerable root and butt decay in several trees species in Ontario, including aspen. Recently, primarily because of the studies we carried out on young aspen in Ontario and some work in Wisconsin (Stanosz and Patton 1987), we have become aware of just how widespread and extensive *Armillaria* decay is in the root systems of young, healthy looking dominant and codominant aspen suckers. Armillaria decay is frequently extensive in the root collars of young aspen, but extends little if at all above ground level (Fig. 2a,b). Thus, it may appear to be of negligible importance when only the merchantable stems are considered, but there is little doubt that it causes other losses in the form of reduced increment, increased windfall and breakage, and even some mortality.

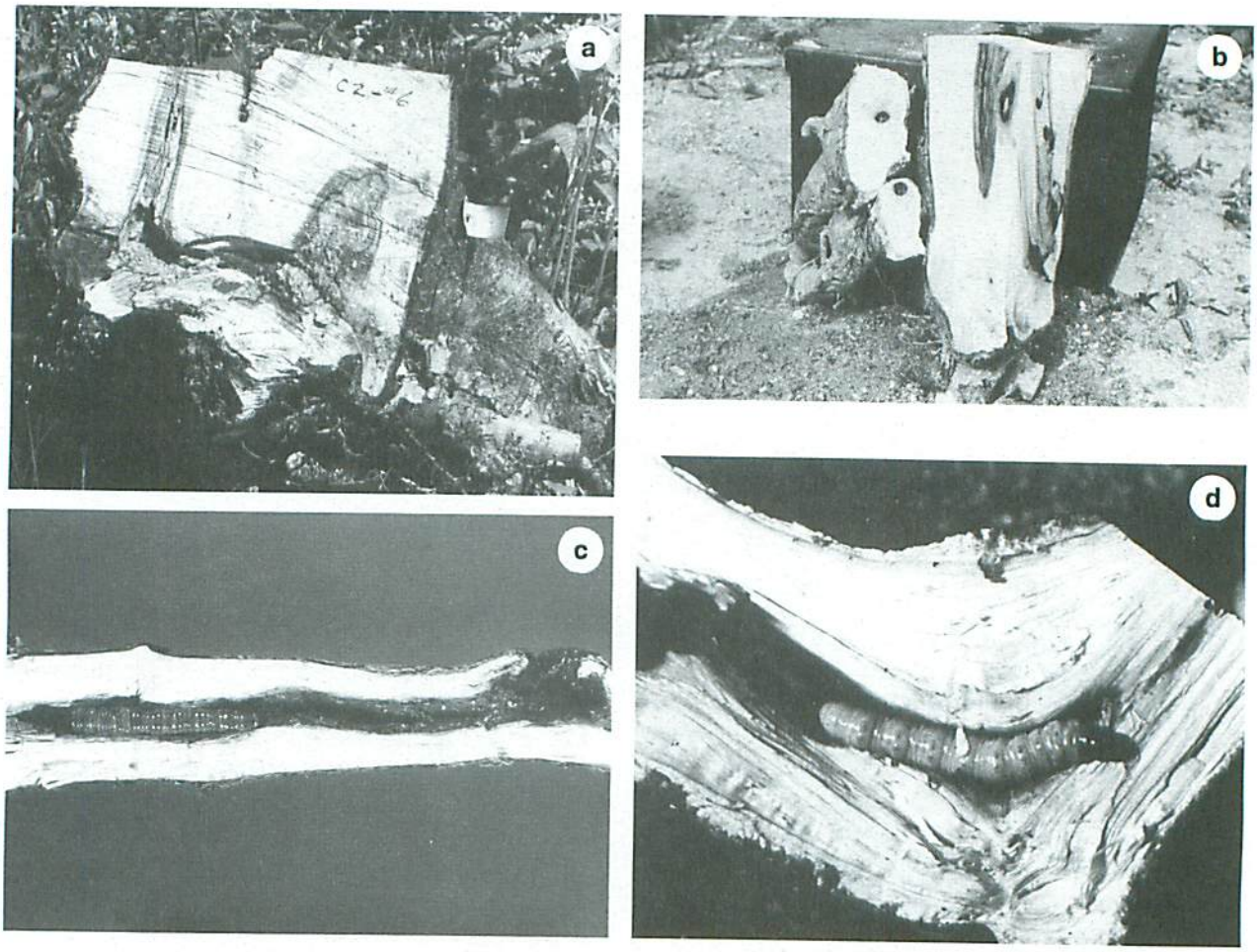

Figure 2. Root problems in young aspen. (a) Root collars of 28-year-old aspen with decay caused by Armillaria *sp. Both stems were sound at a stump height of 15 cm. (b) Roots and root collar of 40-year-old aspen with* Armillaria *decay and tunnels caused by larvae of the ghost moth,* Sthenopis quadriguttatus. *(c)* Sthenopis *larva and tunnel in young aspen root, showing ventilation hole at right (photograph one-half life size). (d)* Sthenopis *larva and tunnel in parent root and root collar of a 14-year-old dominant aspen that survived herbicide spray damage (photograph two-thirds life size).*

In undisturbed 3-, 9- and 15-year-old aspen sucker stands in Wisconsin, Stanosz and Patton (1987) examined the root systems of dominant and codominant suckers. They reported the incidence of *Armillaria* decay at 24, 44 and 72%, respectively. In this study, most root-system invasions by *Armillaria* were by rhizomorph penetration from parent stumps via the parent roots, and by contact with colonized roots. In our studies of suckers damaged by scarification machinery, root-system wounds apparently caused by the machinery appeared to be the most common source of *Armillaria* decay (and of decay caused by five other fungi) (Basham 1988). Nevertheless, in our study of aspen suckers that survived herbicide spraying, *Armillaria* decay was almost as extensive in the root systems as it was in those of scarified trees (Basham 1982a). In these studies we did not give the determination of the exact mode of entry of *Armillaria* and other decay fungi as high a priority as did Stanosz and Patton (1987). However, *Armillaria* rhizomorphs were observed and recorded on the roots of almost all suckers examined. Direct infection of healthy, unwounded roots via *Armillaria* rhizomorphs undoubtedly occurred, either by rhizomorphs moving freely through the soil or by contact with infected roots. In untreated "control" suckers, most *Armillaria* infections appeared to be associated with root abnormalities such as stone abrasions, the bases of dead "companion" suckers, and lesions of uncertain origin (many were possibly rhizomorph infection courts). It is of interest that the root systems of the unsprayed suckers were slightly more defective than those of spray-damaged suckers (Basham 1982b).

When we began excavating and dissecting the root systems of young aspen suckers in 1976, we rather expected to find extensive stain and decay. However, we were surprised by the frequent occurrence of long (8- to 11-mm-

diameter) tunnels, obviously bored by insect larvae. Living larvae were found in some root systems; these were identified as larvae of the moth *Sthenopis quadriguttatus* (Grt.), commonly called the ghost moth (Fig. 2b,c,d). A few years later, Vallée and Béique (1979) reported the occurrence of this borer in the root systems of 130 of 538 trees (24%) examined in a poplar plantation near Matane, Quebec. Of the 12 poplar species and hybrids sampled, none showed resistance to the insect. Adult ghost moths have been collected throughout most of Quebec where poplars grow. In 1981, the Forest Insect and Disease Survey (FIDS) of Forestry Canada's Ontario Region reported that *S. quadriguttatus* was present throughout northern Ontario based on light-trap captures of adults and on root-boring activity in young (<10 years of age) aspen stands (Gross and Syme 1981).

Table 3 shows the frequency of occurrence of ghost moth larval tunnels in the root systems of 640 aspen in Ontario ranging from 7 to roughly 40 years of age. This represents all aspen root systems that we examined in our studies of aspen quality. A surprisingly high proportion (58%) of the root systems contained one or more larval tunnels. The last column of Table 3 reveals that these percentages increased with increasing stand age, ranging from 30% of the aspen sampled at ages 7 to 9 to 75% at ages 17 and 29. Trees that had survived scarification or herbicide spray damage comprised 70% of the sample. However, the 190 undamaged control trees had a slightly higher frequency of occurrence of larval tunnels (61%) than the 450 treated aspen (57%). Casual samplings of the root systems of intermediate and suppressed trees revealed no distinguishable differences in larval tunnel occurrence than in dominant or codominant trees. These results suggest that there is little relationship between the occurrence of larval tunnels in root systems and stem development and vigor.

All root system parts contained tunnels, but distal parent roots were the most frequently invaded tissue (Table 3). Tunnels in roots and root collars, and a ghost moth larva occupying a tunnel, are shown in Figure 2. The tunnels were generally found in the central wood of the roots and root collars, and seldom extended above ground level. Ventilation (access) holes to the outside of roots or root collars, through which frass and bore dust are expelled, can serve as entry points for root-staining and root-decaying fungi (Basham 1988). However, in most cases the larval tunnels were surrounded only by a narrow band of stained wood in which decay and decay-causing fungi were seldom found. There is little evidence from these studies that root-boring ghost moth larvae have a serious impact on tree growth rate or wood quality.

Table 3. The occurrence of ghost moth larval tunnels in the root systems of young dominant and codominant aspen in northern Ontario. (All aspen sampled were dominant or codominant trees of sucker origin following cutovers. All were located north of Manitouwadge in north-central Ontario with the exception of the 40-year-old stand, which was located about 50 km from Fort Frances in northwestern Ontario.)

				Number of aspen with larval tunnels in				Suckers with larval tunnels somewhere in root system	
Study	Treatment	Age of aspen	Number of root systems	Root collar	Distal parent root	Proximal parent root	Adventitious sucker roots	No.	%
Effects of scarification	None (controls)	7–9	30	2	4	4	3	9	30.0
	Scarification	7–9	120	15	34	19	15	57	47.5
	None (controls)	13–18	30	14	15	6	21	24	80.0
	Scarification	13–18	90	26	39	20	43	64	71.1
Effects of herbicide spraying	Sprayed	12–14	160	40	46	13	31	86	53.8
	None (controls)	14	20	3	4	1	5	8	40.0
	Sprayed	17	80	23	26	17	20	48	60.0
	None (controls)	17	20	12	10	7	5	15	75.0
Clonal variations	None	27[a]	40	5	9	7	12	23	57.5
	None	29[a]	40	9	14	9	16	30	75.0
	None	40 (?)	10	6	4[b]	2[b]	3	7	70.0
All (total)		7–40 (?)	640	155	205	105	174	371	58.0

[a] The two 40-tree samples of roughly the same age were obtained from stands on different sites 10 km apart.

[b] In the 40-year-old root systems it was difficult to identify parent roots with certainty, and these designations should be described as probable.

EFFECTS OF SCARIFYING ASPEN SUCKERS TO PROMOTE THE DEVELOPMENT OF CONIFERS ON THE QUALITY OF SURVIVING ASPEN

Young aspen sucker stands are sometimes scarified with the objective of improving conditions for the establishment and growth of subsequently planted conifers. Besides reducing the amount of brush and exposing mineral soil, another goal is to kill the suckers or at least slow down their growth and development. However, as a rule, relatively few aspen suckers are killed and the survivors appear to resume normal growth rates after an initial setback. The heavy machinery required for scarification can inflict both stem and root wounds on the surviving suckers (Basham 1982b). In many species of trees such wounds are frequently associated with the initiation and development of internal decay and stain. Because many of the surviving suckers will ultimately reach merchantable size, it is important to know what effects, if any, the scarification treatments are likely to have on the subsequent growth rate and quality of the aspen.

All of the following studies on this subject were designed, and experimental areas selected, by the Northern Forest Research Unit (NFRU, Thunder Bay) of OMNR. Forestry Canada collaborated with NFRU on most of these studies, concentrating primarily on pathological aspects such as the development of stain and decay and the causal microorganisms, and how the extent of decay and stain could be minimized. Studies were carried out in areas and stands selected by OMNR, and the field work was carried out cooperatively, at least in the initial stages of each study.

Scarification at or near the end of the third growing season

The first of our scarification studies was initiated in late August of 1976 about 12 km north of Manitouwadge, in a 7-year-old aspen stand that had originated from a cutover. The stand had been scarified at age 3 in the fall of 1972 to improve conditions for the subsequently planted spruce (*Picea* sp.). It was clear in 1976 that the scarified aspen were thriving and would very likely attain merchantable size eventually, despite visible scarification stem wounds on roughly 75% of the larger suckers. Our objective was to assess the impact of the treatment on the future quality of the aspen.

The initial assessment in 1976 was carried out cooperatively by OMNR and Forestry Canada, 4 years after the stand was scarified. Further assessments were carried out independently by Forestry Canada in 1978, 1982 and 1987 (6, 10 and 15 years after the treatment). Published results are available for the first two assessments (Basham 1982b), and the first three assessments (Basham 1988). Results of the fourth assessment (in 1987) are presented here for the first time. The methodology used in this study was described in the above two publications and will not be repeated here, except to emphasize that control trees were usually obtained within the scarified stand in fairly large pockets obviously missed by the scarification machinery; sampling was also limited to dominant and codominant suckers that appeared to have the greatest potential to eventually become crop trees, regardless of the presence or absence of stem wounds. Some of the data from the earlier reports on this study are repeated here in tabular or graphic form, but those reports should be referred to by anyone interested in the complete picture.

Table 4 and Figure 3 show the average stem size of the sampled scarified and unscarified aspen at the four periods of assessment. The average stem volume of the scarified trees was roughly 50% of that of the control trees at the first three assessments, and 60% of the control trees at the final 1987 assessment. The average height, DBH and stem volume of the scarified suckers were all very significantly ($P < 0.01$) less than those of the unscarified suckers (Basham 1988). Ten years after scarification the rate of height growth of the dominant scarified suckers had caught up with that of the unscarified suckers (Table 4); however, DBH growth rate took approximately 15 years before it equaled that of the controls.

It was pointed out earlier that Smith (1973) found that between 5 and 7% of the total stem volumes of 5-, 10-, 15- and 20-year-old aspen suckers in northern Ontario were stained or decayed (mostly stained). Table 5 shows that the control suckers had similar levels of defect. At 4 and 6 years

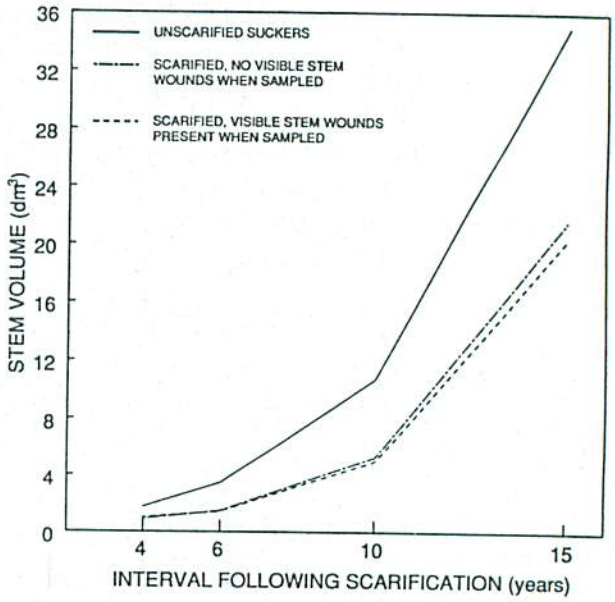

Figure 3. Average stem volume of unscarified aspen suckers, and of scarified suckers with and without visible stem wounds, at four intervals after most of the stand was scarified when the suckers were 3 years old.

after scarification, treated suckers had approximately 25% of their stem volume defective, not only because the stems were smaller than the unscarified stems but also because they contained, on average, a greater volume of stained and decayed wood (Table 6). At 10 and 15 years after scarification, the proportion of the stem volumes of scarified suckers affected by stain and decay decreased to about 17 and 12%, respectively (Table 5). That this decrease was due primarily to an acceleration in sucker growth rate at these ages is evident from the fact that the average actual volume of stained and decayed stem wood in these trees was still increasing (Table 6). In fact, the average volume of defect (stain plus decay) per scarified stem almost tripled in the 5 years between the last two samplings (1982 and 1987).

Table 6 shows that there was very little difference in the volume of stem stain and decay between unscarified suckers and scarified suckers that bore no visible stem wounds at all four samplings. The latter had far greater percentages of stem volume defective (Table 5) solely because their stems were smaller. Sucker stems bearing visible scarification wounds were the most defective, particularly in terms of the amount of advanced decay (Table 5). Grouping the wounded suckers by wound severity classes (Table 6) revealed that the total volume of stem decay and stain progressively increased with increasing numbers and severity of stem wounds at each of the four sampling periods. This is not surprising, since stem scarification wounds, particularly the larger ones, were frequently associated with above-normal amounts of stem stain and with stem decay (Fig. 4a,b,d).

Table 4. Average size of scarified and unscarified aspen sucker stems at four intervals after scarification at age 3. (All aspen suckers were in the dominant or codominant crown class when sampled.)

Years after scarification	Age of suckers	Treatment	Visible scarification wounds	Number of suckers	Average stem Height (m)	DBH (cm)	Volume (dm^3)
4	7	unscarified	n/a	20	3.9	2.8	1.74
		scarified	absent	9	3.0	2.1	0.92
		scarified	present	51	3.0	2.0	0.98
6	9	unscarified	n/a	10	4.6	4.1	3.46
		scarified	absent	19	3.7	2.8	1.47
		scarified	present	41	3.5	2.7	1.43
10	13	unscarified	n/a	20	5.9	6.7	10.74
		scarified	absent	12	5.1	4.9	5.28
		scarified	present	48	5.0	4.6	4.97
15	18	unscarified	n/a	20	8.8	9.5	35.00
		scarified	absent	14	7.9	7.6	21.62
		scarified	present	46	7.7	7.4	20.39

Table 5. Average percentage of stem volume affected by decay and stain in the stems of scarified and unscarified aspen suckers at four intervals after scarification at age 3.

Years after treatment	Age of suckers	Treatment	Visible scarification wounds	Number of suckers	Average % of inside-bark stem volume represented by Advanced decay	Advanced plus incipient decay	All decay plus stain
4	7	unscarified	n/a	20	–	trace[a]	6.4
		scarified	absent	9	–	0.1	17.4
		scarified	present	51	0.7	5.1	28.6
6	9	unscarified	n/a	10	–	0.1	8.8
		scarified	absent	19	–	0.1	14.3
		scarified	present	41	1.6	3.4	27.1
10	13	unscarified	n/a	20	0.2	1.6	7.4
		scarified	absent	12	0.5	2.0	13.1
		scarified	present	48	3.0	4.5	18.6
15	18	unscarified	n/a	20	0.2	1.4	4.9
		scarified	absent	14	0.4	1.3	8.9
		scarified	present	46	2.0	3.1	13.4

[a] Recorded as trace if present but <0.05%.

Table 6. Average extent of decay and stain in the stems of scarified and unscarified aspen suckers at four intervals after treatment, with suckers grouped according to the presence and severity of scarification wounds.

Years since treatment	Age of suckers	Treatment	Severity of stem scarification wounds[a]	Number of suckers	Average % of stem volume affected by decay and stain	Average volume per stem (dm^3)[b]			
						Advanced decay	Incipient decay	Stain	Total decay plus stain
4	7	unscarified	n/a	20	6.4	–	0.01	0.10	0.11
		scarified	1	9	17.4	–	0.01	0.15	0.16
		scarified	2	22	24.6	trace	0.01	0.21	0.22
		scarified	3	14	30.5	0.01	0.08	0.23	0.32
		scarified	4	15	33.9	0.02	0.05	0.26	0.33
6	9	unscarified	n/a	10	9.8	–	0.01	0.23	0.24
		scarified	1	19	14.3	–	0.01	0.20	0.21
		scarified	2	16	20.3	trace	0.02	0.27	0.29
		scarified	3	12	22.3	0.02	0.02	0.30	0.34
		scarified	4	13	33.4	0.05	0.04	0.31	0.40
10	13	unscarified	n/a	20	7.6	0.02	0.15	0.55	0.72
		scarified	1	12	13.1	0.03	0.08	0.58	0.69
		scarified	2	17	17.0	0.06	0.10	0.59	0.75
		scarified	3	17	17.4	0.12	0.08	0.73	0.93
		scarified	4	14	20.1	0.26	0.11	0.59	0.96
15	18	unscarified	n/a	20	4.9	0.07	0.43	1.20	1.70
		scarified	1	14	8.9	0.08	0.19	1.65	1.92
		scarified	2	15	9.6	0.12	0.16	2.06	2.34
		scarified	3	16	9.0	0.20	0.27	1.84	2.31
		scarified	4	15	11.3	0.58	0.23	1.78	2.59

[a] Wound classes: 1 = no visible stem scarification wounds; 2 = all scarification wounds completely healed over, callused, at year 15, such wounds occurring on no more than 30 cm of stem length; 3 = one or more open wounds at years 4, 6 and 10 (maximum horizontal distance between wound calluses of 10, 6 and 3 mm, respectively), at year 15, all stem scarification wounds callused over, but occurring on more than 30 cm of stem length; 4 = one or more open wounds, in years 4, 6 and 10, horizontal distances between wound calluses in the most severe wound greater than the maximum set for class-3 trees.

[b] Decay <0.005 dm^3 was recorded as "trace".

Advanced (very soft) stem decay is uncommon in aspen suckers younger than age 20, and averages about 0.03% of stem volume (Smith 1973). This level was found in the control suckers and in the unwounded scarified suckers sampled at ages 13 and 18 (10 and 15 years, respectively, after scarification). Scarified suckers bearing visible stem wounds, on the other hand, had 3 and 2% of their stem volume affected by advanced stem decay at those ages (Table 5). Ten different decay-causing fungi were isolated from these decays, and these fungi are known to be associated with stem decay in mature aspen in Ontario. Suckers with the most severely wounded stems (wound class 4, Table 6) had by far the most advanced decay. At ages 13 and 18, 10 and 15 years after scarification, they had roughly 10 times the volume of advanced stem decay found in unscarified suckers (Table 6), and approximately 7% of their stem volumes were affected by advanced decay; this figure is extremely high for trees so young. It is encouraging that, even 15 years after being scarified, the excessive stem decay and stain in the wounded trees were limited to the lowermost 1 to 1.5 m of the stem, the region that bore the scarification wounds.

The root systems of all suckers sampled in 1976, 1978 and 1982, and half of the root systems of suckers sampled in 1987, were excavated, dissected and examined. The average diameter of the parent roots, and the average number and diameter of adventitious sucker roots per tree are shown in Table 7 for scarified and unscarified aspen suckers at the four intervals following the treatment. As soon as 4 years after scarification, the average diameters of the

roots were noticeably greater in the control suckers than in the scarified suckers. In addition, control suckers had an average of 9.5 adventitious roots per stem compared with 5.6 for scarified suckers. In each of the next three samplings, similar differences were found between unscarified and scarified sucker root systems. At 4 and 10 years after scarification, these differences in root system sizes were statistically significant (Basham 1988).

In addition to the root systems being smaller in scarified than in unscarified suckers, they were also more

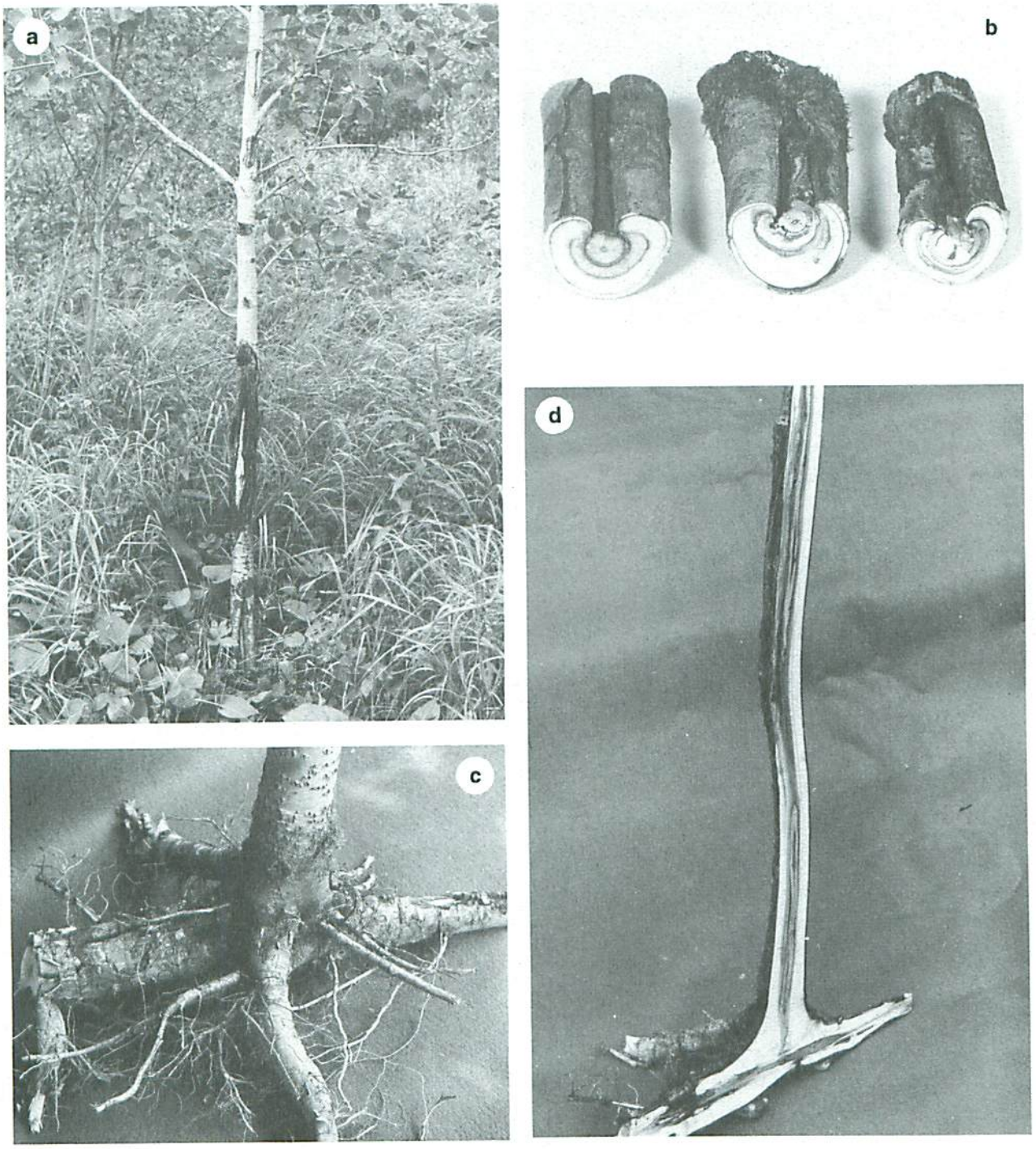

Figure 4. Aspen suckers that survived scarification at age 3. (a) Severe open wounds, 6 years after scarification. (b) Stem sections of 13-year-old aspen, 10 years after scarification, showing extensive decay associated with scarification wounds. (c) and (d) Aspen sucker 10 years after scarification, showing wounds on parent roots caused by scarification equipment, and stem and root decay associated with scarification wounds.

Table 7. Average diameter (30 cm from root collar) and number per tree of various types of roots in scarified and unscarified aspen suckers at four intervals after treatment.

Treatment	Years since treatment	Age of suckers	Average diameter (cm)			Average number of adventitious sucker roots per tree		
			Distal parent root	Proximal parent root	Larger adventitious sucker roots[a]	Larger[a]	Small	Total
Controls	4	7	2.0	1.1	0.9	2.7	6.8	9.5
	6	9	3.8	2.0	1.3	4.1	4.3	8.4
	10	13	6.6	3.3	2.5	6.0	5.9	11.9
	15	18	7.0	3.2	4.4	4.9	5.4	10.3
Scarified	4	7	1.5	0.8	0.7	1.5	4.1	5.6
	6	9	2.8	1.5	1.0	3.0	4.0	7.0
	10	13	5.3	2.4	2.3	3.7	4.8	8.5
	15	18	5.8	2.7	3.3	3.2	4.2	7.4

[a] Roots with diameters >0.4 cm at age 7, >0.7 cm at age 9, >1.2 cm at age 13, and >1.7 cm at age 18.

defective. Table 8 shows that defect (stain or decay) was quite common in the root systems of unscarified trees, particularly in the root collars and parent roots. However, defect occurred with slightly greater frequency in all parts of the root system in scarified suckers (Table 8). These data are somewhat misleading in that they consider the presence of defect but not the extent or type (stain or decay). The latter two factors were considered for the 4-, 6- and 10-year samplings, in which overall root system defectiveness was assessed (Basham 1988). This assessment revealed that scarified suckers had more defective root systems than unscarified suckers. Two-sample t-test comparisons suggested that these differences were probably statistically significant (4-year sample P = 0.07, 6-year sample P = 0.03, 10-year sample P = 0.06).

Table 8. The occurrence of defect (stain or decay) in the root collars and roots of scarified and unscarified aspen suckers at four intervals after treatment.

Treatment	Years since treatment	Number of sucker root systems examined	% of root collars and roots in which some defect was found			
			Root collar	Distal parent root	Proximal parent root[a]	Larger adventitious sucker roots[b]
Controls	4	20	80.0	50.0	50.0	12.5
	6	10	70.0	70.0	70.0	20.0
	10	20	95.0	75.0	90.0	25.8
	15	10	100.0	60.0	75.0	36.6
Scarified	4	60	98.3	66.7	59.3	21.9
	6	60	96.7	71.7	68.3	19.9
	10	60	100.0	96.7	80.0	36.0
	15	30	100.0	90.0	73.3	47.3

[a] In a few root systems, the proximal parent root could not be identified with certainty

[b] Roots with diameters >0.4 cm at age 7, >0.7 cm at age 9, >1.2 cm at age 13, and >1.7 cm at age 18.

Decay was much more common in the root systems than in the stems of the aspen suckers, including unscarified suckers. There are many avenues of entrance for decay-causing fungi, including stone abrasions, ghost moth root-borer openings, and the bases of dead "companion" suckers. Approximately 50% of the scarified root systems had an additional potential decay entry site, wounds caused by the scarification machinery. These were, for the most part, inflicted on the root collars and on the upper surface of the enlarged distal parent root (Fig. 4c,d). Extensive advanced decay caused by fungi belonging to the genus *Armillaria* was frequently associated with root-system scarification wounds. Thus, it is not surprising that the root systems of scarified suckers were appreciably more defective than those of unscarified suckers. *Armillaria* decay was also present to a lesser degree in the root systems of the control suckers. However, six other decay-causing fungi that are known to cause decay in mature aspen were isolated from the root systems of scarified suckers, but never from unscarified suckers.

At 4 and 10 years after scarification, stem sections taken from all 160 sampled suckers were examined. By counting back 4 or 10 annual rings, the relative size of the stems at the time they were scarified was estimated. For the 120 scarified suckers, there was a significant correlation between stem diameter when scarified and the frequency

and severity of stem wounding (Basham 1988): the smaller stems at the time of scarification tended to be those with no or few visible stem wounds when sampled, whereas the larger stems usually had more, and more severe, stem wounds. It was also observed that the stems with no, or only one or two, small wounds had faster average diameter growth rates in the 4 or 10 years after scarification than the stems with severe stem wounds. Thus, Figure 3 and the last column of Table 4 reveal a slightly greater rate of stem volume increase in scarified suckers with no visible wounds than in wounded scarified suckers over the 11 years of the study.

The slower average rate of growth of the stems of scarified suckers compared with the controls can thus be partly explained by the suppressive effect of stem scarification wounds. Another cause can likely be found below ground. In their first few years, aspen suckers are largely dependent on distal parent roots for nourishment and growth. As mentioned earlier, these roots begin to expand in diameter a year or so after suckering commences. This expansion probably brings these roots nearer the soil surface, so that by the time suckers are 3 years old, they are more likely to be scraped and gouged by scarification machinery (Fig. 5c). About 35% of the scarified distal parent roots bore such wounds in this study. Scarified suckers had smaller and more defective root systems than unscarified suckers (Tables 7, 8), with disruptions of the roots' physiological functions probably resulting directly from the wounding or from the occasional severing of the parent root network by the scarification machinery. All this would almost certainly have an inhibitory affect on stem growth.

Although severely wounded sucker stems appeared to be almost growing at a normal rate towards the end of this study, 15 years after they had been scarified, it seems likely that because of their somewhat faster growth rate the unwounded scarified trees will account for a higher proportion of the crop trees at merchantable size than the 25% so designated when suckers were randomly selected for this study. However, many crop trees will bear stem scarification wounds, and the majority of those wounds will

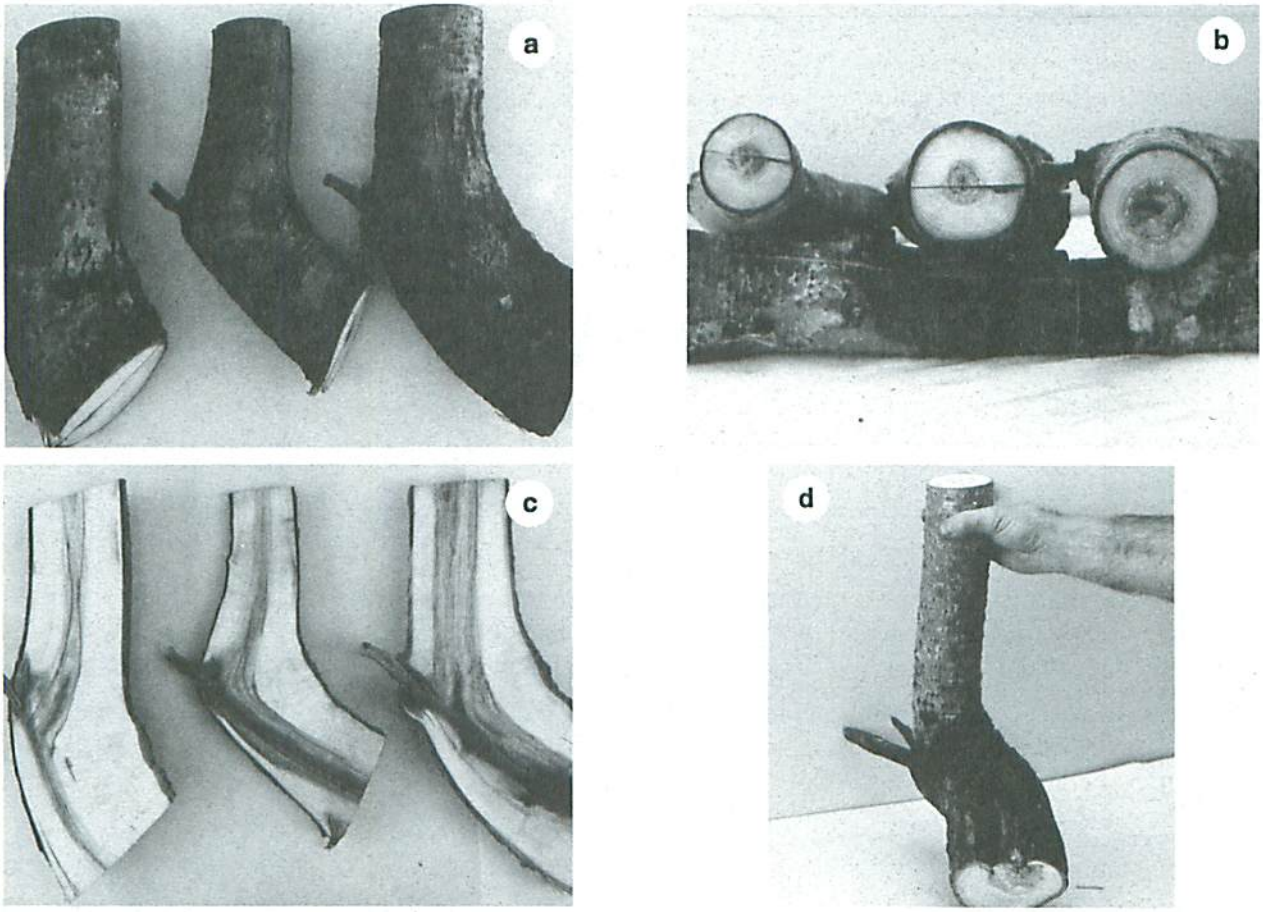

Figure 5. Aspen approximately 22 years old that survived scarification damage at age 2. (a, c) Basal stem crooks in three of the more severely damaged trees, showing leaders killed soon after scarification flattening, and lateral branch development into replacement leaders. (b) Tops of stem sections shown in (a) and (c), showing some stem stain but no decay. (d) Basal crook with remains of two dead leaders that occurred in successive years.

be associated with stem decay. Furthermore, all scarified trees, whether stem-wounded or not, are likely to have above-normal levels of root system decay and stain. Thus, it appears that scarification of 3-year-old aspen sucker stands will reduce the eventual quality of those stands when they reach merchantable size.

Scarification at the end of the sixth growing season

The preceding results suggest that scarification carried out in aspen stands older than 3 years, presumably with larger stems, would result in even more frequent and severe stem wounding and consequently higher average levels of stem decay in the surviving aspen. We wished to test this hypothesis, and to get some idea if the excessive stem decay and stain associated with scarification stem wounds would remain limited to the wounded stem region (the lowermost 1 to 1.5 m of the tree) after more than 15 years had elapsed since the scarification.

With the cooperation of OMNR's NFRU, an aspen stand scarified 21 years earlier (at age 6) was found roughly 30 km west of Kakabeka Falls; 150 aspen in this 27-year-old stand were sampled in 1987. This included 15 trees in pockets that appeared to have been missed by the scarification machinery (scarification rows could still be detected). As in the earlier study, the sample trees were felled, dissected and examined for defects; however, root systems were not examined. The 135 scarified trees were arbitrarily divided into five "wound severity" classes based on the extent of stem damage apparently attributable to the scarification operation. The results are shown in Table 9.

The average stem volume of the unscarified aspen was roughly 15% greater than that of the scarified trees 21 years after the treatment. As expected, scarified aspen had, on average, more stem wounds and wounds of greater severity than the aspen scarified at age 3 in the previous study. Very few scarified trees lacked visible stem wounds. An average of roughly 8 dm^3 of decay and stain (about 20% of this was decay) occurred in the stems of the scarified aspen. This was almost four times greater than the average volume found in the stems of 3-year-old scarified aspen 15 years after scarification (Table 6). As was the case in the preceding study, Table 9 shows a positive correlation between the extent of stain and decay and the frequency and severity of stem wounds and deformities caused by the scarification treatment.

An average of 15% of the stem volume of the scarified aspen was decayed or stained 21 years after scarification. In the preceding study, roughly 11% of stem volume was decayed or stained 15 years following scarification. However, despite the much greater volume of decay and stain in the stems of the aspen scarified at age 6, excessive decay and abnormally extensive zones of stain were still virtually confined to the lowermost 1 to 1.5 m of the stems (where scarification wounding had occurred) 21 years after scarification. Above this height, the occurrence of stain and decay in scarified and control trees was virtually identical.

Scarification before the third growing season

The scarification study conducted in a stand scarified at age 3 indicated that, when scarified, the smaller-diameter aspen stems tended to escape injury altogether or to sustain only relatively minor scarification wounds. This suggested that scarification carried out in aspen stands younger than

Table 9. Average extent of decay and stain in the stems of scarified and unscarified 27-year-old aspen (scarified at age 6), with trees grouped according to the severity and number of wounds and deformities attributable to the scarification operation.

Treatment	Severity of stem scarification wounds and deformities[a]	Average stem volume (dm^3)	Number of trees	Average volume per stem (dm^3)				Average % of stem volume affected by decay and stain
				Advanced decay	Incipient decay	Stain	Total decay plus stain	
Unscarified	n/a	60.9	15	0.18	0.25	3.60	4.03	6.6
Scarified	All	52.9	135	0.52	0.58	6.83	7.93	15.0
Scarified	1		30	0.28	0.40	4.42	5.10	10.6
	2		28	0.37	0.35	6.08	6.80	14.0
	3		24	0.63	0.57	6.73	7.93	16.3
	4		27	0.61	0.67	6.93	8.21	14.1
	5		26	0.91	0.91	9.51	11.33	17.6

[a] Severity increases from group 1 to group 5. Group 1 trees had a slight basal crook and no stem wounds, or had only one healed-over wound less than 10 cm in length, whereas group 5 trees had at least two stem wounds occurring on more than 50 cm of stem length and included the only six trees with open (unhealed) wounds.

age 3 would result in fewer stem wounds and consequently less stem decay and stain because of the smaller stems. We carried out two studies in cooperation with OMNR to test this hypothesis.

An aspen sucker stand that resulted from a harvesting operation carried out about 20 km north of Manitouwadge in the spring of 1978 was scarified between 31 July and 1 August 1979, when most suckers had completed one and a half growing seasons. Part of the stand was left unscarified to provide a control area. Fifteen dominant or codominant suckers from the scarified portion of the stand and an additional 15 suckers from the unscarified area were sampled within a day of the scarification treatment. On or about 1 August 1980 and 1981, similar samplings were carried out. Scarification methods and equipment were similar to those used in the earlier study.

Immediately after scarification, there was little difference in stem stain and decay between the scarified and unscarified suckers, as was expected. Roughly 4% of the inside-bark stem volume of all trees was defective (mostly stain). By 1981, 2 years after scarification, some differences were apparent. Whereas the 15 control suckers had an average stem volume of 0.47 dm^3, that of the 15 scarified suckers was 0.43 dm^3. The control suckers had 6.6% of their stem volume defective compared with 8.7% for the scarified suckers. Sample sizes were too small for meaningful statistical analyses. More meaningful, perhaps, are observations made at the time of the treatment. The dominant 1.5-year-old suckers were about 1.5 m in height at that time. Those in the direct paths of the scarifier barrels were flattened, and many were killed, mostly by being separated from their parent root systems. The extent of this mortality reduced subsequent stand density somewhat, but not critically. Most of the flattened suckers that survived remained flattened or were slightly raised 2 days after the treatment. Because of the flexibility of the stems, very few stem scars were caused by the scarification machinery. The few scars seen were near the base of stems scraped by the sides of the scarifier in passing. When we carried out our final sampling in 1981, when most suckers were 3.5 years old, it appeared that some of the flattened suckers that were alive in 1979 had died. The leaders of most of the partially raised suckers had resumed a near-vertical alignment, but in some suckers that had remained flattened, the leaders were dead or dying; in many of these cases, lateral branches were beginning to develop into replacement leaders.

Root systems of the sampled scarified and unscarified aspen suckers were excavated and examined. By 1981, 2 years after scarification, the root systems of scarified suckers were only slightly smaller and slightly more defective than those of unscarified suckers. Unlike in the earlier study of aspen scarified at age 3, these differences were not pronounced. One reason for this may well be that only six of the 45 scarified suckers (13%) bore scarification wounds on the vital distal parent root, compared with 34% in the earlier study.

The second of these studies was carried out in two aspen stands 21 and 23 years old, which, according to OMNR operational records, had been scarified at age 2. The stands were located northeast of Longlac and west of Kakabeka Falls. Based on detailed operational maps and still-discernible scarification rows, 150 dominant or codominant aspen were sampled from the scarified areas in each stand. No attempt was made to sample trees from unscarified portions of the stand.

The average stem volume of the 21-year-old trees sampled near Longlac was 44 dm^3, close to the expected volume for untreated aspen at that age (Table 1). The average volume of the 23-year-old stems near Kakabeka Falls was 68 dm^3, greater than the normal for untreated aspen (Table 1). Thus, it appears that scarification at age 2 had no long-term deleterious effect on the subsequent growth of the aspen destined to form crop trees at stand maturity.

Very few stem wounds attributable to scrapes or gouges by scarification machinery were detected on the 300 trees sampled, even after the stems were felled and dissected. Only 12 of the trees bore such wounds, 10 of these in the Kakabeka Falls plot. However, roughly 30% of the sampled trees in both areas had noticeable stem crooks from ground level to a height of approximately 0.5 m. These crooks were about evenly divided between those subjectively graded as minor, moderate or severe. Evidently, most if not all of the crooks were the result of stems being flattened during scarification at age 2 and the subsequent death of the leaders, with lateral branches taking over as replacement leaders (Fig. 5a,c). Occasionally, two dead leaders, occurring one or two years apart, were involved in crook formation (Fig. 5d).

Upon dissecting the stems it was discovered that virtually no decay, and little more than normal levels of stain, were associated with the basal crooks caused by scarification (Fig. 5b). The average extent of stem decay in the 300 scarified sample trees was 0.9% of total stem volume, comparable to what one would expect to find in 21- to 23-year-old untreated aspen (Table 1). The average proportion of stem volume affected by decay plus stain (8.6%) was only slightly above the amount to be expected in untreated aspen stands (Table 1). Thus, it appears that the scarification of aspen sucker stands at age 2 did not appreciably increase the levels of stem stain and decay as the survivors reached maturity. Root systems were not examined in this study; presumably, some wounding occurred during scarification, thereby increasing root system defectiveness somewhat. Basal stem crooks can be expected in roughly one-third of crop-sized trees; however, they are apparently not a serious quality defect.

Conclusions and recommendation

Based on studies in aspen sucker stands that had been scarified at 1.5, 2, 3 and 6 years, mortality caused by scarification is not critical to aspen stand development. Damage to the root systems, and to a lesser extent to the stems, can reduce stem growth rate somewhat for up to 10 or 15 years, but the surviving aspen will eventually attain crop size. Many of these aspen stands will likely be harvested, and the scarification operation can have an impact on the quality of that aspen. Scarification of aspen suckers when they are small and resilient, generally when 1 or 2 years old, is recommended. Some suckers are killed, but the flexible, resilient small stems are usually not damaged very much and generally sustain only minor reductions in growth rates for a few years. At maturity, these aspen will likely be of similar internal and external stem quality to those in unscarified stands. On the other hand, the stems of suckers larger than roughly 1.5 cm in diameter at 30 cm above ground level are frequently wounded severely by scarification machinery because of their greater rigidity (Basham 1988). Most 3-year-old and older aspen suckers are of this size. The root systems of these suckers are also more likely to be wounded during scarification than those of smaller suckers, because the root collars are larger and the distal parent roots have increased appreciably in diameter, have become more succulent, and are closer to the soil surface.

Scarification wounds are usually associated with excessive stained wood, and serve as entry points for stem and root decay. The extent of the excessive stem decay and stain is directly related to the size and severity of the stem wounds. Aspen scarified at age 6 sustained more stem wounding, and contained more excessive decay and stain as a result, than did aspen scarified at age 3. It appears that aspen with scarification stem wounds have the growth potential to attain merchantable size, and that the excessive stem decay and stain in such trees will remain confined, for the most part, to the wounded regions of the stem, the lowermost 1 to 1.5 m. When harvested, scarified aspen should contain considerable timber of normal quality above that height. However, excessive basal decay in stem-wounded aspen could result in stem breakage at or near maturity. Furthermore, these stands will likely have higher than normal levels of decay and stain in their root systems, making windthrow more probable, particularly in the larger trees. Clearly, if the intention is to harvest such stands, this should be carried out as soon as it is feasible to do so after they reach merchantable size.

EFFECTS OF SCARIFYING TO PROMOTE ASPEN SUCKERING ON QUALITY

The steadily increasing commercial demand for aspen partly explains recent recommendations that stands on the better aspen sites, both relatively pure aspen stands and mixedwood stands with an aspen component, should be considered for aspen management (Morley 1986, Davidson et al. 1988). In such cases, clearcutting is usually the recommended harvesting method. Because residual understory, brush and slash inhibit sucker production, mainly by preventing sunlight from reaching the soil and increasing the temperature of the rhizosphere, any reduction in their occurrence generally promotes sucker development. Scarification following harvesting is the usual method of accomplishing this goal.

In the mid 1970s, OMNR's NFRU established four scarification trials after aspen harvests carried out during the dormant season in four widely scattered areas in northern Ontario. The purpose of these trials was to determine the best season and intensity of scarification to produce the optimum number of high-quality suckers. A preliminary report on the effects on stocking density and height growth of aspen suckers for the first three growing seasons has been published (Weingartner 1980). Details on the experimental methodology are available in that paper. The results indicated that scarification carried out in the spring before sucker emergence had increased the stocking density after 2 years. Heavy scarification resulted in a greater increase than light scarification. However, height growth of the dominant suckers was less than that of the controls, particularly when scarification was carried out after initial sucker development (i.e., in early summer or fall).

When the aspen suckers in the scarified stands were 5 years old, OMNR staff sampled an additional 190 trees. The trees were selected by randomly choosing points within the sample plots, and sampling a predetermined number (usually from three to five) of dominant or codominant suckers at each point. The trees sampled were those that appeared most likely to develop into crop trees. Forestry Canada staff dissected and described the stems and root systems, measured the extent of stain and decay, and recorded the type, location and severity of wounds.

The intensity of scarification ("heavy" or "light") had a negligible effect on the growth rate and quality of the sampled suckers, and was disregarded in subsequent analyses. The effects of the season of treatment (spring, before sucker emergence; early summer, after sucker emergence; and fall, after the suckers had completed one growing season) on sucker size, stem wound frequency, stem quality and root system quality are shown in Table 10. Figure 6 shows the average stem sizes and the occurrence of stain and decay in the stems of unscarified suckers and suckers scarified in the three different seasons.

The average height (1.8 m) and stem volume (0.32 dm^3) of the 30 suckers sampled from areas scarified in the early summer, after sucker emergence, were appreciably less than those for the 51 control suckers from unscarified areas (2.9 m and 0.83 dm^3, respectively). At the time of the

Table 10. Effect of scarification after dormant-season harvesting of aspen stands on upland sites on the quality of 5-year-old suckers at four widely scattered locations[a] in northern Ontario.

Scarification treatment and season	Number of suckers examined	Average stem Height (m)	Average stem Vol. (dm^3)	Average number of stem wounds per tree	Average % of stem volume Decayed	Average % of stem volume Decayed or stained	Average number of roots per tree[b]	Average diameter of roots (cm)[c]	% of root collars decayed	% of roots decayed
None	51	2.9	0.83	0.5	0.4	7.7	6.2	1.7	33.3	14.5
Spring, before sucker emergence	56	3.0	0.92	0.6	0.2	4.4	5.7	1.7	38.1	17.9
Early summer, after sucker emergence	30	1.8	0.32	0.8	3.5	13.1	5.5	1.5	34.7	18.1
Fall, after suckers had completed one growing season	53	2.4	0.61	1.1	1.7	10.9	4.9	1.3	42.2	20.3

[a] Sample plots were located near Atikokan in Atikokan district, in the Dog River region of Thunder Bay district, in Hartington Township of Thunder Bay district, and near Longlac in Geraldton district.
[b] excluding roots less than 0.7 cm in diameter 25 cm from the root collar
[c] at 25 cm from the root collar

early-summer scarification, the dominant suckers were no taller than 30 cm, and the mechanical action of the scarifier apparently killed many of the suckers in their paths. Two years later, Weingartner (1980) observed very little re-suckering in those paths. Although some new suckers may have been produced by year 5, most would not likely have been considered dominants and therefore very few, if any, would have been included in the sample of 30 suckers. The relatively small average size of these 30 suckers can probably by attributed mainly to mechanical damage to the young suckers during the treatment.

Table 10 shows that the average height and stem volume of the 53 suckers sampled from areas scarified in the fall were slightly less than those of suckers sampled from the control areas 5 years after the treatment. Similar results for average heights of dominant suckers were obtained 3 years after the treatment (Weingartner 1980).

In sharp contrast to the above two groups of suckers, the 56 suckers sampled 5 years after treatment from areas that had been scarified in the spring before sucker emergence had an average stem height and volume slightly greater than those of the controls (Table 10). Weingartner (1980) found that after 3 years dominant suckers from such areas had somewhat shorter heights than those from untreated areas. Analysis of the data presented in his Table 2 shows that average heights of dominant suckers were 9.8 and 3.3% less than the control means 1 and 2 years after the treatment, respectively. This suggests that after an initial reduction in stem growth, possibly caused by parent root damage during scarification, suckers growing in areas scarified in the spring soon began to grow somewhat faster, on average, than suckers in unscarified areas.

Only 10 stem wounds that appeared likely to have been caused by the scarification treatment were observed on all of the sampled suckers. Two of these were on suckers scarified in the early summer after sucker emergence; the remaining eight were on 1-year-old suckers scarified in the fall. The average numbers of stem wounds of all types per tree for each group of suckers are shown in Table 10. Suckers scarified in the fall had roughly twice the frequency of occurrence of stem wounds as controls, but scarification wounds played a relatively minor role in the difference. Presumably the flexibility and small size of the 1-year-old stems when they were scarified explain the relatively few scarification stem wounds on these suckers.

Figure 6 shows that not only were the stems of suckers sampled from areas scarified in the spring somewhat larger than those of the control suckers, they also had smaller average volumes of stain and decay 5 years after the treatment. It is difficult to explain why this should be so, other than that the number of trees sampled was small and that this may be merely a sampling anomaly. Nevertheless, the results indicate that post-harvest scarification carried out before sucker emergence will not have a long-term deleterious effect on the size or quality of the second-growth aspen.

Although the greatest average volume of stain and decay was found in the suckers subjected to fall scarification at age 1, the suckers sampled after early summer scarification had the highest percentages of stem volume

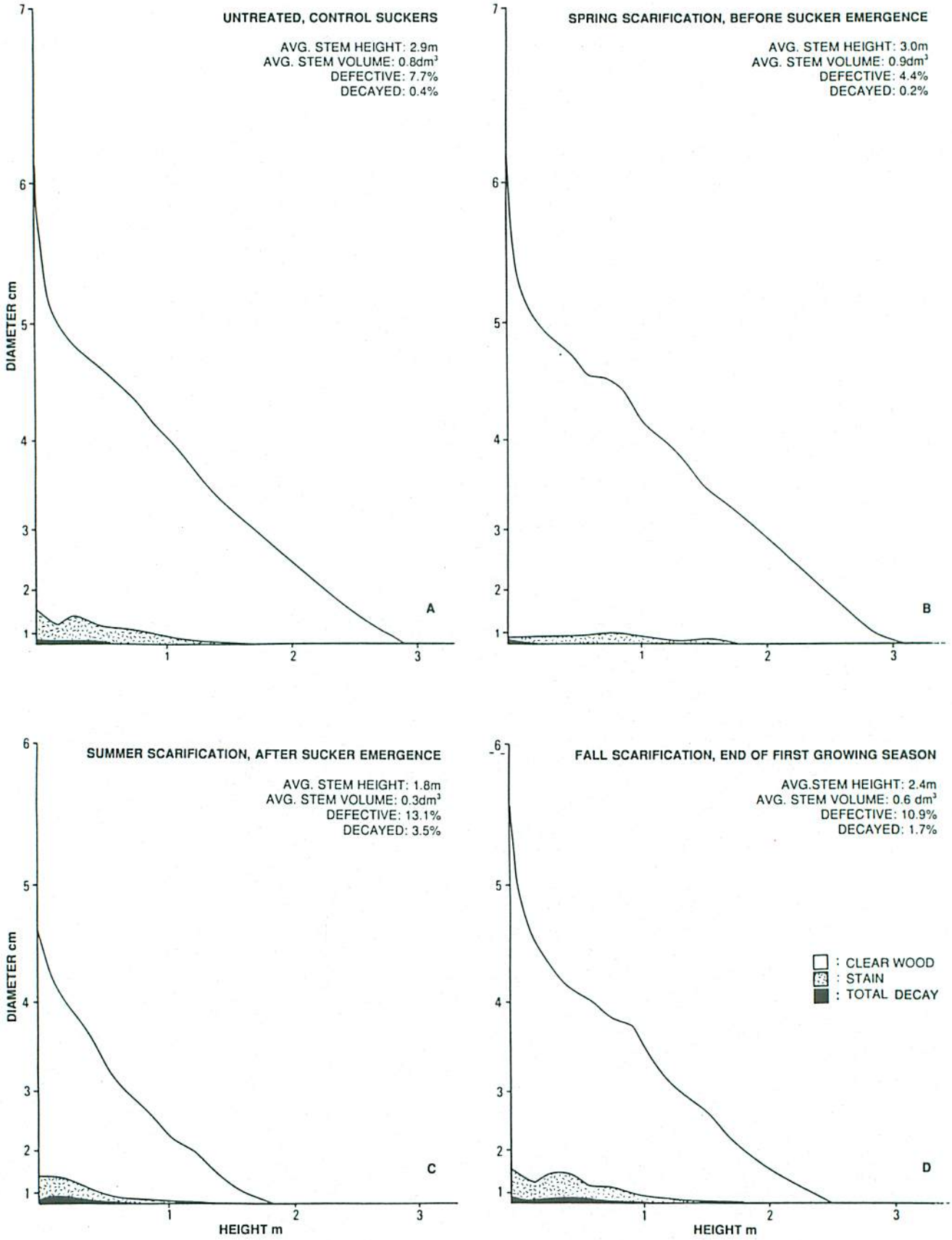

Figure 6. Average stem dimensions, and percentages of stem volume defective (decayed or stained) and decayed, for 5-year-old aspen suckers of cutover origin scarified at three different times after harvesting.

defective because of their relatively small size (Table 10, Fig. 6). The 53 suckers scarified in the fall at age 1, when sampled 5 years later at age 6, were far less defective than suckers scarified at age 3 sampled 4 and 6 years later (Table 5). These data on suckers scarified at age 1 corroborate the earlier conclusion that aspen suckers scarified at age 1 or 2 are subjected to less stem wounding and internal stem defect than suckers scarified at age 3 or over.

The root systems of the four classes of 5-year-old suckers showed less disparity in size and quality than the stems (Table 10). In sequence, from unscarified suckers through the three seasonal treatments, there was a slight trend for average root system size and quality to decrease. However, the most severely affected root systems, those of suckers scarified in the fall, were not significantly smaller or more stained and decayed than those of the unscarified suckers. As explained in the previous section of this report, the reason for this is very likely that most root systems of these young suckers escaped wounding because of their relatively small size and because the suckers were too young for much upward swelling of the vital distal parent root to have occurred.

The above results, based on examinations of 5-year-old aspen suckers, and the earlier results from 2- to 3-year-old suckers (Weingartner 1980), can be considered little more than preliminary results of this study. Hopefully, OMNR will carry out additional samplings in the near future. Nevertheless, the two preliminary samples strongly suggest that for the least disruption of growth rates and for the best stem quality in the surviving aspen, post-harvest scarification treatments should be carried out as soon as possible, preferably in the spring before sucker emergence. If this "window of opportunity" is missed, treatment should probably not be carried out until at or near the end of the growing season.

EFFECTS OF HERBICIDE SPRAYING TO PROMOTE CONIFER DEVELOPMENT ON THE QUALITY OF THE SURVIVING ASPEN

An estimated 217,825 ha were treated with herbicides for forest management purposes in Canada in 1988, and 42% of this (92,080 ha) was in Ontario (Campbell 1990). In Ontario, 97% of the two most commonly used herbicides (glyphosate and 2,4–D) were applied aerially (Campbell 1990). Most of the herbicide operations in Ontario had release of conifers as their objective.

Many herbicide treatments in Ontario involve aerial applications on young aspen stands, not necessarily to kill the aspen but to suppress their development for a period of time and thereby favor the growth of underlying (usually planted) conifers. Although this practice started in Ontario in the late 1940s, it did not become widespread until the 1960s. It soon appeared that most of the sprayed aspen, after a few years' setback in stem growth and development, resumed normal or near-normal growth. At that point, because the aspen were so much taller than the planted conifers, it seemed likely that they would eventually reach commercial size and that many such stands would be harvested. Besides reducing the aspen growth rate, the herbicide killed many tops. By the early 1970s, there was growing concern that the spray damage could be associated with a significant reduction in the quality of mature aspen survivors.

To address this concern, in 1976 OMNR's NFRU selected a 12-year-old aspen sucker stand north of Manitouwadge that had been sprayed with herbicide in July 1969, during its fifth growing season. White spruce was planted in the stand about 3 months later. The herbicide was one frequently used in those years, a mixture of 2,4–D and 2,4,5–T. The latter compound was deregistered in Canada in 1986, and is no longer used. Nevertheless, the herbicides commonly used today, including 2,4–D, have similar effects, externally at least, on sprayed aspen. The results of 2,4–D plus 2,4,5–T herbicide damage on aspen growth and quality are therefore meaningful as indications of what can be expected from other herbicide sprays.

Before any trees were sampled, Forestry Canada was asked to cooperate in this study, primarily to determine the extent and importance of internal stem and root defects that may have resulted from the spray damage. Assessments of sprayed dominant and codominant aspen were carried out jointly in 1976, 1978 and 1981. No satisfactory unsprayed "control" area was found in the stand until 1978, so only sprayed aspen were sampled in 1976. Controls were included in 1978 and 1981.

Preliminary results acquired by analyzing the 1976 and 1978 data have been published (Basham 1982a), and details of the methods used are outlined in that report. By 1978, the surviving 14-year-old suckers appeared to have normal levels of stem stain and decay for that age. Diameter growth had been markedly suppressed for 2 years following the treatment, and widespread top kill (Fig. 7) had actually reduced stem heights. However, after these setbacks, normal growth rates appeared to have resumed. Sprayed suckers had relatively defective root systems, with many root collars and roots (particularly parent roots) containing zones of advanced decay and ghost moth larval tunnels. However, the root systems of the unsprayed control suckers were slightly more defective. Stained wood associated with the killed tops spread very slowly downwards in the stems and no harmful decay-causing microorganisms were detected therein. All untreated aspen sucker stems were observed to have some stained wood as a result of relatively early branch mortality and frequent top killing caused by "natural" agents including shoot blight disease, frost and insects. Aspen that survive herbicide damage appear to have much the same potential as unsprayed suckers to produce good-quality crop trees (Basham 1982a).

Results of the 1981 sampling, carried out when the suckers were 17 years old, are presented here for the first time. Table 11 and Figure 8 show that by 1981, 12 years after spraying, the sprayed sucker stems were still only about half the volume of the unsprayed stems. In the 3 years from 1978 to 1981, the average sprayed tree had smaller height and diameter increments than the average unsprayed tree. These results cast doubt on the conclusion (Basham 1982a) that stem growth rates were reduced for only the first few years after the spray, a conclusion arrived at with only one control sample (1978) for comparison. The unsprayed (control) suckers sampled in 1981 clearly revealed the faster growth rate of control suckers compared with sprayed suckers during the 3 years from 1978 to 1981.

Table 12 shows the extent of stain and decay in the stems of sprayed and unsprayed aspen suckers 7, 9 and 12 years after treatment. The association of stained stem wood with herbicide-killed tops 9 years after spraying is shown in Figure 9 and the average stem volume and extent of internal defective wood of sprayed and unsprayed aspen 12 years after the treatment is shown in Figure 8. Table 12 reveals that the extent of decay in sprayed and unsprayed stems differed little and was insignificant. In 1981, 12 years after the spray operation, the average volume of stained wood was greater in the stems of unsprayed than of sprayed aspen. However, because the average unsprayed stem was so much larger than the average sprayed stem, the percentage of the stem volume that was defective was greater in sprayed than in unsprayed aspen. Figure 10 shows graphically that the volume of stained stem wood in sprayed aspen increased from 1976 to 1981, but the total stem volume increased at a far greater rate. Hence, the percentage of the stem volume of sprayed aspen that was defective in successive samplings in 1976, 1978 and 1981 decreased from 9.9% to 7.6% to 5.1%, respectively (Table 12). The 1981 results support the conclusion reached based on the 1976 and 1978 results, namely that surviving herbicide-damaged aspen will likely develop into crop-size trees with normal levels of stem defect. However, because of reduced growth rates, it will likely take them a few years longer to attain crop (merchantable) size.

The 80 dominant or codominant sprayed aspen suckers sampled in each of the three assessments were arbitrarily divided into three groups of roughly equal numbers of trees

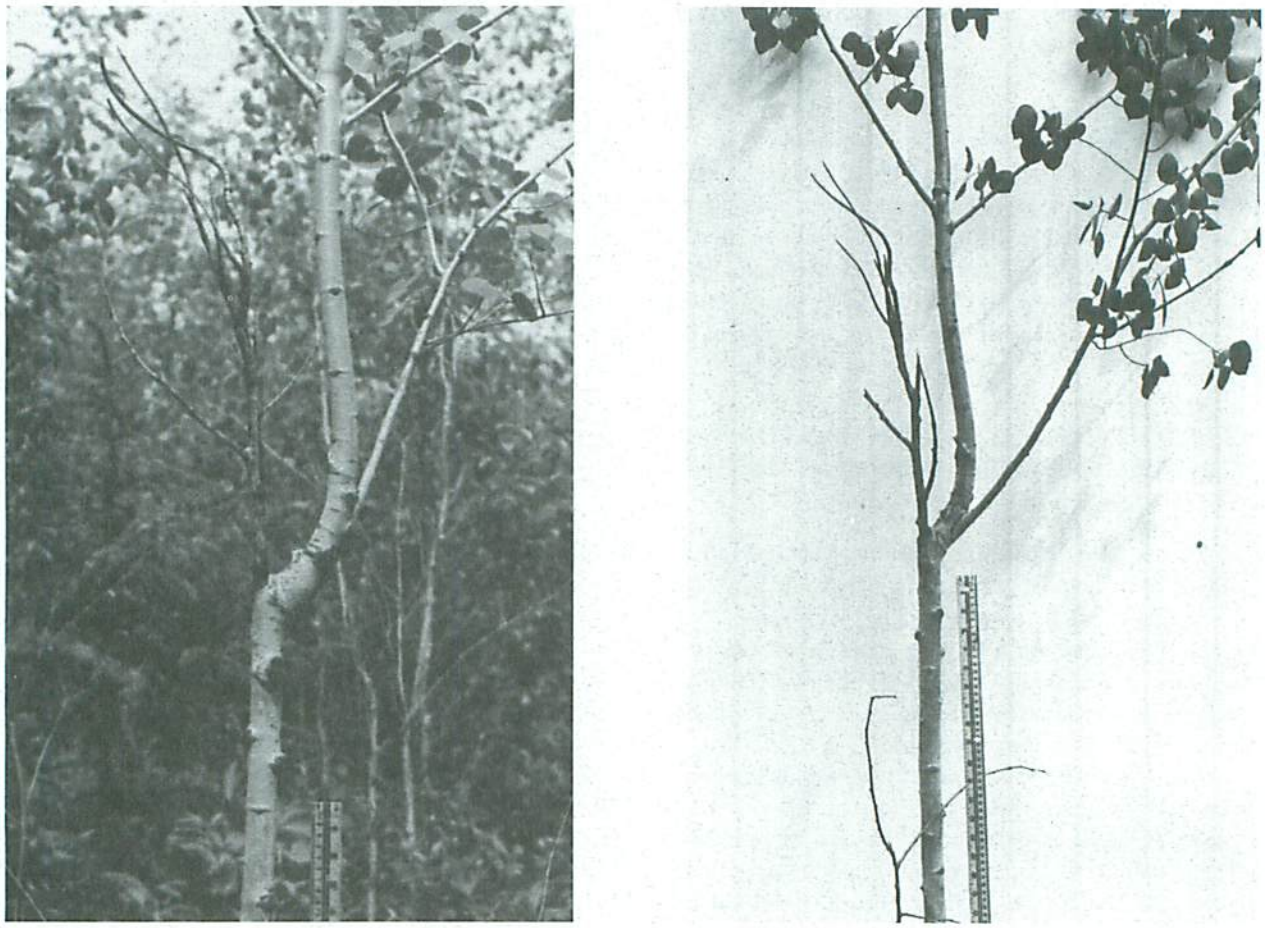

Figure 7. Aspen sprayed at age 5 with 2,4–D and 2,4,5–T, photographed at age 12. The killed top was caused by the herbicide.

Table 11. Average size of herbicide-sprayed and unsprayed aspen sucker stems at three intervals after treatment at age 5. (All aspen suckers were in dominant or codominant crown classes when sampled, and were within a sucker stand originating from a single cutover.)

Years since treatment	Age of suckers	Treatment	Number of suckers	Average stem Height (m)	DBH (cm)	Volume (dm^3)
7	12	sprayed	80	4.39	3.53	2.33
9	14	sprayed	80	5.46	3.89	3.14
		unsprayed	20	6.56	4.95	6.11
12	17	sprayed	80	6.35	5.51	7.83
		unsprayed	20	8.30	6.86	15.25

based on the height at which the base of the killed top occurred. Table 13 shows that the stems of the group with the highest top-kill base were, on average, the largest stems whereas the stems of the group with the lowest top-kill base were the smallest. Within each group, the average proportion of stem volume that was defective decreased steadily with each successive assessment, from an overall average of 10% 7 years after the spray to 4.8% 12 years after the spray. This reflects the fact that stain originating from the top kill primarily moved downward in the stems and was confined to and occupied much of the portion of the stem present in 1969, the year of the spray, and spread very little, if at all, into stem wood formed after 1969.

Table 14 shows that the average root diameter of the unsprayed aspen suckers was only slightly and insignificantly larger than that of the sprayed suckers. There was no consistent difference between the numbers of adventitious roots in sprayed and unsprayed suckers. These data were not included in the preliminary report on this study (Basham 1982a).

The occurrence of stain and decay in the root systems of sprayed and unsprayed aspen suckers is shown in Table 15. There was little difference between sprayed and unsprayed aspen in the percentage of roots or root collars that contained some stain or decay. When the type (decay or stain) and extent of defect were considered, the root systems of sprayed suckers tended to be somewhat more defective than those of unsprayed suckers. However, this difference was not statistically significant.

In summary, the addition of the 1981 data to those of 1976 and 1978 refuted the earlier conclusion (Basham 1982a) that setbacks in height and diameter growth directly attributable to the herbicide damage were of only a few years' duration. By 1981, 12 years after spraying, treated trees were still growing somewhat slower than unsprayed trees. The 1981 data confirmed that herbicide-caused top-kill was not an entry point for stem decay and that stain associated with top-kill was of limited extent and of no apparent significance as far as future stem quality was concerned. Pronounced crooks in the stems at the point where lateral branches had replaced killed leaders and assumed apical dominance were observed in 1976; these were not as pronounced in 1978, and were difficult to detect by 1981. A similar situation was observed in herbicide-damaged aspen by Perala (1971). Sprayed aspen appear to have good potential as quality crop trees, and since the majority of aspen in Ontario develop crooks from dead leaders due to a variety of causes, even in the absence of herbicide, the only drawback to spray-damaged trees should be the additional years required for them to attain merchantable size.

STEM DECAY IN MATURE ASPEN AND ITS EXTERNAL INDICATORS

Stain (discolored, firm wood) appears to originate from dead leaders, dead branch tips and branch stubs in most cases. Thus, virtually all aspen stems contain stained wood by the age of 10, and this stain generally increases in extent until the tree dies. Stain is primarily a physiological–

Table 12. Average percentage of stem volume affected by decay and stain in the stems of sprayed and unsprayed aspen suckers at three intervals after spraying.

Years since treatment	Age of suckers	Treatment	Number of suckers	Average volume per stem (dm^3)[a] Advanced decay	Incipient decay	Stain	All decay plus stain	Average % of stem volume defective
7	12	sprayed	80	–	trace	0.23	0.23	9.9
9	14	sprayed	80	trace	0.01	0.23	0.24	7.6
		unsprayed	20	trace	0.01	0.32	0.33	5.4
12	17	sprayed	80	0.01	0.04	0.35	0.40	5.1
		unsprayed	20	trace	0.03	0.64	0.67	4.4

[a] Less than 0.005 dm^3 was recorded as "trace".

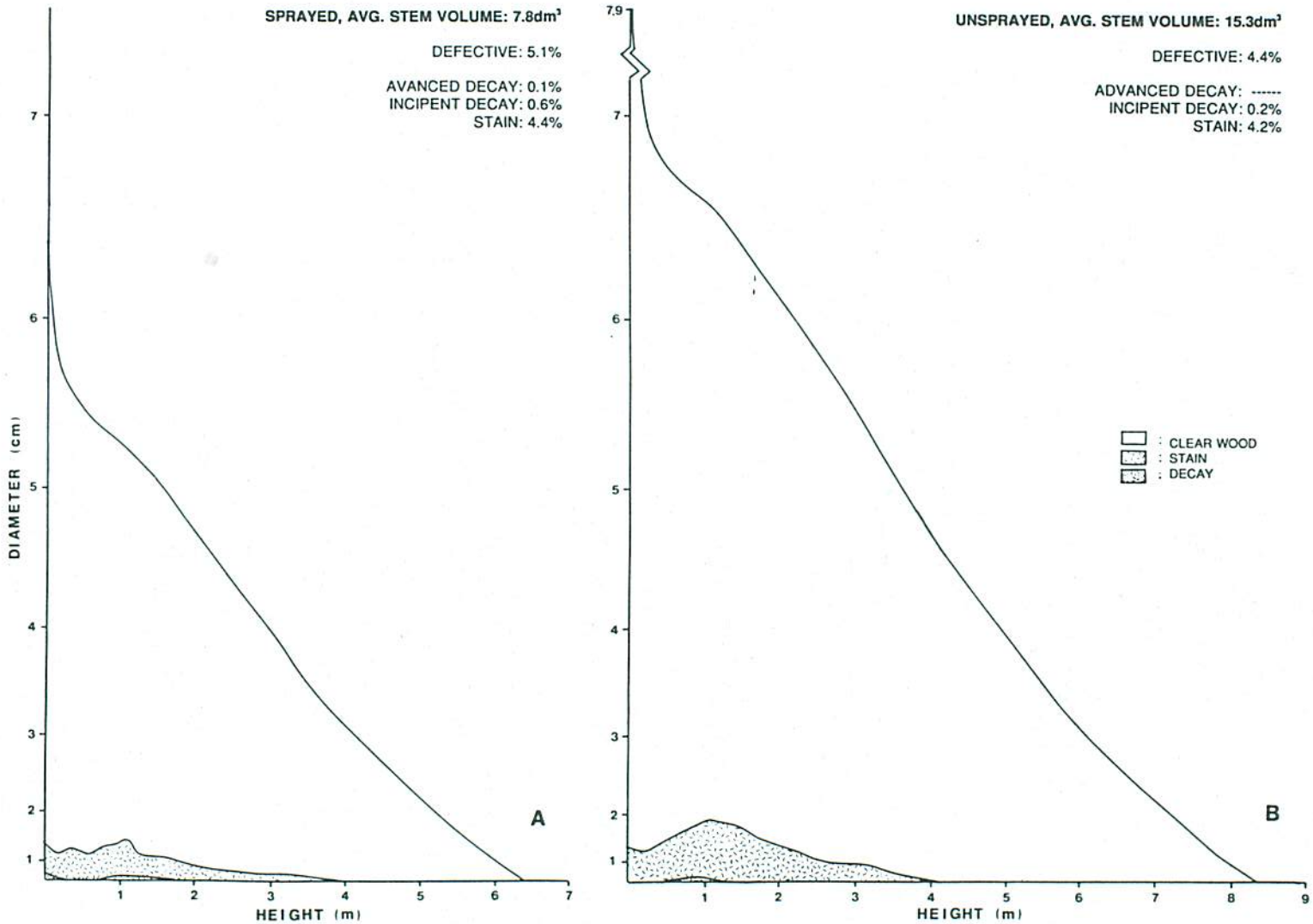

Figure 8. Comparison of average stem volumes and extent of stem defect in (a) sprayed and (b) unsprayed 17-year-old aspen, sampled 12 years after the spray treatment.

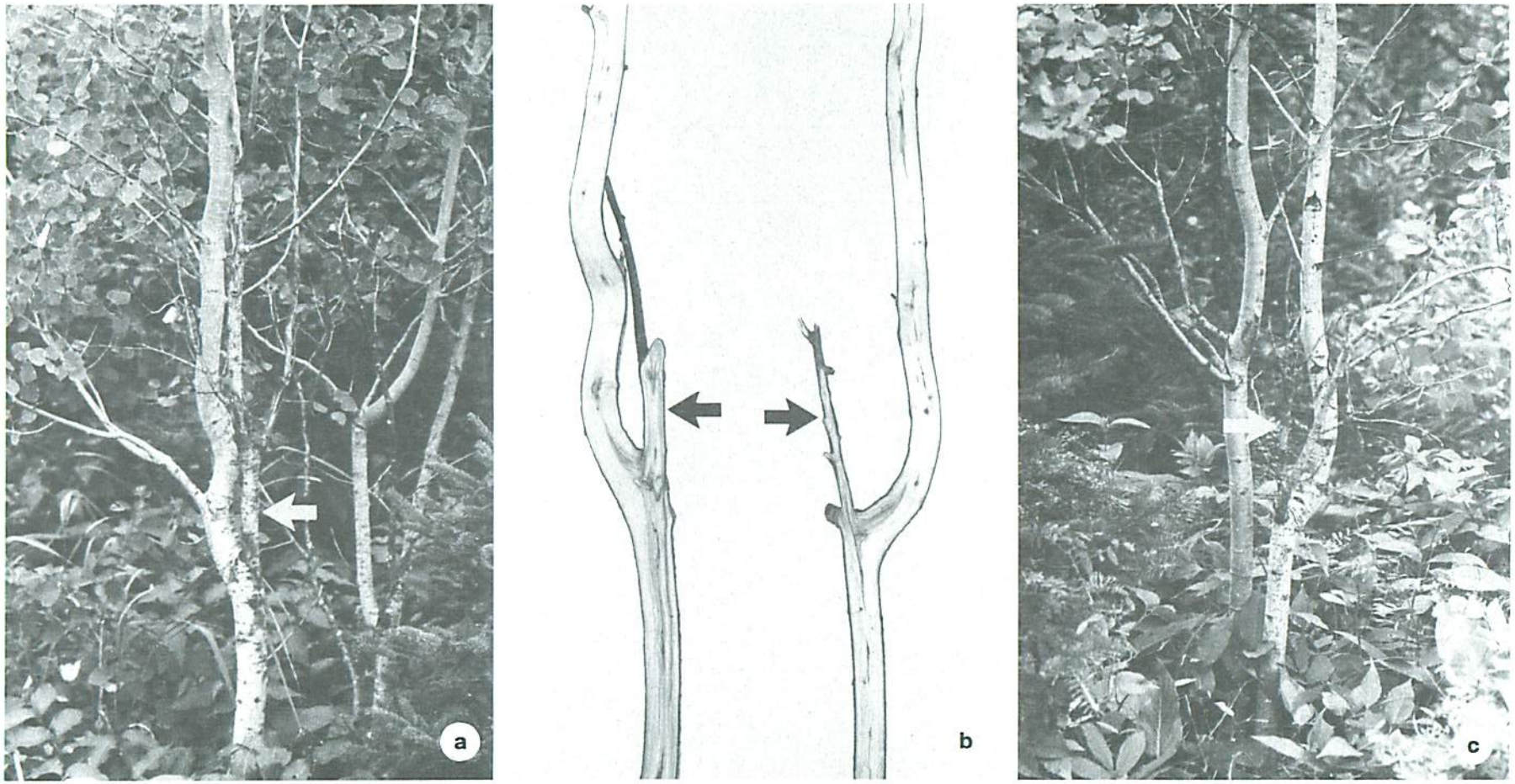

Figure 9. Stained wood associated with herbicide-killed tops. (a, c) Dead leaders on surviving aspen, 9 years after spraying. (b) Internal condition of the aspen arrowed in (a) and (c), showing stained wood associated with the killed tops.

biochemical process; however, some stained wood may harbor decay-causing fungi or may even represent the initial stage of wood decay. The fungi that cause decay generally enter aspen stems via stem wounds or relatively large (>1.5 cm in diameter) dead branches or branch stubs. Thus, except when wounded at an early age (e.g., scarification survivors), aspen younger than 20 to 25 years seldom have much, if any, decayed stem wood. However, from this age on, the frequency of occurrence of potential entry points for decay fungi generally increases, so that the number of pockets of stem decay and the overall extent of decay increase as a rule as trees get older. In Ontario, the average stem stain volume in aspen exceeds the decay volume until the 41–60 year age class; however, stem decay accounts for between 50 and 65% of the average total stem defect in older trees (Table 16) (Basham and Morawski 1964).

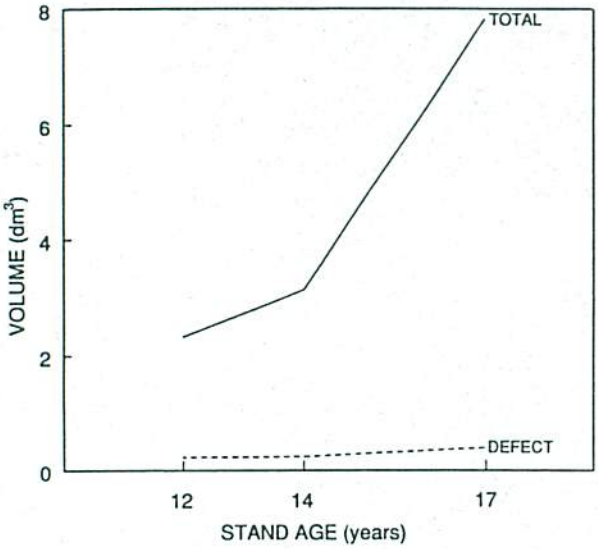

Figure 10. Average total stem volume and extent of stem defect in herbicide-damaged aspen at three times after treatment at age 5. (All defect was stain except at age 17, when a small amount of decay was present.)

Table 16 is based on 2,458 mature aspen sampled throughout Ontario and shows the direct relationship between age class and the percentage of the merchantable stem volume that was defective. It shows a steady increase in the percentage of defective stem volume with age, with at least one-third of the merchantable stem volume affected by decay or stain in trees above the 81–100 year age class. Decay alone accounted for between 20 and 25% of the merchantable stem volume in aspen at least 100 years old. Most of the stem decay (88.5%) occurred in the trunk region above breast height. Three distinct types of decay were found: a yellow or yellow-brown "stringy" decay in the butt of the stem, a similar type of decay in the trunk, and a creamy-yellow "spongy" decay that occurred primarily in the trunk but occasionally extending down into the butt region. The latter decay generally accounts for between 75 and 80% of the advanced stem decay in mature and overmature aspen. Affected wood is extremely soft and weak and is not only useless in most manufacturing processes but is also detrimental.

The fungi that are associated with stem decay in mature and overmature aspen in Ontario have been reported (Basham 1958, Basham and Morawski 1964). These papers present the frequency of occurrence of the various fungi and the type of decay with which they are generally associated. The stringy butt decays, which frequently originate in the root system, are caused by several fungi, including one or more species of *Armillaria*. Almost all of the stringy trunk decay is caused by the fungus *Radulum casearium*. The major decay type, spongy trunk decay, is caused by *Fomes igniarius* (recently renamed *Phellinus tremulae*). Unlike the other fungi associated with stem decay in aspen, *F. igniarius* produces fruiting bodies or conks on the stems that persist for several years (Fig. 11a). Figure 11 (b, c and d) shows typical aspen trunk decays caused by this fungus. The creamy-yellow, spongy wood often has characteristic black zone lines outlining or running irregularly through the advanced decay in transverse sections of decayed stems.

For a forest manager to control or minimize the extent of stem decay in aspen, harvesting aspen stands before they reach an age at which excessive stem decay has developed is an obvious

Table 13. Average stem volume and volume of stain and decay (defect) in three damage classes of herbicide-sprayed aspen suckers at three intervals after treatment.

Years since spraying	Age of suckers	Range of heights to base of herbicide damage (m)	Number of suckers	Average stem volume (dm^3)	Average volume of stem defect (dm^3)	Average % of stem volume defective
7	12	0.85–1.30	27	1.70	0.16	9.4
		1.31–1.50	27	2.10	0.21	10.0
		1.55–2.10	26	3.14	0.33	10.5
9	14	0.50–1.10	28	2.99	0.20	6.7
		1.11–1.30	26	2.88	0.22	7.6
		1.40–1.80	26	3.79	0.32	8.4
12	17	0.35–1.00	26	6.21	0.37	5.5
		1.01–1.25	26	7.91	0.40	4.7
		1.28–2.15	28	9.57	0.42	4.0

Table 14. Average diameter (30 cm from root collar) and number per tree of various types of roots in herbicide-sprayed and unsprayed aspen suckers at four intervals after treatment.

Treatment	Years since treatment	Age of suckers	Average diameter (cm)			Average number of adventitious sucker roots per tree		
			Distal parent root	Proximal parent root	Larger adventitious sucker roots[a]	Larger[a]	Small	Total
Controls	9	14	4.0	1.7	1.6	5.7	4.7	10.4
	12	17	4.4	2.1	2.1	6.9	9.6	16.5
Sprayed	7	12	1.6	0.8	0.8	4.1	5.6	9.7
	9	14	3.2	1.5	1.4	4.9	7.1	12.0
	12	17	4.2	2.0	2.0	5.3	8.8	14.1

[a] Roots with diameters >0.4 cm at age 12, >0.7 cm at age 14, and >1.0 cm at age 17.

procedure (Basham 1991). This "pathological rotation age" will be influenced by stem growth rate and by the product involved. Since *F. igniarius* appears to be responsible for 75 to 80% of the advanced stem decay in aspen, any measures that can be taken to reduce infection by this fungus are worthy of consideration.

Our knowledge of the means by which *F. igniarius* infects aspen and colonizes the wood of the stem is incomplete. There is disagreement among those who have investigated this subject on whether branch stubs or stem wounds are the primary avenue of infection for *F. igniarius*. The controversy was perhaps best summed up by Wikström and Unestam (1976). Based on a literature review and their own observations, they concluded that branch stubs were the most likely infection courts for *F. igniarius*, but did not rule out the possibility of infection through stem wounds.

Decay caused by *F. igniarius* is rare in aspen younger than 40 years. In 1976, we examined 120 aspen (10 clones) in a stand approximately 40 years old about 180 km northwest of Fort Frances. In 13 of the trees, pockets of advanced stem decay caused by *F. igniarius* were found. These ranged in size from 2 to 75 dm^3. Based on the age of the trees and the size of most of the decay pockets, it is reasonable to assume that these were relatively new infections. Sections of the stems containing the decay pockets, including those of parts just above and below the decay, were sliced into disks approximately 5 cm thick. No evidence of any stem wound, visible at the time of sampling or old wounds that had subsequently healed, was found in any of the 13 decay sections. On the other hand, the decay pockets appeared to have originated at a prominent branch stub in all cases. These results coincide with the prevailing opinion that branch stubs are the primary means by which *F. igniarius* gains entry to aspen stems.

Conks of *F. igniarius* produce literally billions of airborne spores, more or less continuously from early spring to late autumn (Riley 1952). Spores can travel several miles; when one happens to land on a suitable part of an aspen stem and other conditions are favorable, it is able to germinate and infect the stem. *Fomes igniarius* spores, if viable, are capable of germinating on the pith and adjacent growth rings of aspen branch stubs (Brown and Merrill 1971) and on aspen sapwood wounds (Manion and French 1968). There is indirect evidence that stem wounds can and do lead to *F. igniarius* infections in aspen (Basham 1960). The fact that branch stubs appear to be the more common entry point for *F. igniarius* stem decay may be based simply on the reality that there are far more branch stubs than stem wounds on most aspen stems.

Most trembling aspen with extensive stem decay caused by *F. igniarius* bear one or more conks of the fungus on their stems. Riley and Bier (1936) reported that conks on eleven 60- to 70-year-old aspen near Petawawa, Ontario, were invariably associated with advanced stem decay. The decays extended from 0.3 to 1.8 m above and below the highest and lowest conks on the stems. In our studies of aspen clones, which are discussed in detail in the next section of the present report, we felled and dissected 120 aspen in a stand approximately 40 years old near Fort Frances and another 120 aspen in a 65-year-old stand north of Manitouwadge. We found stem decay caused by *F. igniarius* in 28 (11.7%) of these 240 trees. Eleven of these 28 trees bore no *F. igniarius* conks; with one exception, these were the trees with the smallest decay volumes. Of the 17 trees with conks on the stems the number of conks ranged from 1 to 14. Advanced *F. igniarius* decay always extended above and below the highest and lowest conk. In the 40-year-old stand, the average extension was 0.99 m above and 0.84 m below the conk-bearing portion of the stem, whereas average extensions were 1.32 m above and 1.0 m below the conks in the 65-year-old stand.

We also examined 240 aspen, mostly between 103 and 110 years old, in the clonal study in two other stands north of Manitouwadge. Decay caused by *F. igniarius* was present in 47.5% of the trees; in many cases, two or more separate decay infections had merged, making it difficult to

Table 15. The occurrence of defect (stain or decay) in the root collars and roots of herbicide-sprayed and unsprayed aspen suckers at three intervals after treatment.

Treatment	Years since treatment	No. of sucker root systems examined	% of root collars and roots in which some defect was found			
			Root collar	Distal parent root	Proximal parent root[a]	Larger adventitious sucker roots[b]
Controls	9	20	95.0	70.0	75.0	27.3
	12	20	90.0	80.0	70.0	25.5
Sprayed	7	80	98.75	61.2	51.4	26.1
	9	80	91.25	65.0	70.9	28.5
	12	80	97.5	81.25	77.5	30.9

[a] In a few root systems, the proximal parent root could not be identified with certainty

[b] Roots with diameters >0.4 cm at age 12, >0.7 cm at age 14, and >1.0 cm at age 17.

Table 16. 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)	Number of trees	Average merch. volume (dm^3)	Average defective (decay and stain) vol. (dm^3)	Merchantable volume	
				Decayed (%)	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

determine the vertical extent of decay from a single infection. Conks of *F. igniarius* were present on 74% of the infected trees. In a study of aspen decay carried out in the 1950s between Longlac and Manitouwadge, we examined 1,623 trees between 60 and 180 years old; within 20-year age classes conks were present on the stems of between 79% and 97% of the trees that had stem decay caused by *F. igniarius* (Basham 1960).

Although severe stem wounds and forked stems are generally associated with internal decay in aspen, their sparse occurrence plus the apparent frequency with which dead branches and branch stubs serve as entry points for stem decay make them of little value in estimating decay extent in aspen stands. The presence of *F. igniarius* conks on the stems is by far the most reliable indicator of internal stem decay. The absence or sparse occurrence of conks in an aspen stand suggests it is relatively free of decay caused by *F. igniarius*. Stem decay pockets caused by *F. igniarius* sometimes have no associated conks, but such pockets are relatively rare as a rule. However, it should be borne in mind that *Radulum casearium* and other Basidiomycete fungi, although less common than *F. igniarius*, can cause extensive stem decay in aspen with no visible external signs of their internal presence and activity.

CLONAL VARIATIONS IN STEM GROWTH RATE AND THE INCIDENCE OF STEM DECAY AND STAIN

Until the 1960s, the typical clonal growth habit of aspen had been widely overlooked. The vast majority of aspen in pure or mixedwood stands in Ontario originated as suckers that develop vegetatively from tree roots. Most of these stands are a mosaic of clones (groups of genetically identical trees). Thus, whereas the single stem is a genotypic growth habit that usually ceases to exist when that tree dies for most species other than aspen, the clone is the typical genotypic unit of growth and development for aspen. Furthermore, whereas the aboveground parts of an aspen clone seldom exist for more than 150 years, the suckering ability of the roots after tree death usually ensures that the same clone or genotype will regenerate the area for an indefinite period of time following fire or harvesting (Zahner and Crawford 1965, Barnes 1966).

Different aspen clones in the same stand possess different genetic potentials for stem growth rate, form, wood properties and phenology (Kemperman 1977). Since aspen stands are almost always even-aged, it would not be difficult to classify clones on the basis of growth rate, form, etc. if they could be identified. In the mid 1970s, OMNR's NFRU began a study of trembling aspen clones. The broad objective was to manipulate the clonal composition of natural stands of aspen by harvesting methods and silvicultural treatments that would favor superior clones and select against inferior clones. The idea that some degree

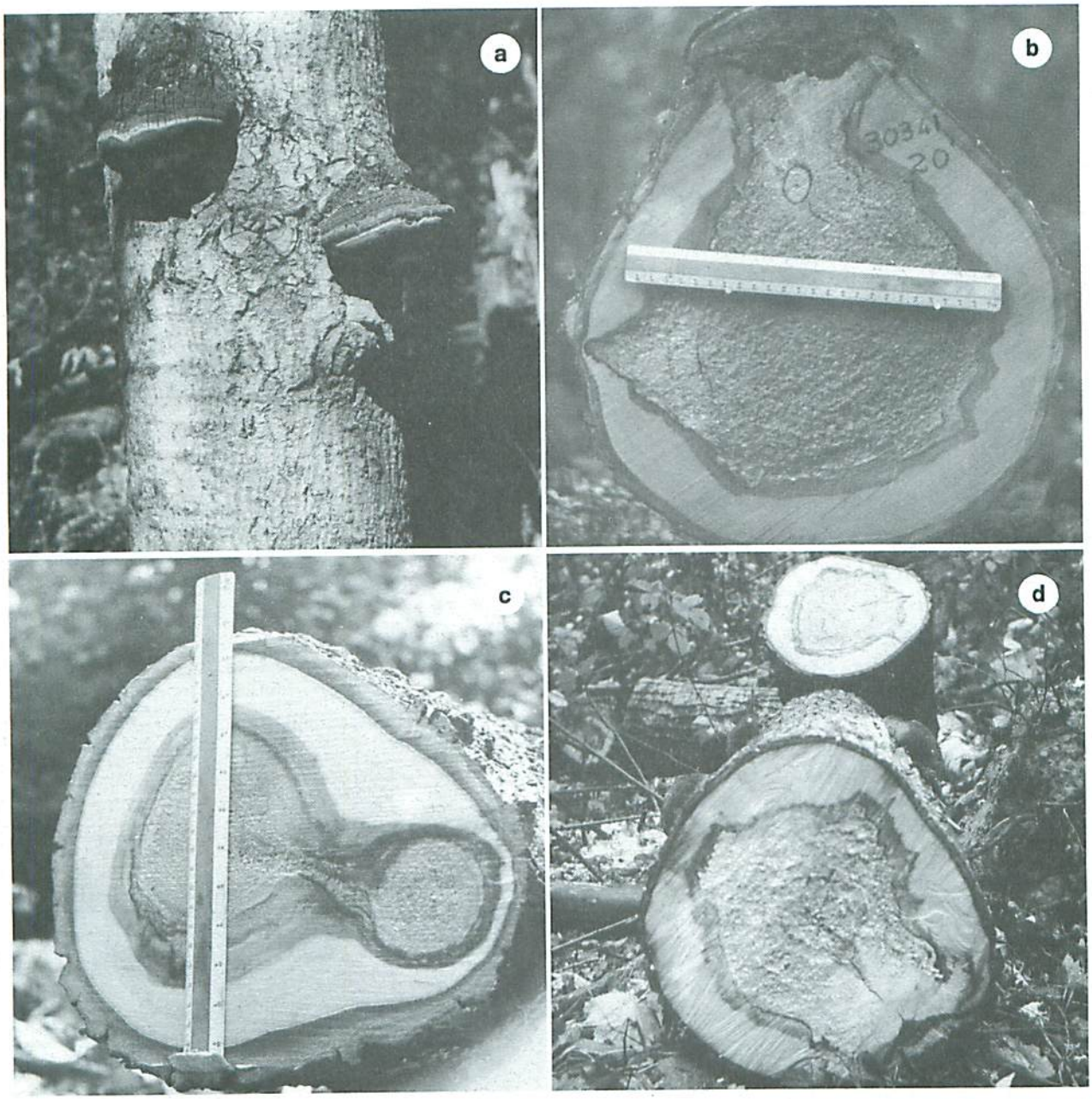

Figure 11. Stem decay caused by Fomes igniarius *(*Phellinus tremulae*). (a) Conks (fruiting bodies) on a living aspen. (b, c, d) Transverse sections of aspen stems, showing advanced decay.*

of interclonal variability in stem stain and decay resistance may exist was part of the rationale behind this cooperative investigation, and Forestry Canada staff were to concentrate on this aspect. Clearly clones with relatively fast stem growth and good form that also developed relatively little stem stain and decay would be the ideal components of future aspen stands.

A major difficulty in dealing with aspen clones is that of identifying individual clones. Once the leaves have fully flushed and until fall coloration begins, this is extremely difficult. One must rely on morphological characteristics that are variable among clones but consistent within clones, such as the appearance of lenticels, bark color and texture, the extent of self-pruning, branch angle and general stem form. Leaf size and shape can also be used. Clearly, this can be a very time-consuming and difficult task. However, there are two periods of the year, each lasting from 2 to 3 weeks, in which identification of clones is much easier: one is during fall coloration and leaf fall, the other during the period of leaf flushing (Fig. 12a). As a rule, adjacent clones vary considerably in these features, permitting quick tentative identifications; however, identities must be confirmed by observations of the morphological characteristics noted above.

In our cooperative clonal study, OMNR staff tentatively identified clones in the fall, and confirmed their boundaries the following spring during the period of leaf flushing (late May to early June) in 1975, 1976 and 1977. At least two separate observations were made of each clone in the spring, since clones differ in their rates of leaf flushing. This ensured that the delineation of a clone did not include two clones that happened to be at the same flushing stage at that particular time. All selected trees in each clone were carefully checked when sampled for stem morphological characteristics and consistency of leaf patterns to confirm they all belonged to that particular clone. In only one of 60 clones studied was there any doubt; three trees had leaves that were almost but not quite the same as leaves on the other trees sampled in that clone. They were replaced by three other trees that did possess leaves with characteristic patterns for the clone in question. Thus we felt confident that all of the trees sampled from a particular clone did belong to that clone and were genetically identical.

Six pure aspen stands were chosen, and 10 clones were sampled within each. To minimize any influence that site may have had, the 10 clones in each stand were chosen on what appeared to be a homogeneous site. Three of the stands were of cutover origin, two roughly 30 km north of Manitouwadge (28 and 30 years old when sampled) and the other in Menany Township in Fort Frances District. According to logging records, the latter stand was roughly 45 years old when sampled; however, ring counts on breast-height stem discs from some of the sampled trees that were examined a few years later suggested many trees were as young as 34. In the present report, the stand was considered to have been roughly 40 years old. The three other stands were of fire origin north of Manitouwadge; when sampled they were 65, 106 and 107 years old. The approximate center of each selected clone was located, and for the two youngest stands, the 12 dominant and codominant trees and the four intermediate trees closest to this point were sampled. In the four oldest stands, the closest nine dominant and codominant trees and the nearest three intermediate trees were sampled. In each clone, the sample trees were felled, stem dimensions and other data (including the type and extent of decay and stain within each stem) were recorded. A more detailed account of the methodology used in this study has been presented in an earlier report (Weingartner and Basham 1985).

In the latter report, all trees sampled in each clone, including the 200 in the intermediate (INT) crown class, were grouped for analyses. In this way, the data and results were more representative of the entire clones and stands than the analyses that included only the 600 dominant and codominant (D–CD) trees. Analyses revealed that in most cases there was little if any correlation between external clonal tree characteristics and the extent of internal stem decay and stain (Weingartner and Basham 1985). In all six stands there was significant ($P<0.05$) or highly significant ($P<0.01$) interclonal variation in stem height, DBH, volume, branch diameter, degree of self-pruning, percentage of stem volume stained and percentage of stem volume stained and/or decayed. These consistent significant interclonal variations strongly suggested that the genetic constitution

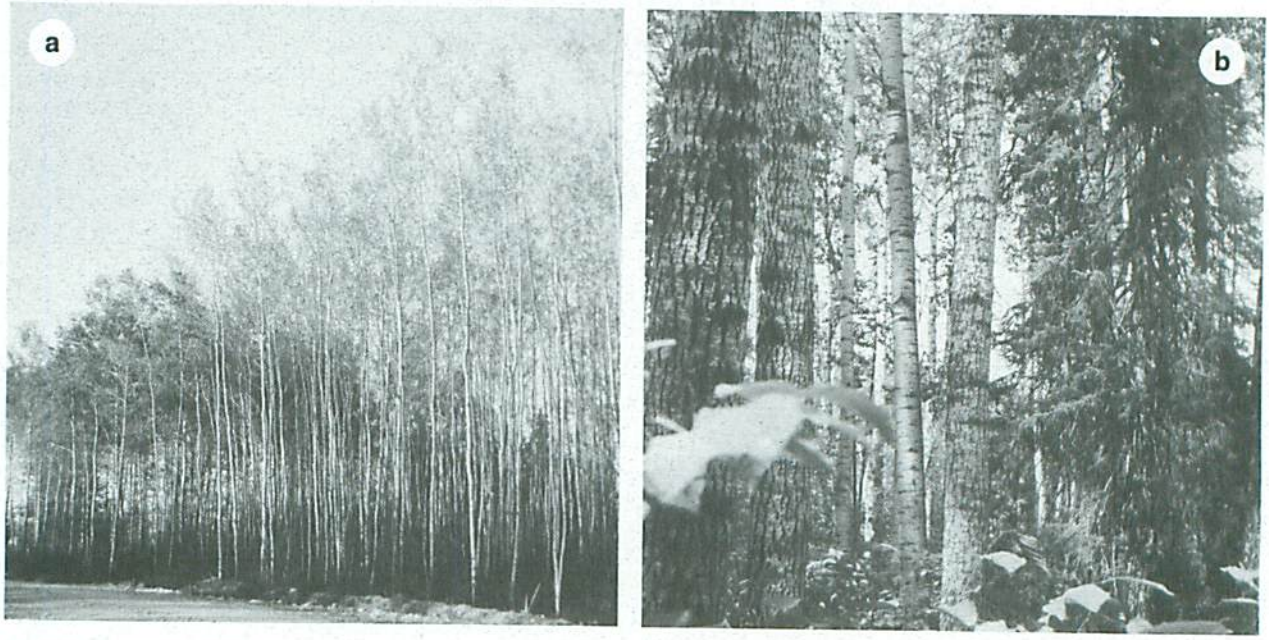

Figure 12. (a) Roadside clones of 26-year-old aspen north of Manitouwadge (photo taken at the end of May). The near clone is beginning to flush, the distant clone is almost fully flushed. (b) 107-year-old aspen clone in Anthony Lake sample plot north of Manitouwadge.

of the clones contributed significantly to the observed variations. Nevertheless, with the exception of tree height and percentage of stem volume stained, more than two-thirds of the variation was judged to be "due to environmental variables that have yet to be positively defined" (Weingartner and Basham 1985). Information on the fungi associated with the observed stem decay and stain and their clonal variability is included in that report.

Following the publication of the earlier report on this study a comparison of the defectiveness of INT and D–CD trees was carried out. In the mature stands at Stevens and Anthony Lake, where *Fomes igniarius* stem decay was extensive, virtually the same proportions of INT and D–CD trees were infected (47 and 48%, respectively). In all of the stands, the average volume of INT trees was 41.5% of the average volume of D–CD trees (Table 17). This proportion ranged from 50% in the youngest (28-year-old) stand at Camp 15 to 37% in the 65-year-old stand at Kagiano Lake. Table 17 shows that the average volume of stem stain plus stem decay was less in the INT trees than in the D–CD trees within 54 of the 60 clones. However, because of the substantially smaller total stem volume of INT trees, in 54 of the clones a higher average percentage of the stem volume was defective in INT trees compared with D–CD trees. In all six stands the average percentage of the stem volume in the form of decay or stain was greater in INT trees than in D–CD trees (Table 17). In the three youngest stands,this difference was only 1 or 2%; however, the difference ranged from 10 to 15% in the older stands. These results suggest that INT trees, at least in stands less than 50 years old, are no more susceptible to invasion and spread of defect than D–CD trees and that they could develop stems with relatively low percentages of defective wood if adequately released. However, in stands more than 50 years old, trees in the intermediate crown class usually contained a substantially higher percentage of defective stem wood than their dominant and codominant neighbors and release at this stage would have little effect on stem quality.

The earlier report on this clonal study (Weingartner and Basham 1985) presented several tables of data, primarily stand averages, on the six stands. The present report differs in that many data on the individual clones within those stands are presented. The emphasis is more on clonal properties and potential, their variability within stands on uniform sites, and interclonal variability among individual trees. To get a better indication of each clone's potential, Tables 18 to 23 show stem size and defect data for only the dominant and codominant trees sampled in each clone. This also makes direct comparisons among clones within each stand more meaningful.

Stem dimensions for each clone are shown in columns 2 through 5 of the six tables. Despite growing on uniform sites, the interclonal variability in average stem diameters, heights and volumes within each stand is striking. In all but one stand (Stevens, Table 22) the average stem volume of the clone with the largest trees was more than twice the average stem volume of the clone with the smallest trees. Perhaps even more striking is the range in stem sizes within individual clones (Column 4, Tables 18-23). (Note that the same numbers, used for different stands, may mean different clones.) Diameter and height ranges are not shown, but within clones, the diameters of the sampled D–CD trees showed considerably more variation than did the heights of those trees. As a rule, the largest trees sampled within an individual clone had two to three, or occasionally even four (Clone 2, Table 18), times the volume of the smallest D–CD tree. This is a reflection of the fact that although all trees in the same clone have the same *potential* for growth (they are genetically identical), *actual* growth depends on many factors including the degree of competition, condition of the root system, quality of the microenvironment, etc. This makes it difficult to select the one clone in a stand that is

Table 17. Comparison of stem volume and defectiveness[a] in 600 dominant or codominant (D–CD) aspen and 200 intermediate (INT) aspen in six stands (10 clones per stand) in northern Ontario. (Trees were randomly selected: 12 D–CD trees and 4 INT trees per clone at Camp 15 and Ramsey Lake, 9 D–CD and 3 INT per clone at the remaining locations.)

				Number of clones (INT vs. D–CD trees)					
		Average inside-bark stem volume (dm^3)		Average volume of defect per stem		Average % of stem volume defective		Average % of stem volume defective	
Stand	Age	D–CD	INT	Higher	Lower	Higher	Lower	D–CD	INT
Camp 15	28	52	26	10	0	8	2	11.8	12.8
Ramsey Lake	30	89	43	9	1	9	1	12.7	16.0
Pinewood	40?	274	105	10	0	8	2	18.0	20.3
Kagiano Lake	65	630	223	8	2	10	0	19.9	29.2
Stevens	106	710	314	9	1	10	0	31.1	46.4
Anthony Lake	107	903	393	8	2	9	1	24.3	35.5
Total				54	6	54	6		

[a] Stem decay plus stain.

superior in growth characteristics to all of the other sampled clones. For example, in the Ramsey Lake stand (Table 19), clones 3, 9, 1 and 4 can clearly be ruled out because of their relatively small stems. Three clones (7, 10 and 2) had considerably higher average stem volumes than the others. Clone 7 had the largest average stem volume, but the largest individual tree was from Clone 10. One could claim that this indicates clone 10 to be a faster growing genotype than Clone 7 because the single large tree demonstrates the potential for growth that all trees in clone 10 possess. On the other hand, perhaps Clone 7 was the faster growing genotype but none of the 12 D–CD trees sampled were growing under ideal conditions that would have enabled them to demonstrate this capacity. In any event, from a practical point of view it is not necessary to identify the single superior clone in a stand. If clones can be delineated, it is relatively easy to select the clones with the best growth characteristics simply by choosing the clones that contain the largest trees and that have the best stem form.

Do aspen clones differ in their resistance to the development of stem decay and stain? Are some clones more likely to have extensive stem defect than others? Do virtually decay-free clones exist? Costly procedures to manipulate the clonal composition of stands in favor of fast-growing clones with good stem form would be ill advised if those clones were susceptible to extensive stem decay and stain, but might be worthwhile if those fast-growing clones were also relatively resistant to decay.

It is much more difficult to classify clones by stem defectiveness categories than by stem growth rates or form. Whereas clonal growth rates and stem form are established in immature stands and remain basically unchanged, levels of stem defect generally increase as stands and clones age, but at different and largely unpredictable rates. Thus, a relatively sound clone at age 28 (Camp 15) may develop considerable defect by the time it reaches maturity. Similarly, in overmature stands (e.g., Stevens, Anthony Lake) defective clones may have been relatively defect-free when sampled at age 75. In other words, when clones are sampled one obtains a "snapshot" of stem defect at that age, and this may not be indicative of the level of defect when the clone reaches harvestable age. Furthermore, stem defect is composed of essentially three distinct types (advanced decay, incipient decay and stain), and manufacturers of different aspen products—and even different mills that manufacture the same product—frequently have widely diverse views concerning the relative importance of the three defect types. For example, advanced decay is frequently converted in the chipping process to dust or fines in the manufacture of chemical pulps and never reaches the mill or digester, and thus is not regarded as a serious defect; however, extensive stain can be a major concern. On the other hand, advanced decay is a serious defect in the production of plywood, construction lumber and some particle boards, and is not tolerated, whereas 20 to 30% stained wood may be allowed. In a few products (e.g.,

Table 18. Average size and defectiveness of the 12 dominant or codominant aspen stems closest to the center of each of 10 clones in the 28-year-old "Camp 15" stand, about 25 km north of Manitouwadge in north-central Ontario.

Clone number	Average DBH (cm)	Height (m)	Avg. total stem volume (dm^3/tree) Range	Avg.	Avg. % of stem volume affected by Advanced decay	Incipient decay	Stain	All defects	Average weighted[a] volume of defect per tree (dm^3)	Avg. defect index[b]
3	11.7	14.8	42.9–121.7	73.6	0.5	0.8	6.6	7.9	7.57	10.3
10	12.0	12.7	38.4–110.3	69.3	0.7	2.8	8.1	11.6	11.44	16.5
7	11.9	12.4	40.0–119.1	64.1	1.8	1.2	12.7	15.7	16.95	26.4
6	10.9	12.2	32.5–88.9	56.9	0.1	0.5	10.2	10.8	3.75	6.6
1	10.2	13.2	36.5–116.1	53.5	0.1	0.2	4.7	5.0	1.73	3.2
2	10.1	13.0	23.6–110.3	53.4	0.1	0.7	7.8	8.6	3.11	5.8
5	10.4	12.7	33.9–67.6	51.1	0.5	2.0	9.5	12.0	7.02	13.7
9	9.7	10.7	23.4–53.5	38.3	0.8	1.0	11.3	13.1	3.24	15.5
8	9.6	11.0	27.8–63.5	38.2	0.7	1.1	17.5	19.3	6.97	18.2
4	9.2	10.7	21.0–49.8	32.8	1.2	1.2	8.5	10.9	6.14	18.7
Avg.	10.7	12.3	21.0–121.7	52.1	0.9	1.1	9.8	11.8	8.21	15.6

[a] Based on the relative importance of the three types of defect. The volume of stain, which accounted for 83% of the defect in these 120 trees, was halved; the volume of incipient decay was doubled; and the volume of advanced decay was multiplied by 10.

[b] The percentage of the average stem volume represented by the average weighted volume of defect. See explanation on page 33.

Table 19. Average size and defectiveness of the 12 dominant or codominant aspen stems closest to the center of each of 10 clones in the 30-year-old "Ramsey Lake" stand, about 35 km north of Manitouwadge in north-central Ontario.

Clone number	Average DBH (cm)	Height (m)	Avg. total stem volume (dm^3/tree) Range	Avg.	Avg. % of stem volume affected by Advanced decay	Incipient decay	Stain	All defects	Average weighted[a] volume of defect per tree (dm^3)	Avg. defect index[b]
7	15.8	14.4	52.0–185.3	130.4	trace[c]	0.9	10.7	11.6	9.60	7.4
10	14.7	15.4	60.9–226.3	124.8	0.8	1.9	13.4	16.1	23.47	18.8
2	15.5	13.4	57.9–162.9	119.1	0.1	0.3	9.3	9.7	8.00	6.7
8	13.7	13.1	54.5–156.8	92.0	0.1	0.6	14.3	15.0	8.61	9.4
6	13.3	12.6	55.8–125.9	85.1	0.2	1.0	13.6	14.8	9.42	11.1
5	13.2	12.7	48.1–130.5	83.6	0.1	0.8	9.3	10.2	6.37	7.6
4	12.4	12.8	48.6–89.7	74.8	-	0.1	9.1	9.2	3.58	4.8
1	11.9	12.5	39.9–115.6	63.1	0.2	0.3	8.3	8.8	3.88	6.1
9	11.2	13.1	38.6–123.9	61.3	0.1	2.1	18.2	20.4	8.48	13.8
3	11.4	12.3	35.0–89.9	58.9	-	0.2	7.7	7.9	2.45	4.2
Avg.	13.5	13.1	35.0–226.3	88.8	0.3	0.8	11.6	12.7	9.36	10.5

[a] Based on the relative importance of the three types of defect. The volume of stain, which accounted for about 91% of the defect in these 120 trees, was halved; the volume of incipient decay was doubled; and the volume of advanced decay was multiplied by 10.

[b] The percentage of the average stem volume represented by the average weighted volume of defect. See explanation on page 33.

[c] Less than 0.05%.

Table 20. Average size and defectiveness of the nine dominant or codominant aspen stems closest to the center of each of 10 clones in the 40(?)-year-old "Pinewood" stand, about 80 km northwest of Fort Frances in northwestern Ontario.

Clone number	Average DBH (cm)	Height (m)	Avg. total stem volume (dm^3/tree) Range	Avg.	Avg. % of stem volume affected by Advanced decay	Incipient decay	Stain	All defects	Average weighted[a] volume of defect per tree (dm^3)	Avg. defect index[b]
8	24.6	24.1	228.8–818.8	508.3	2.6	0.8	12.0	15.4	168.77	33.2
10	22.4	22.5	178.7–462.3	355.9	0.5	0.6	20.1	21.2	57.34	16.1
5	21.1	20.8	160.8–493.3	305.8	0.7	0.6	15.5	16.8	47.01	15.4
6	19.8	22.5	213.6–382.1	295.9	1.3	0.3	15.3	16.9	66.83	22.6
2	19.1	21.4	118.2–515.1	263.3	1.1	0.2	23.9	25.2	60.88	23.1
9	18.3	20.2	111.7–303.7	228.2	0.1	0.1	9.2	9.4	13.88	6.1
7	16.8	21.1	161.3–299.0	220.3	0.1	0.8	12.2	13.1	19.68	8.9
3	16.5	20.3	115.1–368.7	208.4	0.7	1.2	18.2	20.1	38.23	18.3
4	17.0	19.4	118.0–271.1	201.3	0.8	0.4	23.8	25.0	42.62	21.2
1	16.8	19.2	116.0–339.8	189.7	0.2	0.4	13.0	13.6	16.85	8.9
Avg.	19.6	21.2	111.7–818.8	273.8	1.2	0.7	16.1	18.0	57.20	20.9

[a] Based on the relative importance of the three types of defect. The volume of stain, which accounted for about 90% of the defect in these 90 trees, was halved; the volume of incipient decay was doubled; and the volume of advanced decay was multiplied by 10.

[b] The percentage of the average stem volume represented by the average weighted volume of defect. See explanation on page 33.

Table 21. Average size and defectiveness of the nine dominant or codominant aspen stems closest to the center of each of 10 clones in the 65-year-old "Kagiano Lake" stand, about 40 km northwest of Manitouwadge in north-central Ontario.

Clone number	Average DBH (cm)	Height (m)	Avg. total stem volume (dm^3/tree) Range	Avg.	Avg. % of stem volume affected by Advanced decay	Incipient decay	Stain	All defects	Average weighted[a] volume of defect per tree (dm^3)	Avg. defect index[b]
4	30.5	28.5	688–1,104	886	1.0	2.8	27.6	31.4	256.0	28.9
2	30.2	27.6	645–1,217	878	0.7	3.3	20.0	24.0	206.6	23.5
7	25.9	27.8	463–945	672	0.6	2.8	12.2	15.6	115.3	17.2
3	25.4	28.1	457–781	653	0.7	2.5	16.7	20.0	127.5	20.3
9	25.7	27.7	521–888	645	1.7	2.6	8.3	12.6	171.7	26.6
5	26.2	26.2	425–1,161	631	0.4	1.0	23.2	24.6	112.7	17.9
1	23.4	26.3	363–765	543	0.4	0.7	8.4	9.5	51.0	9.4
8	23.4	27.1	404–632	519	1.0	6.6	8.0	15.6	140.8	27.1
6	23.3	25.0	334–729	491	0.2	0.2	21.8	22.1	62.0	12.6
10	21.3	22.9	277–609	381	0.2	3.0	13.1	16.3	54.5	14.3
Avg.	25.9	26.7	277–1,131	630	1.0	2.3	16.5	19.8	146.0	23.3

[a] Based on the relative importance of the three types of defect. The volume of stain, which accounted for about 83% of the defect in these 90 trees, was halved; the volume of incipient decay was doubled; and the volume of advanced decay was multiplied by five.

[b] The percentage of the average stem volume represented by the average weighted volume of defect. See explanation on page 33.

Table 22. Average size and defectiveness of the nine dominant or codominant aspen stems closest to the center of each of 10 clones in the 106-year-old "Stevens" stand, about 45 km north of Manitouwadge in north-central Ontario.

Clone number	Average DBH (cm)	Height (m)	Avg. total stem volume (dm^3/tree) Range	Avg.	Avg. % of stem volume affected by Advanced decay	Incipient decay	Stain	All defects	Average weighted[a] volume of defect per tree (dm^3)	Avg. defect index[b]
7	32.5	25.6	510–1,188	898	2.5	9.8	8.3	20.6	192.1	21.4
5	31.8	24.4	645–996	831	2.5	9.4	23.9	35.8	239.9	28.9
6	31.0	25.3	616–1,029	827	10.0	4.8	23.4	38.2	384.8	46.5
1	32.0	23.5	608–1,188	826	5.7	4.4	16.6	26.7	246.0	29.8
3	30.5	25.0	519–1,339	727	12.4	3.0	23.2	38.6	377.2	51.9
8	30.7	23.2	592–849	712	7.9	5.8	9.2	22.9	243.2	34.2
10	30.0	22.6	521–817	688	1.2	6.5	16.1	23.8	125.0	18.2
9	26.4	23.8	428–858	596	8.2	3.5	20.5	32.2	228.0	38.3
2	26.2	25.0	442–787	567	0.9	1.9	27.9	30.7	104.8	18.5
4	26.7	22.3	367–643	521	10.9	4.1	23.7	38.7	253.1	48.6
Avg.	30.0	24.1	428–1,339	710	6.2	5.2	19.7	31.1	238.9	33.6

[a] Based on the relative importance of the three types of defect. The volume of stain, which accounted for about 63% of the defect in these 90 trees, was halved; the volume of incipient decay was not changed; and the volume of advanced decay was multiplied by three.

[b] The percentage of the average stem volume represented by the average weighted volume of defect. See explanation on page 33.

Table 23. Average size and defectiveness of the nine dominant or codominant aspen stems closest to the center of each of 10 clones in the 107-year-old "Anthony Lake" stand, about 35 km northwest of Manitouwadge in north-central Ontario.

Clone number	Average DBH (cm)	Height (m)	Avg. total stem volume (dm^3/tree) Range	Avg.	Avg. % of stem volume affected by Advanced decay	Incipient decay	Stain	All defects	Average weighted[a] volume of defect per tree (dm^3)	Avg. defect index[b]
6	36.6	29.3	886–2,409	1,438	7.8	7.3	18.9	34.0	572.1	39.8
8	34.8	30.2	949–1,783	1,349	4.3	1.5	8.1	13.9	286.0	21.2
5	32.3	29.9	778–1,468	1,031	6.7	5.7	28.5	40.9	420.5	40.8
10	34.3	26.8	659–1,494	1,011	3.4	4.3	16.6	24.3	233.0	23.0
4	31.2	29.0	684–1,195	913	1.4	5.0	18.6	25.0	167.3	18.3
1	29.5	28.9	742–1,080	910	3.5	2.7	6.1	12.3	148.2	16.3
3	28.7	28.1	651–1,000	790	3.3	3.8	21.8	28.9	187.9	23.8
9	26.4	28.7	580–1,035	727	5.8	4.4	12.3	22.5	203.5	28.0
2	27.9	24.7	479–845	649	4.4	4.8	20.8	30.0	184.4	28.4
7	24.9	25.6	407–911	558	1.9	7.4	21.1	30.4	133.1	23.9
Avg.	30.5	28.0	407–2,409	903	4.4	4.3	15.6	24.3	227.3	25.2

[a] Based on the relative importance of the three types of defect. The volume of stain, which accounted for about 64% of the defect in these 90 trees, was halved; incipient decay was not changed; and the volume of advanced decay was multiplied by three.

[b] The percentage of the average stem volume represented by the average weighted volume of defect. See explanation on page 33.

furniture lumber and chopsticks), all defects are considered serious and are eliminated if possible. Thus, a clone with a certain defect level at maturity may be considered of suitable quality by one manufacturer but unsuitable by another.

In a study of aspen clones in Manitoba, Wall (1971) concluded that there was no evidence that clones that combined fast stem growth, good form and relative freedom from stem decay were the norm. The earlier report on our Ontario clonal study supported this view with the conclusion that "the clonal dimension statistics are independent of the defect statistics" (Weingartner and Basham 1985). Only five of the 60 clones that we examined could confidently be classed as superior clones based on growth rate plus low levels of stem defect, and four of these were in immature (28- and 30-year-old) stands, with no guarantee that they would remain relatively defect-free until they reached harvest age. Analysis of the six stand tables (Tables 18 to 23) and of the stem defect in individual trees within the clones revealed marked inconsistencies in the relationship between clonal stem growth rate and the occurrence of stem decay and stain.

Tables 18 to 23 show the average extent of defect in the stems of the dominant or codominant trees in each of the 10 clones sampled in the six northern Ontario aspen stands. These stands range in age from 28 to 107 years, with only one (Kagiano Lake, Table 21, at age 65) at the stage of development ideal for harvesting. To compare clonal defectiveness within stands, different table columns can be used depending on the aspen product under consideration and the acceptable levels of decay and stain. Before discussing each table in detail, the method adopted for weighting the average volume of stem defect per tree (the second-last column in each table) should be examined. As indicated in the footnotes beneath each table, the volume of stained wood was halved for all six stands; in all but the two oldest stands, the volume of incipient decay was doubled; and the volume of advanced decay was multiplied by 10 in the three youngest stands, by five in the 65-year-old stand, and by three in the two oldest (over 100 years) stands. These factors were based on the presumed relative seriousness or impact of these types of defect as far as most forms of utilization are concerned. Advanced decay was given more weight in younger than in older stands to reflect its potential to develop into, or as an indicator of, higher amounts of advanced decay that would likely occur in the stems by the time they reached an age and size suitable for harvesting. Similarly, incipient decay is regarded as more serious in the younger than in the older stand because it normally develops into advanced decay with time.

The last column in Tables 18 to 23, the "defect index", is based on this method of weighting defect types. It clearly gives more weight to the volume of stem decay and less to

that of stem stain; therefore, in comparing stands or clones within stands, this column should be used where decay has a serious impact and some stained wood is acceptable. On the other hand, where stain is considered a serious defect and some decay can be tolerated, the average proportion of stem volume affected by all defects, regardless of type (third column from the right), can be used as a basis for comparison. The relative defectiveness of clones can sometimes depend on which method is used. Thus, Table 21 (Kagiano Lake) indicates that if stain is a serious defect but decay is of little concern, Clone 5 is the most defective of the 10 clones sampled. However, should decay be considered serious to unacceptable but some stain is allowable, five clones would be rated as more defective than Clone 5. Clone 1 would rate as the least defective clone regardless of which type of defect was considered the most serious (i.e., no matter which column was used).

The following paragraphs discuss each of the six aspen stands we studied in some detail, and describe the more interesting and meaningful differences in stem growth rate and defectiveness between and within the 10 clones examined in each stand.

Table 18 (the 28-year-old "Camp 15" stand) reveals that the nine D–CD trees in Clone 1 had the lowest average stem defect based on either the percentage of stem volume defective or on the defect index. Four other clones had larger average stem volumes. However, the largest sample tree in Clone 1, presumably that which most closely reflected the clone's growth potential, was just marginally smaller than the largest tree sampled in the stand (in Clone 3). Clone 1 is clearly a relatively superior clone, at least at this early stage in the development of this aspen stand. Clone 3 was also rated superior despite having only slightly less than the average level of stem defect. It did, however, have the largest stems of any of the clones sampled, including the largest tree in the stand (14.6 cm DBH, 16 m tall, with a stem volume of 121.7 dm^3). Clones 10 and 7 had relatively large average stem volumes (Table 18), but could not be rated superior because of average or higher-than-average levels of stem defect. Although clones 1 and 3 stand out as superior among the 10 clones, at age 28 this was a relatively young stand, possibly three or four decades away from reaching merchantable size. Very little stem decay is normally found in aspen that young; indeed, only one tree was affected by *F. igniarius* decay and no trees were infected by *Radulum casearium*, the other fungus responsible for most stem decay in trembling aspen. It is possible that one or both of these two "superior" clones could develop extensive stem decay by the time they reach a size suitable for harvesting, and at that time may no longer be classed as relatively superior.

In the Ramsey Lake stand, 30 years old when sampled, the three least-defective clones (numbers 1, 3 and 4) also had the smallest stems in terms of maximum stem volume (Table 19). On the other hand, two (clones 2 and 7) of the three clones with the largest stems were only slightly more defective than clones 1, 3 and 4, and because they were less defective than the stand average, they were classed as superior. The largest tree sampled in this stand was in the other fast-growing clone (Clone 10); it was 19.5 cm in DBH, 16.5 m tall and had a volume of 226 dm^3. Clone 10 had the second-largest average stem size; however, it was easily the most defective of the 10 clones, particularly as far as advanced and incipient decay were concerned. As in the case of the Camp 15 stand, the stand's immature stage of development and the fact that *F. igniarius* decay was apparently not yet established in any of the sampled stems make it impossible to predict whether clones 2 and 7 will retain their relatively superior rating when the stand reaches maturity.

The 10 clones sampled in the Pinewood stand, judged to be approximately 40 years old, are summarized in Table 20. This table shows clearly that none of the clones can be considered superior. Three of the clones (1, 7 and 9) had far less stem defect than the others; however, they were in the lower half of the clones in terms of average stem size. Clone 8 was easily the fastest-growing clone, with an average stem volume (508 dm^3) 40% larger than that of the second-fastest-growing clone (Clone 10). It also had the largest tree sampled (32 cm DBH, 25 m tall and a stem volume of 819 dm^3). Clone 8 did have a somewhat lower percentage of total defective stem volume than the stand average, but it had by far the most advanced decay of any clone and a higher level of incipient decay than the stand average. On that basis, Clone 8 can hardly be considered superior.

Thirteen of the 120 dominant–codominant aspen examined in the 40-year-old Pinewood stand had some advanced stem decay caused by *F. igniarius*. Two of the 13 trees were in Clone 8, and had the two largest volumes of *F. igniarius* stem decay in the stand. None of the other trees sampled in this clone, including the largest tree and the three trees classed as intermediate, were decayed by *F. igniarius*. In fact, the largest tree was the only one sampled in this clone that was completely free of any advanced decay. Although this 32-cm-diameter tree might be described as a "super tree" on the basis of size, clearly its freedom from advanced stem decay cannot be attributed to a genetic resistance to *F. igniarius* infection and development.

The 10 clones examined in the 65-year-old Kagiano Lake stand are summarized in Table 21. It is difficult to designate any of these clones as relatively superior, once again because the faster growing clones were generally the most defective. Two clones (numbers 2 and 4) had far greater average stem volumes than the others. The largest tree in clone 2 (35 cm DBH, 29 m tall and a stem volume of 1,217 dm^3) was also the largest sampled in this stand. Both it and the largest tree sampled in Clone 4 (1,104 dm^3)

had considerable stem decay caused by *F. igniarius*. Both clones had levels of stem stain above the stand average, and average levels of stem decay, and therefore could not be classed as superior. Despite ranking sixth in average stem volume, Clone 5 had the second largest tree sampled, with a stem volume of 1,161 dm^3. This tree had no advanced stem decay but did have considerable stain; in fact, Clone 5 was second only to Clone 4 in the extent of stain. The least stem defect occurred in Clone 1; however, this clone's stems were relatively small, the largest being only 765 dm^3. Clearly, no clone or clones in this stand can be classed as superior when growth rate and defectiveness are both considered.

In the 106-year-old aspen stand near Stevens (Table 22), the three sampled clones with by far the lowest defect indices were numbers 10, 2 and 7; the only two clones with less than 16% of stem volume stained were clones 7 (8.3%) and 8 (9.2%), and the clone with the largest average stem volume was Clone 7. Clone 7 is very clearly a relatively superior clone. Two of the nine other clones were considered potentially superior (Clone 5, which ranked second to Clone 7 in average stem size, and Clone 1, which ranked fourth in size). Clone 6 ranked third in size but was one of three extremely defective clones in this stand. However, Clone 5 had three times as much stem stain as Clone 7, higher than the stand average, and was rejected on that basis. The largest tree in Clone 1 was the same volume as the largest tree in Clone 7 (1,188 dm^3), but the nine trees sampled in this clone had more than twice as much advanced stem decay and twice as much stain as the trees in Clone 7; therefore, Clone 1 also could not be classed as superior. The largest tree sampled in the Stevens stand was in Clone 3; it was 40 cm in DBH, 26 m tall, and had a stem volume of 1,339 dm^3. This tree had an average amount of stem stain and very little advanced decay; however, seven of the eight other trees sampled in Clone 3 had considerable advanced decay as well as extensive stain. Two clones (clones 2 and 10) had very little decay, but they were among the four clones with the smallest average stem volumes. Of the trees sampled in all 10 Stevens clones, 44% had advanced stem decay, usually quite extensive, caused by *F. igniarius*. The only superior clone (Clone 7) had only one sample tree with this defect; this was the largest tree in the clone, with a total stem volume of 1,188 dm^3, including 84 dm^3 of advanced *F. igniarius* decay. Although Clone 7 appeared relatively superior when sampled at age 106, had this stand been harvested at age 70, it may not have been the largest and the least defective of the 10 clones at that time.

None of the 10 clones in the 107-year-old Anthony Lake stand stood out as superior clones when stem size and defectiveness were considered (Table 23). Of the six aspen stands involved in this clonal study, this stand had the greatest interclonal range in average stem volumes; the average stem volume of the two largest clones was roughly 2.5 times that of the two smallest clones (Table 23, column 5). Clones 6 and 8 had the largest average stem volumes by a wide margin. The largest clone (Clone 6) also contained the largest tree (50 cm in DBH, 29.5 m tall and a volume of 2,409 dm^3). This relatively huge tree (the second-largest tree sampled in this stand was 1,785 dm^3) also had the largest volume of advanced *F. igniarius* decay of any tree in the study, 503 dm^3. Clone 6 was one of the more defective clones sampled, and therefore could not be classed as superior. Clone 8 had a marginally smaller average stem volume than Clone 6, and the second largest tree, which was also extensively decayed by *F. igniarius*. Clone 8 had somewhat less stem decay and only half as much stain as the stand average, and appeared to be a borderline superior clone. However, closer examination revealed that most of the advanced decay and much of the stain in this clone occurred in four of the five largest trees sampled. On this basis, it was ruled out as a superior clone. Clone 1 was the least defective of the 10 clones sampled, but ranked sixth in average stem volume. As in the Stevens stand, 44% of the trees sampled at Anthony Lake had advanced decay caused by *F. igniarius*. It is interesting to note that of the 13 largest trees sampled, 10 had advanced *F. igniarius* stem decay, and the two greatest volumes of *F. igniarius* decay were found in the two largest trees.

The foregoing descriptions of inter- and intraclonal variations in stem growth rate and defectiveness are presented to emphasize what close examinations of Tables 18 to 23 reveal: marked variations in clonal growth rates and defectiveness and the absence of any consistent relationship between the two within the six stands studied. In addition, some of the more striking and significant variations in the types and extent of stem defects among trees within single clones were outlined.

Data from the 60 clones clearly refute the assumption that relatively fast-growing aspen clones would be less defective than slow-growing clones. Of the five clones classed as superior when both size and defectiveness were considered, four were in the immature (28- and 30-year-old) stands. At the other end of the scale, only six clones could be clearly classed as inferior, combining relatively slow growth rates with high levels of stem defect. The majority of the clones were either relatively fast growing, with average or above-average levels of stem defect, or relatively slow growing, with average or below-average levels of stem defect.

Examination of individual trees within clones provided additional evidence that there are no consistent relationships between growth rate of aspen trees and the extent of stem decay or stain. Examples of clones in which the most defective trees were the largest trees sampled (Kagiano Lake Clone 2, Stevens Clone 5, Anthony Lake Clone 8) are balanced by clones in which the most defective trees were the smallest trees sampled (Kagiano Lake Clone 7, Stevens Clone 4, Anthony Lake Clone 8). Similarly, in clones with

one tree that was considerably larger than the other sampled trees, this was one of the most defective trees in some clones and in others it was one of the least defective. Within almost all clones, individual trees, despite being genetically identical, exhibited great variability in the extent of various types of stem defect. This was particularly so in the case of advanced decay caused by *F. igniarius*. In the 20 clones more than 100 years old sampled at Stevens and Anthony Lake, advanced *F. igniarius* stem decay was present in roughly 46% of the 180 D–CD aspen sampled. The number of stems per clone with this type of defect ranged from one to seven of the nine stems; i.e., none of the 20 clones had all nine D–CD stems free of *F. igniarius* decay, but all had at least two stems free of this type of decay. In our earlier report on this clonal study (Weingartner and Basham 1985), we suggested that resistance or lack of resistance of aspen to *F. igniarius* stem decay appeared to be consistent throughout the population. Although many of the smaller trees in the intermediate crown class had *F. igniarius* decay, there was a tendency for the larger stems to be more frequently infected.

As far as *F. igniarius*, the principal cause of stem decay in mature aspen, is concerned, the foregoing observations lead to two broad postulations. The first is that aspen clones possess very little, if any, difference in their genetic resistance to natural *F. igniarius* stem infection. The second is that aspen stems are infected by *F. igniarius* largely by chance, with a tendency for larger stems of the same age to be somewhat more frequently infected, perhaps only because they usually have more and larger branch stubs, the most common infection court. Thus, larger trees can be regarded as larger "targets" for the billions of airborne spores of *F. igniarius* to which aspen stands are frequently exposed. It is difficult to find any data in this clonal study to refute either postulation. The data suggest that any interclonal variation in stem defectiveness is probably of insufficient magnitude and consistency to have any practical significance. Although it is possible to select clones that have somewhat superior stem form and growth rate, attempts to combine these characteristics with natural genetic resistance to stem decay and stain appear likely to fail.

SITE AND ASPEN QUALITY

Aspen in Ontario grows best on well-drained soils, with the best production occurring on loamy soils with a moderate silt plus clay content (Davidson et al. 1988). Shields and Bockheim (1981) noted that the stems of aspen clones growing on relatively dry sites were usually the first to break up and deteriorate within most climatic regions. The clonal growth habit of aspen must be considered when assessing the influence of site on stem growth, since a genetically superior clone growing on a poor aspen site can have faster height growth than a genetically inferior clone growing nearby on a good aspen site (Zahner and Crawford 1965). Thus, evaluations of site index in aspen stands should be based on observations on several clones, not just one or two.

Buse and Towill (1992) have developed site index curves for trembling aspen growing on a range of soil moisture regimes in the north-central region of Ontario. From these curves, the five stands of our clonal study that were in this region had the following approximate site indices when sampled from 1975 to 1977: Camp 15, Ramsey Lake and Stevens, site index 18; Anthony Lake, site index 22; and Kagiano Lake, site index 24. (The Pinewood stand was outside the region, but for the sake of comparison it would have had a site index of about 25 based on these curves.) The Camp 15, Ramsey Lake and Stevens aspen stands were identified under another system as Site Class 2 and the Kagiano Lake, Pinewood and Anthony Lake stands as Site Class 1 (Plonski 1974).

The interclonal variations in mean heights of D–CD aspen in the six stands used in the clonal study (Tables 18 to 23) emphasize the fact that several clones must be used in the identification of a stand's site index or site class. The range from the tallest to the shortest clone spanned two site classes in four of the stands, and three site classes in the Camp 15 stand (Clone 3 was near the lower limit of site class 1 and clone 4 was near the upper limit of site class 3). In the Pinewood stand, the clone with shortest mean height was near the lower limit of site class 1 and the tallest clone, Clone 8, exceeded the upper limit of site class 1. Inaccurate site quality assessments can result if the clonal composition of aspen stands is ignored and only a small area of the stand is sampled. In a study of 31 clones in northern Ontario, Kemperman (1977) found that the average aspen clone covered 0.12 ha, with the largest clone occupying 0.53 ha. He reported having observed clones in northern Ontario covering as much as 2 ha (5 acres). To ensure that several clones are sampled during site classification, trees from widely scattered locations in the stand should be measured.

In a study on clonal variability in aspen stem decay carried out in Manitoba, Wall (1971) examined four extensive clones, each of which was growing on two distinctly different sites (two clones on wet, poorly drained and on moist sites; one on wet, well drained and fresh sites; and one on moist and fresh sites). In three clones, average stem volumes were, respectively, nonsignificantly greater: (i) on the wet, poorly drained site than on the moist site; (ii) on the moist site than on the wet, poorly drained site; and (iii) on the fresh site than on the moist site. In the fourth clone, a significantly greater average stem volume occurred on the wet, well-drained site than on the fresh site. Wall concluded that "... it is apparent that clones differ in their site preferences" as far as growth rates are concerned. In terms of the percentage of stem volume "decayed"

(probably decay plus stain) in the four clones, no significant differences were found between sites for any clone. For the four clones, nonsignificantly higher decay percentages occurred on wet, poorly drained sites for two clones (versus moist sites); on the fresh site for one clone (versus a wet, well-drained site); and on the moist site for one clone (versus a fresh site). These results indicate that, within aspen clones occupying more than one site, the extent of stem decay and stain is not consistently related to the site differences.

In the OMNR–Forestry Canada aspen clonal study discussed earlier in this report, one of the 10 clones in the Anthony Lake stand (Table 23, Clone 9) was considerably larger than the others and extended over two distinctly different sites. The sample of nine dominant or codominant trees from Clone 9 in Table 23 was referred to as "site zone 9" within this clone. These nine trees plus the trees from the other clones occupied a fairly uniform site with a fresh moisture regime (ranging between 2 and 3). Another sample of nine trees was taken from the portion of Clone 9 situated on a moist site (moisture regime 5), referred to as site zone 9b. A third sample of nine trees (referred to as site zone 9a) was obtained from the portion of the clone between the zone 9 and 9b samples. This "transitional" zone was judged to be on a fresh site (moisture regime 3). In the earlier report on this study (Weingartner and Basham 1985), site zones 9a and 9b were referred to as plots 11 and 12.

A comparison of Clone 9 with the average for all 10 clones on moisture regimes 2 to 3 in the Anthony Lake aspen stand indicates that it was below average in stem DBH and slightly above average in stem defectiveness (Table 24). Thus, Clone 9 could be considered a relatively inferior clone. Table 24 also shows the average size and extent of stem defect in the nine dominant or codominant aspen from each of the three site zones occupied by Clone 9. Although trees from zones 9a and 9b were less defective than those from zone 9, these differences were statistically nonsignificant. The average size of the trees sampled in site zone 9b was appreciably larger than that in zones 9 and 9a, and was only slightly below the stand average. However, the only statistically significant difference was the shorter height of the trees in zone 9a compared with trees sampled in zones 9 and 9b. Clearly, the trees sampled in site zones 9, 9a and 9b revealed no strong evidence that site differences within a clone have much influence on tree growth rate or defectiveness. This is in accord with the results obtained from aspen clones in Manitoba (Wall 1971).

Trembling aspen occurs on a wide range of soil/site conditions in Ontario, especially on dry to fresh, coarse loamy upland soils (Baldwin and Sims 1989). In their silvicultural guide for the poplar working group in Ontario, Davidson et al. (1988) point out that "aspen is relatively productive over a large range of sites", but that dry or dry to fresh sites (drier than soil moisture regime 2) or very wet sites are generally not suitable for trembling aspen production. They even question the suitability of soils with moisture regimes greater than 3 (including moist as well as wet sites) for trembling aspen management. In the two large-scale studies of trembling aspen stem defect in Ontario (involving a total of 4,212 mature and overmature trees), our data indicated that the poorer sites for tree growth, particularly drier sites, tended to be associatedwith marginally higher levels of stem decay and stain than the better aspen sites (Basham 1991).

This tendency for off-site aspen to be somewhat more defective than aspen growing on optimum sites was supported by data from the Anthony Lake and Stevens stands in our clonal study (Tables 22 and 23). These stands, roughly 25 km apart, were about the same age, with most

Table 24. Average size and defectiveness of the nine dominant or codominant aspen stems closest to the center of each of three zones on different sites within Clone 9, plus averages for all 10 clones, in the 107-year-old "Anthony Lake" stand, about 35 km northwest of Manitouwadge in north-central Ontario.

Anthony Lake clone number	Moisture regime	Average DBH (cm)	Average Height (m)	Total stem volume (dm^3) Range	Total stem volume (dm^3) Avg.	Avg. % of stem volume affected by: Advanced decay	Incipient decay	Stain	All defects	Average weighted[a] volume of defect per tree (dm^3)	Avg. defect index[b]
Avg.[c]	2–3	30.5	28.0	407–2,409	903	4.4	4.3	15.6	24.3	227.3	25.2
9	2–3	26.4	28.7	580–1,035	727	5.8	4.4	12.3	22.5	203.5	28.0
9a	3	26.4	27.1	494–923	702	1.8	3.1	8.3	13.2	88.2	12.6
9b	5	29.5	28.5	627–1,196	888	2.9	2.3	8.4	13.6	134.1	15.1

[a] Based on the relative importance of the three types of defect. The volume of stain was halved, incipient decay was not changed and the volume of advanced decay was multiplied by three.

[b] The percentage of the average stem volume represented by the average weighted volume of defect.

[c] Data from Table 23.

sampled trees ranging in age from 103 to 110 years. From soil pits dug within each of the sampled clones, OMNR personnel concluded that the Anthony Lake clones covered soil moisture regimes 2 to 3 (generally regarded as the optimum for trembling aspen), whereas the Stevens clones covered moisture regimes 3 to 4. The 90 dominant or codominant aspen sampled from Anthony Lake had larger stems (average volume 903 dm^3, height 28 m) than the 90 trees from Stevens (average volume 710 dm^3, height 24 m). In addition to being larger on sites with soil moisture regimes 2 to 3 the trees were also less defective (an average stem volume affected by decay and stain of 24%, versus 31% in the trees from Stevens) than trees sampled on sites with soil moisture regimes 3 to 4 at Stevens.

Data from the two other stands in our clonal study that were roughly the same age (28 and 30) and not far apart (roughly 10 km), Camp 15 and Ramsey Lake, offer somewhat more tenuous support for this theory. The stands were selected for this study by OMNR staff because they appeared to be growing on different sites. Again, soil pits were dug within areas covered by each of the 10 clones studied in each stand. The Camp 15 stand was sampled in 1976 and the soil moisture regimes were judged to range from 2 to 3, with an average moisture regime of 2. The Ramsey Lake stand was sampled the following year. Unfortunately, mainly because of staff turnovers, moisture regimes were not determined, although information on soil texture, shrubs, etc. was collected.

Tables 18 and 19 show that the average dominant or codominant tree sampled in 1976–1977 in the Ramsey Lake stand was larger than that sampled in the Camp 15 stand. The differences in average stem volume (89 versus 52 dm^3) and DBH (13.5 versus 10.7 cm) are greater than one would expect based simply on the fact that the Ramsey Lake stand was 2 years older than the Camp 15 stand when sampled. However, the average heights of the dominant or codominant aspen were 13.1 m at Ramsey Lake and 12.3 m at Camp 15, indicating that the two stands had very similar site indices, close to site index 18 (Buse and Towill 1992). This suggested that perhaps there was not that much difference in the two sites as far as aspen growth and productivity are concerned; Tables 18 and 19 show little difference between the two stands in terms of stem defectiveness; the trees at Ramsey Lake had a slightly higher percentage of defective stem volume (12.7 versus 11.8%), but the Camp 15 trees had a higher proportion of that defect in the form of the more serious advanced decay.

Additional work was carried out in these two stands in 1986. One reason for selecting these stands for the clonal study in 1976 was that they were among the oldest pure aspen stands of cutover origin available in the province. As discussed earlier, to investigate the fear that aspen of cutover origin might be even more defective than aspen of natural (mostly fire) origin, we needed the oldest available stands of cutover origin to allow more meaningful comparisons of defect development with increasing stand age. By 1986, these two stands were 38 (Camp 15) and 39 (Ramsey Lake) years old and were considered to be ideal for this purpose. Results of those comparisons have been discussed earlier in this report (see Table 2).

The same portions of each stand used in the clonal study were sampled again in 1986. A grid of line transects was established, with the nearest dominant or codominant aspen to be sampled at each of 150 preselected points on the grid, except that trees closer than 10 m to a stand opening resulting from the earlier clonal study were excluded. A complete sample of 150 D–CD trees was obtained in the Camp 15 stand; however, no aspen that were unquestionably dominant or codominant trees were present in the vicinity of 22 of the preselected points in the Ramsey Lake stand. Consequently, only 128 D–CD trees were sampled in this stand.

Table 25 summarizes the size and stem defect statistics obtained from D–CD aspen sampled in the two stands in 1976–1977 and in 1986. The Camp 15 data reflect a more or less normal increase in stem defect volume and stem size in the decade between samplings. Although the volume of stem defect increased by about 33%, the percentage of the stem volume affected by defect actually decreased because of the much greater relative increase in total stem volume over that period. The ratio of decay to stain was much higher in 1986 than it was in 1976. The average D–CD stem height of 15.6 m indicated a site index of 18 (Buse and Towill 1992) for this stand, similar to that indicated by the 1976 sample.

The average size of the 128 D–CD aspen sampled from the Ramsey Lake stand in 1986 was only slightly larger than that obtained 9 years earlier, in 1977 (Table 25). The average height of 13.9 m in 1977 indicates a site index of 16 versus a site index of 18 in 1977, and the Ramsey Lake aspen stand was reduced to site class 3 (from site class 2) 9 years earlier (Plonski 1974). Table 25 shows that the average volume of 120 D–CD trees sampled in the Ramsey Lake stand was 88.8 dm^3 compared with 52.1 dm^3 for the 120 D–CD trees from Camp 15 in 1976–1977; however, the situation was reversed in 1986, with the average D–CD aspen from Camp 15 having a slightly larger stem volume than the average Ramsey Lake tree (112.7 versus 101.4 dm^3). In 1986, five D–CD aspen were chosen randomly in each of the two stands. Measurement of the annual growth rings at a height of 1.5 m revealed that diameter growth over the previous 10 years in the Camp 15 trees was slightly reduced compared with earlier growth. In the Ramsey Lake trees, this growth reduction was considerably more pronounced, and the diameter increment over the previous 10 years was approximately half of the diameter increment that took place in the five Camp 15 trees.

Table 25. Comparison of stem defect, tree size and apparent growth rate in dominant and codominant aspen in two stands of similar age, 10 km apart, near Manitouwadge, Ontario, based on sampling carried out in 1976–1977 and in 1986.

Stand	Year sampled	Avg. age (years)	Number of trees	Average volume of decay and stain per tree (dm^3)	Average % of stem volume affected by decay and stain	Average stem[a] DBH (cm)	Height (m)	Volume (dm^3)
Camp 15	1976	28	120	6.14	11.8	10.7	12.3	52.1
	1986	38	150	8.21	7.3	13.7	15.6	112.7
						(28.0)	(26.8)	(116.3)
Ramsey Lake	1977	30	120	11.30	12.7	13.5	13.1	88.8
	1986	39	128	11.05	10.9	13.7	13.9	101.4
						(1.5)	(6.1)	(11.3)

[a] number in brackets = % increase, 1976–1986

Meteorological records show that the growing seasons from 1976 to 1986 were somewhat hotter and drier than normal in this region. This could account for much of the relatively small reduction in stem growth in the Camp 15 stand. The question that naturally arises is why both the height and diameter growth rates of the D–CD aspen in the Ramsey Lake stand were apparently reduced to such a greater degree than those in the nearby Camp 15 stand during that decade. That different sampling procedures were used in 1976–1977 and in 1986 can be ruled out, since exactly the same procedures were used in each stand. What appeared to be significant was the discovery of an impervious layer of clay and silt about 2 cm thick approximately 20 cm below the surface at six random locations in the Ramsey Lake stand. This had not been included in the soil pit descriptions made in 1977. It seems likely that the relatively hot and dry growing seasons from 1976 to 1986 resulted in severe desiccation in the soil above this impervious layer. In the mid 1970s, most aspen roots probably found it difficult to penetrate the clay–silt layer to reach the moister soil below, hence the trees were subjected to considerable moisture stress. No such impervious layer could be found in the soil of the Camp 15 stand in 1986. An additional hint that the Ramsey Lake site had less available soil moisture than the Camp 15 site was provided by the virtual absence of mountain maple (*Acer spicatum* Lam.) in the shrub layer of the Ramsey Lake stand; in contrast, this species occurred profusely in the Camp 15 stand. The abundance of beaked hazel (*Corylus cornuta* Marsh.) in the shrub layer of the Ramsey Lake stand was also significant: in northern Ontario, hazel has a tendency to occur on somewhat drier than normal sites, whereas mountain maple has the opposite tendency (Bell 1991).

Both Ramsey Lake and Camp 15 stands occurred on deep mineral soils of similar texture except that the proportion of clay at Camp 15 was roughly four times higher than that at Ramsey Lake. The presence of an impervious layer about 20 cm deep in the Ramsey Lake but not in the Camp 15 stand suggests the former had a somewhat drier soil moisture regime than the latter. This is supported, admittedly somewhat weakly, by differences in the composition of the shrub layer in the two stands. Based on an examination of the 10 soil pits dug in Camp 15 and other evidence, soil scientist Dr. Geoff Pierpoint of OMNR judged that the Camp 15 stand had an average soil moisture regime of 2. Had Dr. Pierpoint or someone with his experience in soils and site classification done a similar review of the Ramsey Lake stand site, I am confident that it would have been designated as soil moisture regime 1 or possibly 1 to 2.

In the 1986 samples of D–CD aspen in the two stands, the average percentages of total stem volume affected by decay or stain were 10.9% at Ramsey Lake and 7.3% at Camp 15. These results support the theory that aspen growing on drier sites (drier than soil moisture regime 2) are likely to have somewhat higher levels of stem defect than aspen growing on sites with moisture regime 2 or 3.

IMPLICATIONS FOR ASPEN MANAGEMENT

Trembling aspen is one of the most defective of Ontario's forest tree species, particularly among the species of major commercial importance (Basham and Morawski 1964, Basham 1991). The wisest methods of managing aspen, based on all of our available knowledge, cannot transform it into a relatively defect-free, sound species such as black spruce (*Picea mariana* [Mill.] B.S.P.) or red pine (*Pinus resinosa* Ait.). Nevertheless, several things can be done (or avoided) to minimize the impact of stem decay and stain; many of these have been touched on in this report. However, because the report attempts to cover a wide variety of topics, it is necessarily somewhat disjointed, and an assortment of management recommendations are scattered throughout the text. This final section of the report will summarize the major points relating to management of the species. The topics will not be discussed in the same

order that they appeared in the text. Two or three points not yet covered in the report have been added because I felt their relevance and importance dictated their inclusion.

Root decay and defect

As soon as we began examining the root systems of young aspen suckers and immature trees, it became apparent that this species is generally even more defective below ground than it is above ground. Rather large tunnels (8 to 11 mm in diameter) were found in the center of one or more roots or in the root collars of more than half of the root systems we examined. These were caused by larvae of the ghost moth, and are apparently widespread in Ontario (Gross and Basham 1981). All trees sampled were dominant or codominant; casual observations revealed ghost moth damage was of the same frequency, or of even less frequency, in the intermediate and suppressed trees. Only limited stain surrounded the tunnels; hence, it appears that the ghost moth has very little impact on tree health or vigor. The main drawback of this damage stems from the fact that the larvae form access holes to the outside of roots through which frass and debris are expelled; these openings can serve as entry points for root-decaying fungi.

Stained (discolored, but firm) wood was found in the root systems of all 100 undisturbed aspen suckers we examined that were between the ages of 4 and 15; decayed (discolored and weakened) wood was found in roughly 75% of them. *Armillaria* spp. caused most of the decay in aspen roots. These fungi can spread from an infected root to a healthy root via root contact, and they travel through the soil in the form of rhizomorphs that penetrate roots via wounds (scarification wounds, stone bruises, etc.) or directly through intact bark. Again, the fact that we examined only root systems of dominant or codominant aspen suckers suggests that, at least during this stage of their development, root stain and decay has little impact on sucker growth. However, extensive colonization of the root system by decay fungi such as *Armillaria* spp. can eventually lead to basal stem decay, reductions in height and diameter increment, a predisposition to windthrow and breakage, and even directly to tree mortality.

Stem decay

By the time aspen suckers reach the age of 3, virtually all stems contain some stained wood. These stains, as a rule, are not caused by fungi. They are more likely to be of physiological rather than pathological origin, triggered by aeration and desiccation at openings through the protective bark via dead or broken branches, stem wounds, and dead or broken tops caused by frost, animal browsing, insect or fungal activity, etc. Few aspen reach the age of 3 without any such stem injuries (virtually none by age 10); hence, the development of some stain in young aspen stems is inevitable. By age 30, roughly 10 to 12% of aspen stem volume in the form of stained wood can be expected. Some of that stain may well be pathological, i.e., caused directly by the activity of microorganisms, perhaps including decay-causing fungi.

The stems of all 51 undisturbed aspen suckers sampled at age 5 (Table 10) contained some stained wood, and 32 (63%) also contained measurable amounts of decay. The decayed wood amounted to an insignificant 0.4% of the total stem volume of these 5-year-old suckers. Nevertheless, it indicates how early decay development can start in aspen stems. Decays are caused by fungi, which usually gain entrance to the stem via breaks in the protective bark sheath. Some of the decay pockets were associated with small stem wounds, but the majority were within the stained zones extending inwards from branch stubs. Most decay pockets in vigorous trees this age will be sealed off ("compartmentalized") and will enlarge little if at all. However, as aspen ages, many more new entry points for decay (branch stubs, broken tops, fire scars, etc.) will arise, each a potential site of infection. Larger branch stubs, 1.5 cm or more in diameter, are the most common point of origin of extensive decay pockets in mature aspen. At age 30, between 1 and 2% of aspen stem wood is generally decayed.

Spraying to promote conifers

Spraying young aspen sucker stands to temporarily suppress aspen development and thereby favor the growth of underlying (usually planted) conifers was observed to have little short-term effect on the aspen other than top-kill, which occurred on virtually every sprayed tree. Some stain originated from the dead tops and extended downwards in the stem; however, it seldom extended more than 70 cm downwards, and did not spread into any wood formed after the spray treatment. Hence, it was of little consequence. The killed tops were not an entry point for stem decay, except for occasional very small compartmentalized pockets. Stem crooks resulting from lateral branches assuming apical dominance near the base of the top-kill were barely distinguishable 12 years after the spray treatment. Furthermore, it is normal for two or more stem crooks to occur on young aspen stems, the result of leaders being broken or killed by any of a number of agencies. The only meaningful effect on aspen stand quality resulting from herbicide spraying appears to be the additional time required for the aspen to attain crop size; for example, we observed that treated trees were still growing at a slightly slower rate than were unsprayed trees 12 years after the spray.

Effect of scarification

Scarification of young aspen sucker stands is also used to suppress aspen growth temporarily, but mainly to reduce the volume of slash and disturb the topsoil and humus layers to assist in the establishment and growth of subsequently planted conifers. Our studies show somewhat different

effects on the quality of the surviving aspen, depending on the age of the suckers when scarified. In 1- or 2-year-old stands, many suckers in the paths of the machinery can be killed, but this appears to have no adverse effect on subsequent stand density or stocking. Relatively few scarification wounds are inflicted on the roots or stems of the survivors. Some 1-year-old suckers directly in the path of the machinery can be flattened but not killed; many of those have mild to pronounced basal stem crooks at maturity as a result. Because of the resiliency of young 1- and 2-year-old aspen stems, scarification machinery frequently bends the stems momentarily but does not wound them. Surviving aspen generally sustain only minor reductions in growth rate for a few years, and they will likely differ little in stem quality from unscarified aspen at maturity.

In aspen sucker stands 3 years old or older, far fewer aspen are killed by the scarification operation than in younger stands. However, by age 3 the distal parent roots of the suckers have generally increased appreciably in diameter and are closer to the ground surface, and hence are more likely to be wounded by scarification machinery. Root-system wounds, which occur mainly in the distal parent root and at the root collar, appear to reduce the stem growth rate and serve as entry points for root-decay fungi such as *Armillaria* spp. Most sucker stems are larger and less resilient than those of 1- or 2-year-old aspen, and therefore are frequently wounded by the scarification machinery. All but the smallest such wounds are associated with above-normal levels of stem stain, and most with zones of stem decay. The extent of stem decay and stain in surviving wounded suckers is significantly greater than that in undamaged stems, and is directly related to the size, severity and number of stem wounds. Wounding and stem defectiveness were more pronounced in aspen scarified at age 6. When these trees attain crop size, it appears that this excessive defect will extend only a limited distance above the wounded portion of the stem (the lowermost 1 to 1.5 m). However, this extensive basal stem decay could result in stem breakage prior to harvesting. Furthermore, the excessive root system decay resulting from scarification may predispose the scarified aspen to windthrow. Clearly, to utilize the sound stem wood above 1.5 m in these trees, such stands should be harvested as soon as possible after they reach merchantable size.

Natural versus cutover stands

We will not be able to directly compare the defectiveness at rotation age of aspen stands of natural (mostly fire) origin in northern Ontario with those of cutover origin for some time, since very few stands originated from cutovers before 1945. Nevertheless, we can at least make some predictions by examining the amount of stem defect in our oldest aspen stands of cutover origin and comparing them with levels in aspen stands of fire origin at similar ages. Based on 278 dominant or codominant aspen ranging in age from 37 to 40, felled and dissected in 1986 in stands of cutover origin, there was no evidence that such aspen will be noticeably more or less decadent than their parent stands of natural origin (Table 2). In 35 trees of fire origin in the 31–40 year age class (average age 37 years), the average proportion of total stem volume affected by stain or decay was 7.7%, compared with 9.2% in the 278 aspen of cutover origin. However, although 2.6% of the stem volume of the fire-origin trees was decayed, only 0.7% of the volume of aspen of cutover origin was decayed. By 1996 or so, a more meaningful indication can be obtained when data on 731 fire-origin aspen, with an average age of 49 (Table 2), can be compared with 50-year-old aspen of cutover origin. For now, at least, there appears to be no basis for concern that aspen stands arising from cutovers will be any more defective than their parent stands.

As aspen trees progress beyond age 30 to maturity and overmaturity, new branch stubs are formed and sometimes stems are wounded. Some stained stem wood is generally associated with each new branch stub or dead branch, so the total volume of stain increases with age (although some may be replaced by decay, and in rare instances the total volume of stain will therefore decrease). The volume of stem decay generally increases steadily with age, as does the percentage of the merchantable stem volume decayed (Table 16), since each new branch stub or stem wound is a potential entry point for stem-decay fungi. More than 75% of the stem decay in aspen is caused by one fungus, *Fomes igniarius* (renamed *Phellinus tremulae*). Zones of *F. igniarius* decay, occupying all or most of the heartwood and extending up to 7 or 8 m vertically, are sometimes encountered in mature aspen. The very soft, spongy decayed wood is virtually useless. Prevention of stem infections by this fungus is clearly desirable, but difficult to accomplish since literally billions of airborne spores are produced by each fruiting body (conk) of the fungus, and these can travel miles and retain their viability. Since branch stubs appear to be the principal infection court, the usual recommended practice is to maintain a uniform, fully stocked stand in which natural self-pruning results in earlier branch death and therefore in smaller-diameter branch stubs, which heal over faster, thereby reducing the chances of *F. igniarius* infection. The development of young, fully stocked aspen stands has been recommended to reduce the incidence of the serious Hypoxylon canker disease, which, under certain circumstances, can cause aspen mortality. Aspen should also be protected from fire wounds and other stem wounds, since these can also serve as infection courts for *F. igniarius* and other decay-causing fungi.

Effect of site

The publication *A Silvicultural Guide for the Poplar Working Group in Ontario* (Davidson et al. 1988) defines

sites suitable for trembling aspen management as having well-drained and well-aerated soils with a constant supply of moisture, and a soil moisture regime of 2 to 3 (fresh to very fresh). The increasing industrial demand for aspen in Ontario has helped to promote the idea that, under certain circumstances, attempts to convert aspen or mixedwood stands to coniferous stands are of questionable value. This is particularly true on the best aspen sites, where stand conversion can be difficult because of prolific suckering of the aspen and its rapid early growth (Doucet 1989). When aspen management is planned for such sites it is widely believed that post-harvest scarification will promote optimum sucker development. Preliminary results from trials carried out in four scattered areas in northern Ontario suggest that the intensity of scarification had little effect on the growth rate and quality of the suckers sampled at age 5. However, the timing of the post-harvest scarification might be critical. Although our results are based on only 5 years of sucker growth and should only be considered preliminary in nature, they strongly suggest that scarification should be carried out in spring before the suckers emerge. Late-spring to early-summer treatment, when the suckers were 30 to 40 cm tall, had the poorest results, even poorer than when the scarification was carried out in the fall after the suckers had completed 1 year's growth.

Unlike with species such as jack pine (*Pinus banksiana* Lamb.) and black spruce, there is no statistically significant relationship between site and the incidence of stem stain and decay in aspen in Ontario (Basham 1991). In two large-scale studies of aspen in Ontario carried out in the 1950s, involving more than 4,000 trees, there was a tendency for aspen growing on the best (fresh) sites to be less defective than aspen on drier or moister (wetter) sites. In our clonal study, in which data was collected from 10 clones in each stand, this relationship was tested in two pairs of stands of similar ages. The Camp 15 and Ramsey Lake stands, 28 to 30 years old, were on sites judged to be soil moisture regimes 2 and 1 (or 1 to 2), respectively. The Anthony Lake and Stevens stands, 106 and 107 years old, were judged to be on sites with fairly uniform soil moisture regimes 2 to 3 and 3 to 4, respectively. In both cases, the stands on sites with moisture regimes 2 and 3 (Camp 15 and Anthony Lake) were less defective than the stands on drier (Ramsey Lake) and moister (Stevens) sites. The clonal study also provided evidence that sites with soil moisture regimes 2 and 3 support the fastest height growth of aspen. Only two of the six stands (Stevens and Ramsey Lake) were not located on sites with moisture regimes 2 or 3, and they were the two stands with the lowest site indices. Thus, the 800 aspen we sampled in the clonal study support the already published conclusions that soil moisture regimes 2 and 3 generally are associated with better growth (Davidson et al. 1988) and with somewhat less stem defect (Basham 1991) in northern Ontario aspen.

Clonal growth habit of aspen

Most trembling aspen in northern Ontario originate vegetatively as root suckers, and occur as clones, groups of individuals that originated from a single parent tree. Thus, all individuals within a clone are genetically identical and have the same potential maximum growth rate. In determining site class or site index of a stand of aspen, therefore, measuring several trees that are part of the same clone may be equivalent to measuring only one tree. In the six aspen stands that formed the basis for our clonal study, the range from the tallest to the shortest of the 10 sampled clones spanned two site classes (Plonski 1974) in four of the stands, and three site classes in the Camp 15 stand. Since some clones cover an area as large as 2 ha, and clones are virtually indistinguishable except during 2 or 3 weeks in the spring and fall, accurately determining site index for an aspen stand requires sampling in a manner that ensures at least three or four clones are included.

One of the 60 clones we studied covered an exceptionally large area and occupied three fairly distinct sites. We examined dominant and codominant aspen on each of the sites to test the influence of site on tree dimension and defect parameters within a single clonal genotype. There were no significant differences in either category. Similar results were obtained by Wall (1971) in four large aspen clones in Manitoba. These results lead to the conclusions that (a) the relationship between site and stem defect incidence in aspen is relatively weak and probably not significant, and (b) the influence of site on aspen growth rate within clones is secondary to other factors such as the degree of competition, microenvironment, and so on.

Clonal variation

Only five of the 60 clones we studied could unquestionably be classified as superior clones on the basis of both tree growth rate and stem defectiveness. Four of these five clones were in immature 28- and 30-year-old stands, the age at which decay development is really just beginning, so there can be no assurance that those clones will still be relatively defect-free by the time they attain merchantable size. The supposition that relatively fast-growing, vigorous clones would be more resistant to stem decay and stain than slow-growing clones was not borne out by our results. Only six clearly inferior clones, with relatively slow growth rates and high levels of stem defect, were detected. The majority of the clones (49 out of 60) were either relatively fast growing, with average or above-average levels of stem defect, or relatively slow growing, with average or below-average levels of stem defect. Similar results from aspen clones in Manitoba were reported by Wall (1971).

The results of the joint federal–provincial clonal study suggest that if it should be feasible to manage aspen clonally by favoring the regeneration of fast-growing clones over

slow-growing clones, there is little likelihood that the levels of stem decay and stain in the new stand will be any lower than if all clones had been allowed to regenerate freely. Within an aspen stand, any interclonal variation in stem defectiveness appears likely to be of insufficient magnitude and consistency to have much practical significance. Although it is possible to select clones, or at least individual trees, with superior stem form and growth rate, attempts to combine those characteristics with natural genetic or other forms of resistance to stem decay and stain appear likely to fail.

We found no evidence that there are aspen clones with complete genetic resistance to *Fomes igniarius* infection and decay. Extensive decay caused by this fungus was found in at least two trees in each of the 20 clones studied that were more than 100 years old. Twelve trees were examined in each clone, and at least two trees completely free of *F. igniarius* were also found in each of these mature clones. There were many examples of genetically identical aspen growing within 3 or 4 m of one another, one with no *F. igniarius* decay or much decay of any kind, and the other with an *F. igniarius* decay column extending 4 to 5 m vertically. There were no significant differences among clones in any of the stands we studied in the frequency with which *F. igniarius* was isolated from the stems (Weingartner and Basham 1985). Roughly 6,000 attempts were made to isolate microorganisms from the 800 trees sampled in the clonal study. The results from trees with no *F. igniarius* decay, but which belonged to clones in which many trees did have decay caused by that fungus, were examined carefully. No fungus or bacterium was consistently isolated from such trees, suggesting that the absence of *F. igniarius* decay was not due to the presence of specific microorganisms in the stems acting as natural biological control agents. It is difficult to avoid concluding that chance plays a major role in whether viable spores of *F. igniarius* reach susceptible aspen tissue at a time when all conditions are favorable for successful spore germination, invasion and colonization of the stem.

Tree size

In 90% of the aspen clones we examined, the largest trees sampled, those in the dominant or codominant (D–CD) crown classes, had greater average volumes of stem defect but lower percentages of total defective stem volume than the trees in the intermediate crown class, the smallest trees sampled. When the D–CD trees in each clone were divided in two groups, with one group composed of the largest one-third of the trees (including all of the dominant trees), a similar relationship was found in 85% of the clones. This suggests that there is a tendency for greater volumes of stem decay and stain to occur in the larger trees of each clone in aspen stands of all ages. This is not surprising. Stained wood is frequently present virtually throughout large aspen because it is usually associated with the relatively large number of branch stubs on such trees, and is present as a sheath around decay columns. The larger stems in a stand, the largest "targets" with the most branch stubs as a rule, are the most likely to be "hit" and infected by spores of *F. igniarius* and other decay-causing fungi. Decay, unlike stain, is not, as a rule, confined to the annual growth rings present in the branch stub when the fungus enters the stem. Despite their greater average volumes of stem defect, the larger trees in a stand or clone generally have lower percentages of their total stem volume defective than the smaller trees because of their greater stem size, and, of course, greater volumes of clear, sound wood.

Tree vigor

There is little evidence to suggest that tree vigor has much influence on the rate of spread of a decay pocket once it is established within an aspen stem. Indeed, it would be surprising if it did, since decay occurs in the heartwood, which is mostly dead tissue. The average intermediate tree in an immature aspen stand apparently has a smaller volume of stem decay and stain than its D–CD neighbors; because of aspen's clonal growth habit (which provides it with the genetic potential to grow as fast as those neighbors), it is reasonable to assume that the tree would have an opportunity to develop into a good-quality, crop-size tree if conditions suddenly became favorable for that tree to commence growing at a rate close to its potential. In fact, anything that inhibits aspen from reaching its maximum potential (genetically inherited) growth rate can be viewed as tending to increase the percentage of total stem volume affected by decay and stain. Fast-growing aspen generally add far more clear, sound wood annually than defective wood. In natural stands, many factors are generally responsible for aspen failing to attain their maximum inherited growth rate. Competition with neighboring trees for nutrients, moisture, etc. is frequently the most critical limiting factor. Aspen thinning experiments have resulted in favorable growth responses to decreases in the degree of competition (Steneker 1964, Weingartner 1991). Through careful (though admittedly costly) thinning operations, the competition factor can be largely negated, thereby greatly increasing the opportunity for residual trees to attain their maximum inherited stem growth potential. This, in turn, may well result in more stem decay infections and stain development; however, this should be more than compensated for by the much greater rate at which clear, sound stem wood is formed. Weingartner (1991) is currently carrying out a program of thinning aspen in northern Ontario, but the effects on stem defect will not be known until after the turn of the century. This and other thinning trials on aspen should be carefully monitored to ensure that the pronounced reductions in stand density do not create more favorable conditions for other insect and disease pests of aspen such as Hypoxylon canker.

Extent of decay and stain

Accurate estimations of the extent of stem decay and stain in standing aspen are difficult to obtain, as they are for all of the major forest tree species in Ontario. As in most species, fire scars, other stem wounds, forked crowns or butts, and frost cracks are generally associated with stem decay and excessive stain in mature aspen. However, such injuries in aspen are relatively rare as a rule, certainly in relation to the occurrence of branch stubs and dead branches, which frequently serve as entry points for stem decay. Sophisticated instruments that use X-rays, magnetic resonance, and other methods have been used as non-destructive methods to detect internal stem decay, some successfully. However, they are of very limited practical value in forest stands because most of them are expensive and difficult to move around, and it is difficult if not impossible to test stems at heights above 2 m, where the incidence of decay can be very different from that below 2 m.

Two characteristics of aspen allow somewhat more accurate estimations of the extent of internal defect than are feasible in other species. Because aspen stands generally originate from fires or clearcutting operations, they are virtually always even-aged. Stand age is the one parameter more closely related to the extent of stem decay and stain than any other, for reasons already discussed. Tables that show the average extent of stem defect by age class are available for northern Ontario aspen (Basham 1960, Basham and Morawski 1964, Basham 1991). These tables are based on natural stands, presumably of fire origin, whereas an increasing proportion of future merchantable aspen stands will be of cutover origin. However, as pointed out earlier, an examination of two aspen stands of cutover origin at ages 38 and 39 indicated that they were neither more nor less defective than similarly old fire-origin stands. Along with stand age, site appears to have a slight influence on aspen stem defectiveness. Thus, aspen on sites with soil moisture regimes other than 2 or 3, especially site class 3 (Plonski 1974) stands or those with a site index (Buse and Towill 1992) of less than 16, may have higher percentages of stem volume decayed or stained than is indicated by the tables.

The second characteristic of aspen that is useful in decay estimation is the frequent occurrence of the large, hoof-shaped conks of *Fomes igniarius* on the stems that contain decay. Roughly 75 to 80% of the advanced stem decay in aspen in Ontario is caused by *F. igniarius*, and studies indicate that 80 to 90% of mature and overmature aspen trees containing that type of decay will bear one or more conks on their stems. The decay columns usually extend within the stems approximately 1 m above the highest and below the lowest conks. The abundance of conks gives an indication of the amount of advanced *F. igniarius* decay in the stand. However, trees without conks can still contain some *F. igniarius* decay (although generally relatively small amounts), and the fungi that cause the remaining 20 to 25% of stem decay in aspen commonly show no external sign of their presence.

Minimizing stem decay and stain

It appears that three essential procedures to minimize the impact of stem decay in aspen are to attempt to prevent stem wounds, to harvest trees at an age before excessive stem decay has developed, and to provide conditions for rapid tree growth so that merchantable size can be reached at as young a stand age as possible. The decay resulting from scarification wounds in aspen suckers treated at age 3 or older has been described. Fire scars, sunscald injuries, felling wounds, etc. can be even more damaging because of their relatively large size; everything possible should be done to prevent them.

The age at which aspen stands can be harvested depends, of course, on the product involved and the size of tree required for that product. For pulpwood in northern Ontario, rotation ages of 50 to 60 years are generally feasible. For sawlogs and veneer, larger-diameter trees are required, and stands may take 65 to 75 years to reach the desired size, which means that decay levels on good aspen sites may not be acceptable, and that on poorer sites, particularly those with soil moisture regimes lower than 2, there is a risk of heavy decay losses. For waferboard production, in which some decayed wood can be used with little or no deleterious effect on the end product, rotation ages of from 80 to more than 100 years are feasible.

Since the occurrence and extent of stem decay (and stain) in aspen is so closely related to age, anything that promotes faster stem growth so that the desired stem size can be attained at the youngest possible age should clearly contribute markedly to lowering the impact of decay on product quality and logging costs. We have shown that, within a single clone under uniform site conditions, a faster stem growth rate results in a lower percentage of the total stem volume affected by decay and stain. Although somewhat expensive, thinning young aspen stands may represent a wise long-term investment. For many years, forest pathologists have recommended that aspen be maintained in fully stocked stands with closed canopies to minimize losses from Hypoxylon canker and to produce fewer and smaller branches, thereby reducing infections by decay-causing fungi. However, in a study on the effects of thinning aspen on the incidence of Hypoxylon canker 15 years after thinning and removing all cankered trees, the percentage of living trees affected by Hypoxylon canker did not differ greatly between the thinned and unthinned plots (8% and 5%, respectively) (Anderson and Anderson 1968). Although 23.6% of the trees on the thinned plots were killed by Hypoxylon canker over the 15 years (compared with 14.4% of the trees on the unthinned plots), the thinned plots

had greater tree diameters and considerably more cordwood volume of aspen than the unthinned plots. Other inconsistent results concerning the benefits of thinning aspen and its effects on the impact of Hypoxylon canker have been reported (Anderson 1964). A greater understanding of Hypoxylon canker epidemiology is needed before practical management recommendations to reduce its impact can be made. Little is known about the effects of thinning on the many other insects and diseases of aspen; these are currently being carefully monitored by OMNR as part of thinning experiments in northern Ontario.

Thinned aspen are likely to develop larger branches and branch stubs than they would if left unthinned. The assumption is that this would allow more infections by *Fomes igniarius* and other fungi that cause stem decay. Perhaps aspen should not be thinned until stands are between 15 and 20 years old for this reason. It is conceivable that such stands could reach a harvestable size 25 or 30 years thereafter, depending on the product. Our knowledge of the rate of spread of stem decay infections suggests that during this period, the volume of clear stem wood added would more than compensate for the volume of stem decay attributable to the thinning treatment. We have shown that within aspen clones in natural, unthinned stands there is an inverse relationship between tree growth rate and the percentage of the total stem volume affected by decay and stain. Aspen stands approximately 5, 10, 15 and 20 years old were thinned in 1979, 1980 and 1981 in the experiments mentioned above, and some preliminary results for the 5-year-old thinned stands, 10 years after the treatment, have been published (Weingartner 1991). Future results from this study should greatly enhance our ability to answer questions concerning the effects of thinning aspen on levels of stem decay and stain, and on the impact of other insect and disease pests of aspen.

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