CLASSIFICATION AND MEASUREMENT OF ASPEN DECAY AND STAIN IN ALBERTA

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INFORMATION REPORT NOR-X-314

FORESTRY CANADA
NORTHWEST REGION
NORTHERN FORESTRY CENTRE
1990

The research reported in this publication was funded by the Canada–Alberta Forest Resource Development Agreement.

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Catalogue No. Fo46-12/314E
ISBN 0-662-17634-0
ISSN 0704-7673

This publication is available at no charge from:
Forestry Canada
Northwest Region
Northern Forestry Centre
5320 - 122 Street
Edmonton, Alberta
T6H 3S5

A microfiche edition of this publication may be purchased from:
Micromedia Ltd.
Place du Portage
165, Hôtel-de-Ville
Hull, Quebec
J8X 3X2

Printed in Canada

Hiratsuka, Y.; Gibbard, D.A.; Bakowsky, O.; Maier, G.B. 1990. *Classification and measurement of aspen decay and stain in Alberta.* For. Can., Northwest Reg., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-314.

ABSTRACT

The major types of aspen (*Populus tremuloides* Michaux) decay and stain that occur commonly in Alberta are described and illustrated. Internal stem defects are classified into five new categories on the basis of color and hardness. External indicators of decay and stain and other conspicuous stem abnormalities of aspen are described and illustrated. The use of a prototype wood hardness measuring device is outlined, and sampling and measurement guidelines are presented.

RESUME

Les principaux types de carie et de taches du peuplier faux-tremble (*Populus tremuloides* Michaux) qui se rencontrent couramment en Alberta sont décrits et montrés. Les défauts internes de la tige sont classés en cinq catégories selon la couleur et la dureté. Les signes externes de la carie et des taches ainsi que d'autres anormalités apparentes sont également décrites et montrées. L'emploi d'un prototype de dispositif de mesure de la dureté du bois est décrit, et des recommandations sur la façon d'échantillonner et de mesurer sont présentées.

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NOTE

The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products necessarily imply endorsement by Forestry Canada.

INTRODUCTION

One of the largest concerns affecting the utilization of aspen (*Populus tremuloides* Michaux) is the common presence of wood decay and stain, even in relatively young and small trees. Field recognition of types of decay and stain and standard methods to measure and record these defects are important for accurate assessment of aspen resources. Traditionally, wood defects of aspen have been classified into three categories (advanced decay, incipient decay, and stain), but that system created problems in measuring and recording defects consistently and objectively. This manual has been compiled to describe and illustrate the common types of aspen decay and stain that occur in Alberta, to present a new system of classifying defects into five categories, and to present methods of sampling and measuring these defects.

DISTRIBUTION AND UTILIZATION OF ASPEN IN ALBERTA

The volume and distribution of Alberta's aspen resource has been well documented. Approximately 35% of Alberta's growing stock is composed of hardwoods. Of this, 85% is aspen, and the balance is made up of balsam poplar (*Populus balsamifera* Linnaeus) and white birch (*Betula papyrifera* Marshall).

Aspen is widely distributed throughout North America (Fig. 1) and occurs throughout the forested area of Alberta (Fig. 2). Pure stands are more common in the northern areas.

The total volume of aspen in the province is approximately 850 million m^3. The merchantable volume is currently 831 million m^3, based on a minimum 15-cm stump diameter (outside bark) and up to a minimum 10-cm top diameter (inside bark)[1]. The distribution of merchantable volume by forest is shown in Table 1.

The annual allowable cut of aspen in Alberta is 10.4 million m^3, of which 2.9 million m^3 (27.7%) is currently allocated. The committed wood supply is evenly split between holders of forest management agreements (FMAs) and those not holding FMAs. Utilization of aspen has been well documented recently by Ondro (1989). A summary of the current and planned utilization of the aspen resource in Alberta is presented in Table 2. The current industries utilizing aspen provide approximately 1381 person-years of employment, of which 79% is primarily in the panelboard and pulp products field. An additional 3252 person-years of direct employment and 6505 person-years of indirect employment will be generated as a result of proposed development of this resource (Ondro 1989).

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[1] Timber Management Branch Statistics 89-01-31, Amendment 8, Alberta Forest Service, Edmonton, Alberta.

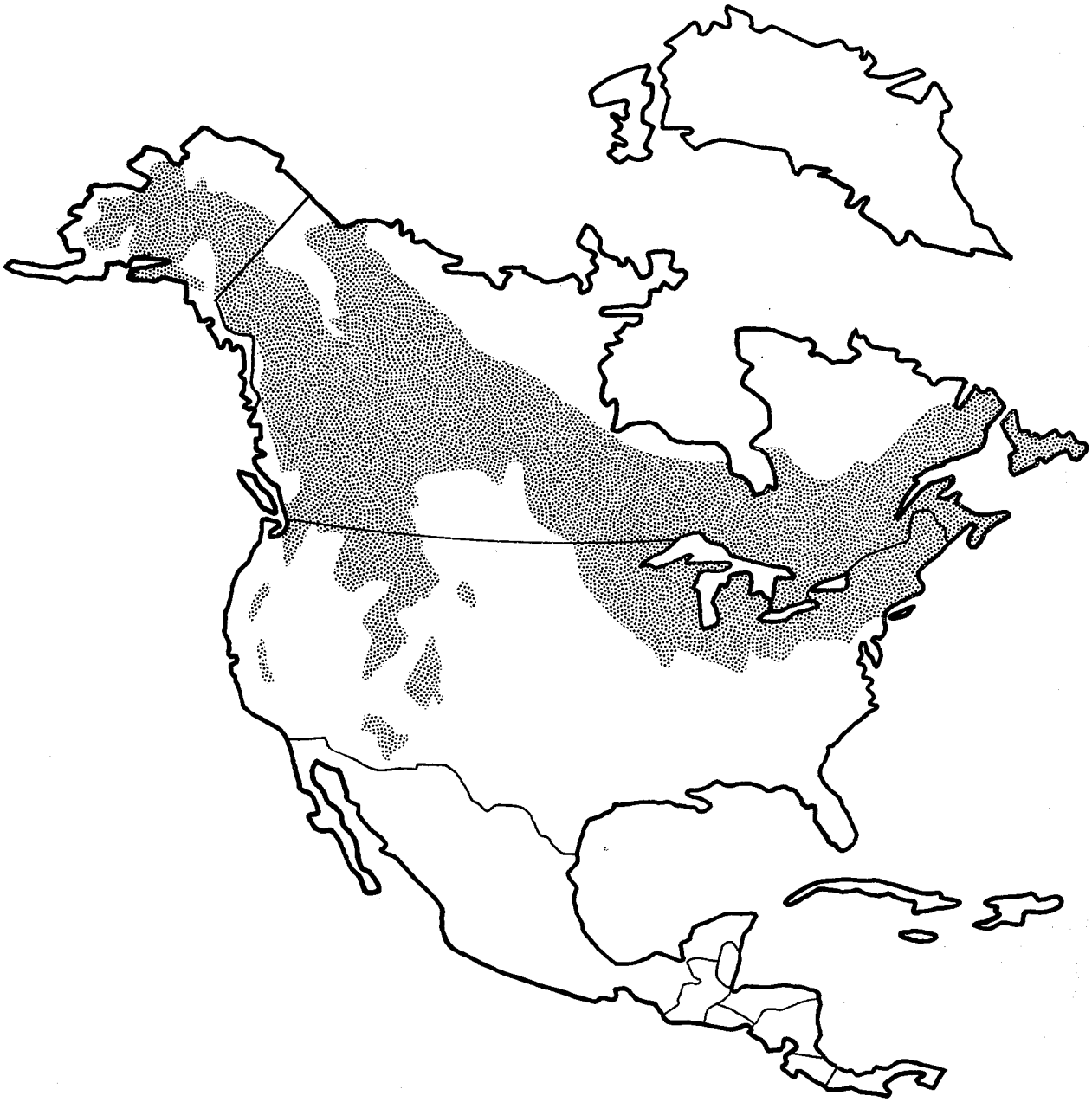


Table 1. Distribution of aspen merchantable volume in Alberta

Forest	Volume (million m^3)	Forest	Volume (million m^3)
Athabasca	49.22	Rocky–Clearwater	28.26
Bow–Crow	7.10	Slave Lake	142.81
Edson	37.31	Whitecourt	67.64
Footner Lake	114.41	Outside managed areas[a]	113.58
Grande Prairie	100.42		
Lac La Biche	56.51	Total volume	831.16
Peace River	113.90		

[a] Areas outside of Commercial (Green) Zone and located mainly in Agricultural (White) Zone.

Table 2. Current and future utilization of aspen in Alberta (Ondro 1989)

Product	Current utilization		Future development		Total	
	No. of mills	Wood supply (m^3/yr)	No. of mills	Wood supply (m^3/yr)	No. of mills	Wood supply (m^3/yr)
Pulp and paper	2[a]	220 632[a]	4	4 395 000	6	4 615 632
Oriented strand board	3	1 083 133			3	1 083 133
Sawn boards	117	58 155			117	58 155
Firewood	N/A[b]	41 500			N/A	41 500
Pallets	2	31 300			2	31 300
Furniture	2	430			2	430
Feed pellets	1	900			1	900
Total	127	1 436 050	4	4 395 000	131	5 831 050

[a] Estimates for two pulp mills are for trial runs of one-half year of production.
[b] N/A = not available.

Figure 1.

Distribution of aspen (*Populus tremuloides*) in North America (Harlow et al. 1979).

MAJOR CAUSES AND CATEGORIES OF DECAY AND STAIN

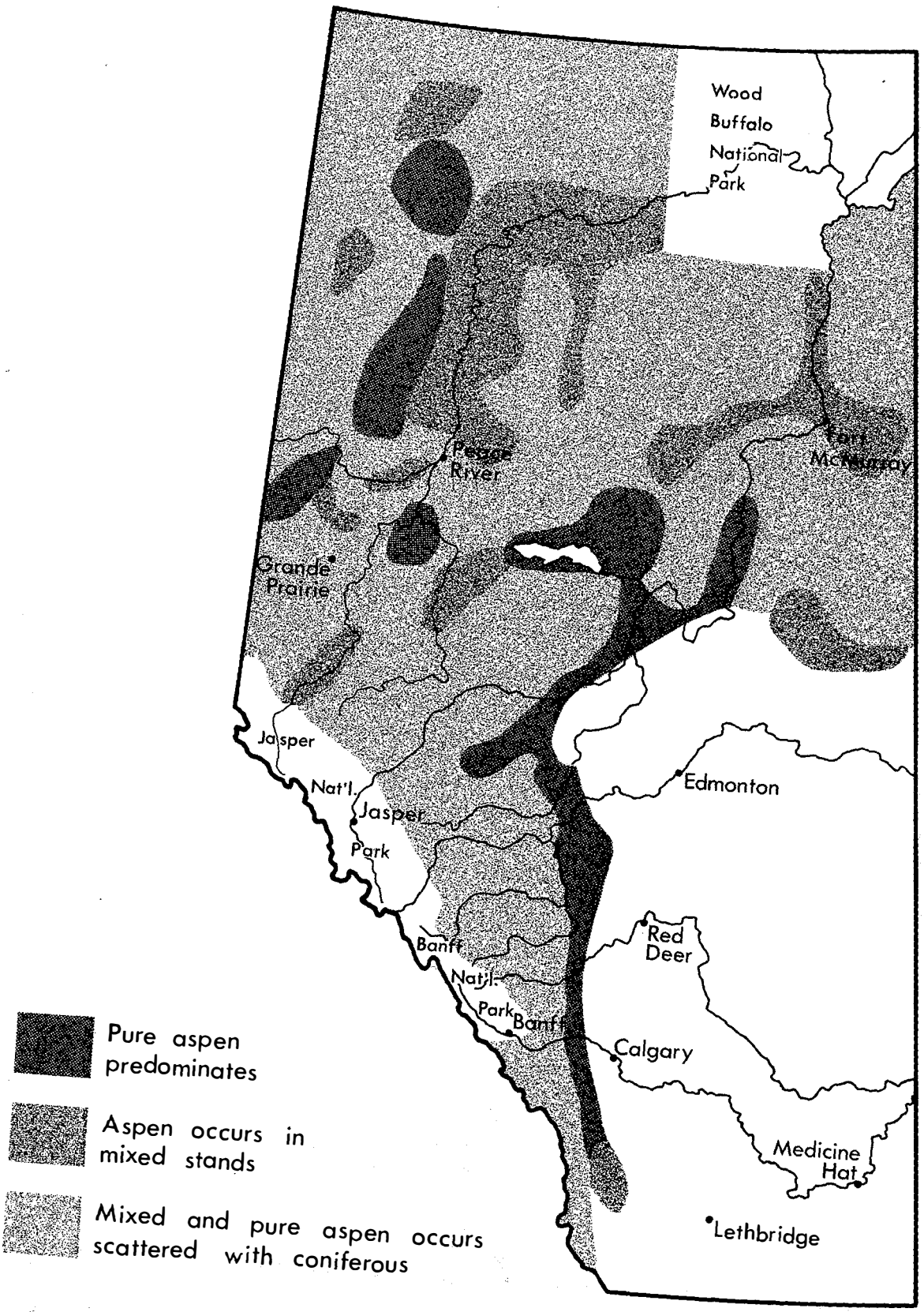
Major Causes

More than 250 species of fungi are known to cause or be associated with decay in North American aspen (Lindsey and Gilbertson 1978). Most are decay fungi of standing dead or fallen trees and are of minor importance to live aspen. Thomas et al. (1960) identified 17 species of fungi that cause the decay of standing live aspen in Alberta. Decay and stain of aspen can be divided into three major categories: trunk rot and stain; root and butt rot; and sapwood decay and stain in stored logs.

The most common and most important cause of aspen trunk rot in Alberta is ***Phellinus tremulae*** (Bondartsev) Bondartsev & Borisov (= *Phellinus igniarius* (Linnaeus: Fries) Quéllet, *Fomes igniarius* (Linnaeus: Fries) J. Kickx fil. f. *tremulae* Bondartsev) (Fig. 3). Thomas et al. (1960) estimated that 38.6% of trunk decay volume is caused by this fungus. In Ontario, Basham (1960) reported that 63.2% of 1754 trees on 47 plots had trunk rot and almost 75% of the volume loss was attributed to *P. tremulae*.

The second most prevalent cause of decay in aspen is ***Peniophora polygonia*** (Persoon: Fries) Boudier & Galzin (= *Corticium polygonium* (Persoon: Fries), *Cryptochaete polygonia* (Persoon: Fries) K. Karsten) (Fig. 4). Although this fungus does not cause large columns of advanced decay as does *Phellinus tremulae*, it is found more often in decayed and discolored wood than *P. tremulae*.

The ***Armillaria*** species (*A. ostoyea* (Romagnesi) Herink or *A. sinapina* Berube and Dessureault) (Fig. 5) is the most common cause of


Wood
Buffalo
National
Park
Peace
River
Fort
McMurray
Grande
Prairie
Jasper
Nat'l.
Park
Jasper
Edmonton
Banff
Nat'l.
Park
Banff
Red
Deer
Calgary
Medicine
Hat
Lethbridge
Pure aspen predominates
Aspen occurs in mixed stands
Mixed and pure aspen occurs scattered with coniferous

aspen butt rot in Alberta. The causal agent of Armillaria root and butt rot has until recently been considered to be *Armillaria mellea* (Vahl: Fries) P. Kummer but now is considered to be caused by five or six closely related but different species. In Alberta, at least two and possibly more species are known to exist (Mallett 1985; Mallett and Hiratsuka 1988). Other common root and butt rot fungi are *Ganoderma applanatum* (Persoon) Patouillard, *Fomitopsis pinicola* (Swartz: Fries) P. Karsten (= *Fomes pinicola* (Swartz: Fries) Cooke), and *Gymnopilus spectabilis* (Fries: Fries) A.H. Smith (= *Pholiota spectabilis* (Fries: Fries) Gillet).

Another common decay organism is *Radulum casearium* (Morgan) Ryvarden (= *Hydnum casearium* Morgan, probably *Radulodon americanus* Ryvarden).

Stain or discoloration of wood is caused by various microorganisms, including fungi of various groups (yeasts, ascomyceteous fungi, and fungi imperfecti) and bacteria. One of the so-called "mineral stains" of sapwood in stored logs is likely caused by invading blue stain fungi belonging to such genera as Ceratocystis and *Verticicladiella*. Many kinds of sapwood stain are known to develop without microorganisms.

Major Categories

The widely used traditional classification system used for categorizing wood defects as advanced decay, incipient decay, and stain has created problems in judging and recording wood defects in aspen. Even among experts, there is no clear agreement on the classification of decay and stain into these categories for decay measurement purposes (Basham 1987). Inconsistencies and abnormalities in decay and stain measurements reported in various papers are likely due to the lack of standard measurement guidelines (Hiratsuka and Loman 1984).

We recommend using five categories of major wood defects for the purpose of decay and stain measurement (Table 3). A key for the identification of defect types is provided in Table 4.

Type A: Decay caused by *Phellinus tremulae*. This category is characterized by a prominent black line that surrounds and often occurs within decayed areas (Figs. 6 and 7A, B). The rot caused by this fungus is white, spongy, and soft. Most of the advanced decay category of the traditional classification was likely caused by this fungus. Type A defects caused by *P. tremulae* usually produce a long decay column, frequently continuing along most of the main stem (Fig. 6). Extensive decay of this type usually occurs more than 2 m above the ground (Basham 1987). This fungus characteristically produces distinct conks (basidiocarps) (Fig. 3B). Hinds (1963) found that the average length of the decay column above and below a conk is 370 ± 21 cm.

Figure 2.

Distribution of aspen in Alberta. (Source: Alberta Forest Service.)

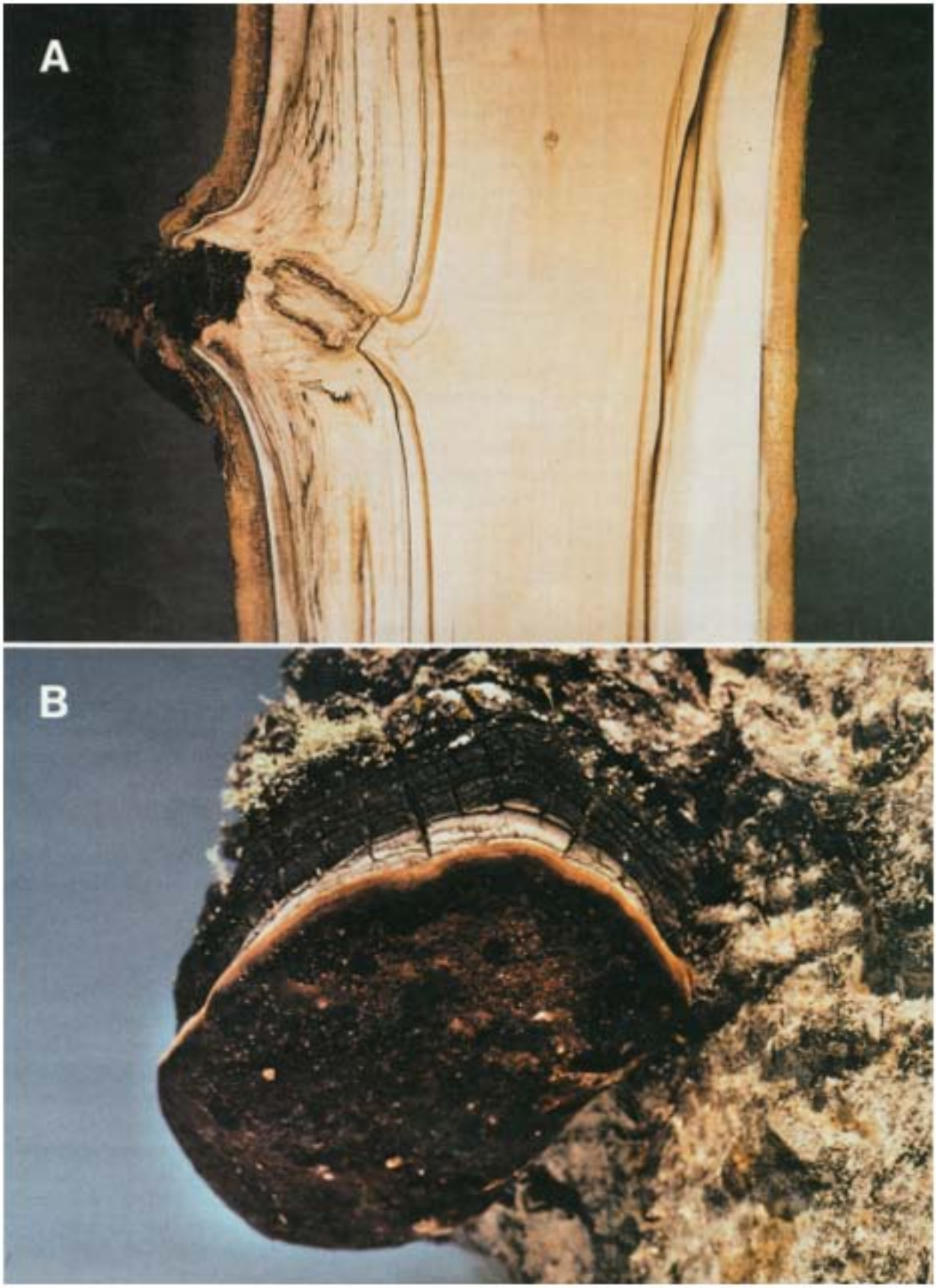

A
B

Table 3. Summary of the defect categories

Type of defect	Causes	Description of defect and external indicators	Defect distribution
A	*Phellinus tremulae*	White spongy rot bordered with black lines. Usually associated with hoof-shaped conks.	Defects usually occur along most of the main stem, less frequently in the bottom part of the trunk.
B	Mostly *Armillaria* spp.	Yellow, stringy rot often surrounded by dark brown fungal and wood material. Black shoestring-like fungal structures (rhizomorphs) present in and around the decay. May find *Armillaria* mushrooms in the late summer or autumn.	Butt rot. Decay up to 1 m above the ground.
C	Mostly *Peniophora polygonia*, occasionally *Radulum casearium*	Stained column with irregular pockets of pinkish to brownish decay. Often associated with pink scale-like fruiting bodies.	Often occurs along large portions of the main stem.
D	Various causes (fungi, bacteria, nonbiotic factors)	Stain of various causes that does not reduce wood hardness.	Variable in distribution.
E	Blue stain fungi	Grayish-black sapwood stain.	Occurs in sapwood. Initiates from cut end or through damaged bark on stored logs.

Type B: Butt and root rot primarily caused by *Armillaria* species. The yellow, stringy rot is often covered by dark brown fungal material mixed with wood (Figs. 5A, 8D, E, and 9C, D). Black, shoestring-like fungal structures (rhizomorphs) are often found within and around the decay. The Type B defect occurs only at the bottom of the tree and tapers off quickly (Fig. 9C), seldom extending more than 1 m above the ground.

Type C: Decay and stain caused by *P. polygonia* and less frequently by *Radulum casearium* and other organisms. This category of defect is characterized by a general discoloration of the wood along with pockets of decay throughout the affected column (Figs. 7C-F and 10). Decay and discoloration of wood caused by *P. polygonia* are conspicuously pink to brownish pink and can occur along large portions of the main stem. The fungus seldom causes large columns of soft structural decay, and most of the affected wood stays relatively firm. Although hardness in general may not be reduced significantly, the infected wood may be more brittle than sound wood. Fibers of the affected areas often pull out, and cut surfaces have a rough appearance, while the adjacent sound wood cuts cleanly (Fig. 7D, E).

Figure 3.

Phellinus tremulae.
A. Decay caused by *Phellinus tremulae.*
B. Conk (fruiting body) of *Phellinus tremulae.*


A
B

Table 4. Key to types of wood defect in aspen

Wood not discolored, no indication of defect	Sound wood
Wood discolored or with other visible indications of defect	
Heartwood defect	
Columns of structural decay	
White trunk rot bordered with black line	Type A
White or brown butt rot, seldom extending more than 1 m above the ground	Type B
Stained columns with irregular decay pockets and soft areas, mostly pink to brownish pink	Type C
Stained columns of various colors and forms without loss of hardness	Type D
Sapwood defect	
Grayish-black or brown sapwood stain	Type E

A distinct splitting of wood often occurs between affected and healthy wood areas (Fig. 10A–D), causing ring shake, which is shrinkage and separation of the annual rings. Defects caused by *P. polygonia* and *R. casearium* are difficult to separate in the field, requiring laboratory isolation to confirm their identity.

The type C defect has been the major area of confusion in the past and was likely recorded as incipient decay or stain under the traditional classification system.

Type D: All heartwood stains caused by fungi, bacteria, and nonbiotic factors, which do not reduce wood hardness as in Types A, B, and C (Fig. 8A–C). Because Type D defects are caused by various biotic and abiotic agents, they are variable in distribution and extent (Fig. 10E, F).

Type E: Grayish to blackish sapwood stains that often develop in stored logs (Fig. 8F). These stains are caused by blue stain fungi, likely belonging to such genera as *Ophiostoma*, *Ceratocystis*, and *Verticicladiella*. This type of stain is often included in the mineral stains category, but the name may be a misnomer as it is caused by fungi. Type E stain typically develops from log ends or damaged bark of the cut log.

Figure 4.

Peniophora polygonia. **A.** Stain and decay caused by *Peniophora polygonia.* **B.** Fruiting bodies of *Peniophora polygonia.*

There are strong indications that *Phellinus tremulae* (cause of Type A defect) and *Peniophora polygonia* (major cause of Type C defect) are mutually exclusive or antagonistic to each other (Navratil and Winship 1978). Most of the trees with Type C defect do not have Type A defect, and in trees where both types coexist there are clear demarcation lines between the areas infected by each organism. Figures 9A and B show a column of Type C defect situated in the center of the stem surrounded by Type A defect, with a very clear separation between the two. Basham (1958) considered *P. polygonia* as well as several other fungi to be preliminary fungi, which were functional in altering the host, thereby permitting the principal fungi, mainly *Phellinus tremulae* and *Ganoderma applanatum*, to become established.


A
B

Studies in several provinces (Basham 1958; Basham and Morawski 1964; LaFlamme and Lortie 1973; Thomas et al. 1960) showed that *Peniophora polygonia* primarily occurs in young or small diameter stems. In this study, *P. polygonia* was commonly observed in older trees as well. Further investigations are necessary to understand the ecological succession of microorganisms leading to various kinds of decay and stain.

EXTERNAL INDICATORS OF DECAY AND STAIN

Certain external characteristics can be useful in providing an indication of the presence of internal decay and stain (Fig. 11). They may signal the presence of a specific type of decay organism but do not provide a reliable estimate of defect volume.

The main external indicators of decay and stain and other conspicuous stem abnormalities are

1) Perennial hoof-shaped conks of *Phellinus tremulae* (Type A defect; Figs. 3B and 11C) are produced at branch scars. The fungus is commonly called false tinder conk or false tinder fungus because of the similarity of the conks to those produced by another decay fungus, *Fomes fomentarius* (Linnaeus: Fries) J. Kickx fil., which is called tinder conk or tinder fungus. Inside fungal tissue of conks of both species have been used as tinder (punk) to start a fire. The conks can be up to 20 cm wide and 15 cm thick, but the majority are 7–15 cm wide and 5–10 cm thick. Longitudinal sections of conks are triangular and have a purplish brown lower spore-producing surface (Fig. 3B). The margin of the upper surface is smooth and pale brown but older surfaces crack and become darker, almost black. Basham (1958) found conks of this fungus on 86% of the trees with Type A defect. Our results, however, indicate a lower percentage of trees with extensive Type A defect are associated with conks.

2) Mushrooms of *Armillaria* species (Type B defects) have honey-colored to dark yellowish brown pilei (caps) and are generally 7 to 12 cm in diameter (Fig. 5B). Distinct membranous annuli (rings) on the upper stems of these mushrooms are one of the important characteristics in the identification of the fungus. The fruiting bodies (mushrooms) are produced only in the late summer or early autumn and, therefore, are not always present. Black, shoestring-like fungal structures (rhizomorphs) are always present with the Armillaria root rot infection. These rhizomorphs are often found in completely decayed wood and around the base of the infected tree. This root rot is sometimes referred to as black shoestring root rot because of the presence of this unique structure. *Armillaria* species often cause significant mortality of young conifer trees. The potential danger of this disease as a mortality-causing and growth-reducing root disease of aspen is not known; however, Stanosz and Patton (1987a, b) concluded that Armillaria root rot may significantly affect regenerated aspen stands, especially under the short rotation management used in Wisconsin.

Figure 5.

***Armillaria* sp. A.** Butt rot caused by *Armillaria* sp. **B.** Mushrooms of *Armillaria ostoyae*.


A
C
E
B
D
F

3) Fruiting bodies of *Peniophora polygonia* (Type C defect) are thin, pinkish-red scaly patches with whitish margins that often curl away from the stem surface (Figs. 4B and 11B). They are usually found on rotten branch stubs or old exposed scars. Fruiting bodies of *P. polygonia* can be difficult to detect in the field because of their small size and light coloring.

4) Basal tree damage (Fig. 11A) is caused by logging equipment, animal feeding or rubbing, and mechanical abrasion from other stems. It can provide an entry point for decay and stain organisms.

5) Rotten branch stubs (Figs. 4B and 11B) are considered the major entry points for decay and stain-causing organisms. Basham (1958) traced approximately 90% of the trunk rots to dead or broken branch stubs. Etheridge (1961), however, suggested that branch stubs may not be the main entry points for *Phellinus tremulae*, and conks appearing at the branch stubs might only be a lateral extension of heart rot caused by this fungus. We often observed *Peniophora polygonia* fruiting bodies on rotten branch stubs.

6) Stem cracks caused by frost or other factors (Fig. 11C) can also serve as the entry points for decay and stain organisms. Basham (1958) found that 84% of the trees with pronounced stem wounds had extensive heart rot (Type A defect), indicating that they were fairly reliable indicators of heart rot.

7) Conspicuous gall formations called black gall or blackish gall (Fig. 11D) have been observed frequently in Alberta (Hiratsuka and Loman 1984) but are not indicative of wood defects. Generally, trees with black galls do not have Type A defects. The cause of the black gall is not known.

8) Some other conspicuous stem symptoms such as rough bark caused by the fungus *Diplodia tumefasciens* (Shear) Zalasky (= *Macrophoma tumefasciens* Shear) (Fig. 11E) or cankers caused by *Hypoxylon mammatum* (Wahlenberg) J.H. Miller (Hypoxylon canker; Fig. 11F) are common in some stands, but they are not indicators of extensive decay or stain.

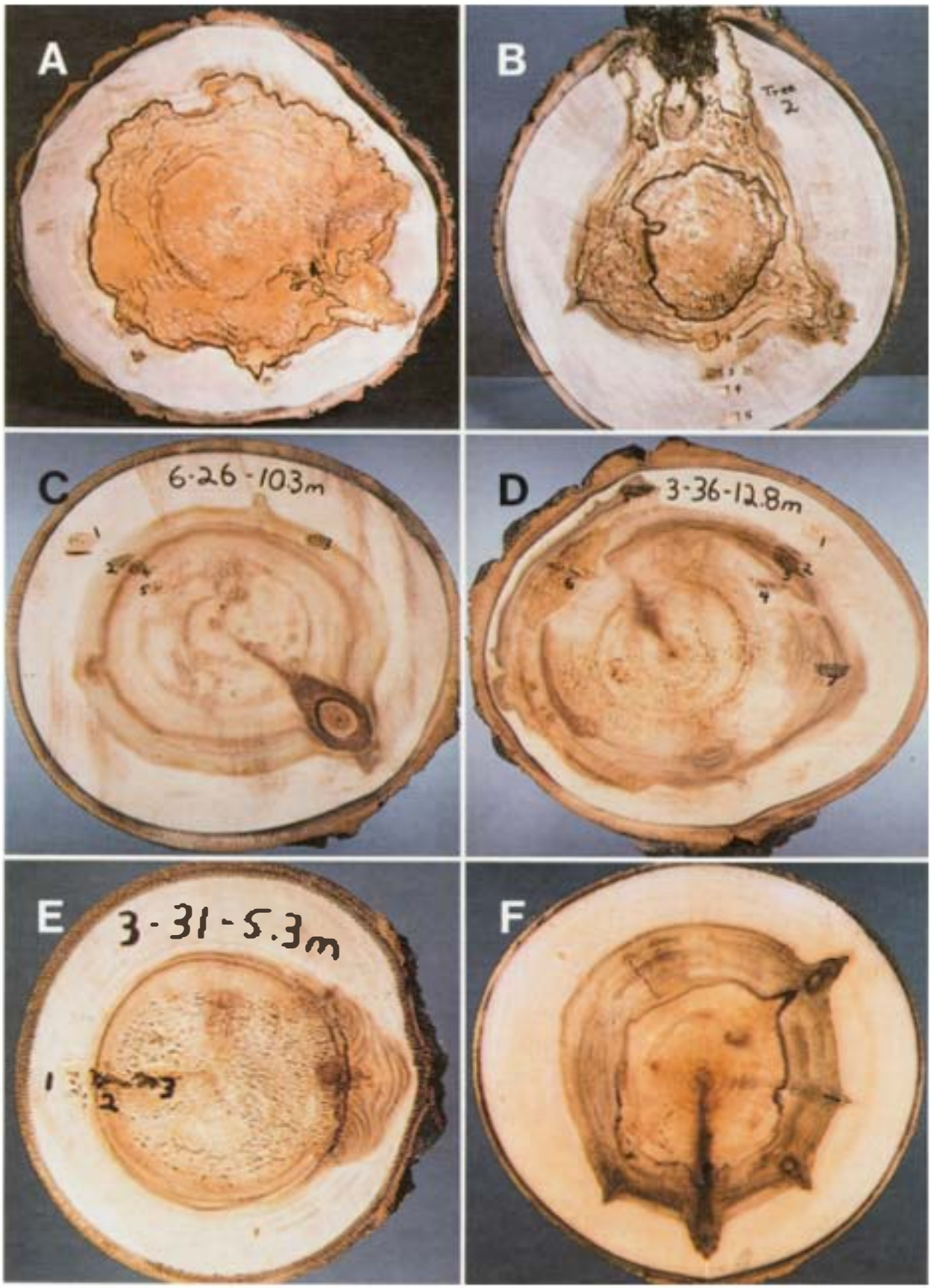
9) Stem damage caused by the yellow-bellied sapsucker (*Sphyrapicus varius varius* Linnaeus) is unique and conspicuous (Fig. 11G), consisting of regular rows of holes about 7 to 10 mm in diameter. The holes made by the yellow-bellied sapsucker often provide entry points for decay and stain organisms, but the extent of stain and decay is usually localized.

IMPACT OF MAJOR DECAY AND STAIN TYPES ON END USES

The economic consequences of the types and degree of decay and stain differ significantly according to the end use. It is important to estimate defect and yield according to the desired end use, because certain defects may affect the yield or the quality of the final product.

Figure 6.

A-F. Decay columns and cross sections of Type A defect.


A
B
C
6-26-103m
D
3-36-12.8m
E
3-31-5.3m
F

Bleached Chemical (Kraft) Pulping

Bleached chemical (kraft) pulping is the pulping process that is most tolerant of the presence of decay and is not affected by the presence of stain (Type D and E defects).

Results from other studies have shown that Type A and B defects result in yield losses in the form of fines (very small particles of fiber). The effect is primarily economic because the product yield, based on wood costs, is reduced. Also, the increased load on the recovery boiler caused by the fines may reduce yield in recovery-limited mills (Breck 1987).

Hunt et al. (1978) reported a significant decrease in strength of pulps produced from samples of decayed aspen (Type A and B defects). They used only decayed portions of wood for testing; however, our laboratory tests could not detect a meaningful difference in pulp strength between sound and decayed wood samples. Samples for the present study contained only an average of 20% Type A and B defects. This proportion may not have been sufficient to override inherent variability in pulp strength.

Chemithermomechanical Pulping

Chemithermomechanical pulping (CTMP) is a more sensitive pulping process than kraft pulping. As such, it is able to tolerate only low levels of stain and decay.

The effect of stain and decay on the pulping process is primarily economic, resulting in loss of yield and increased bleaching costs in order to attain required brightness levels.

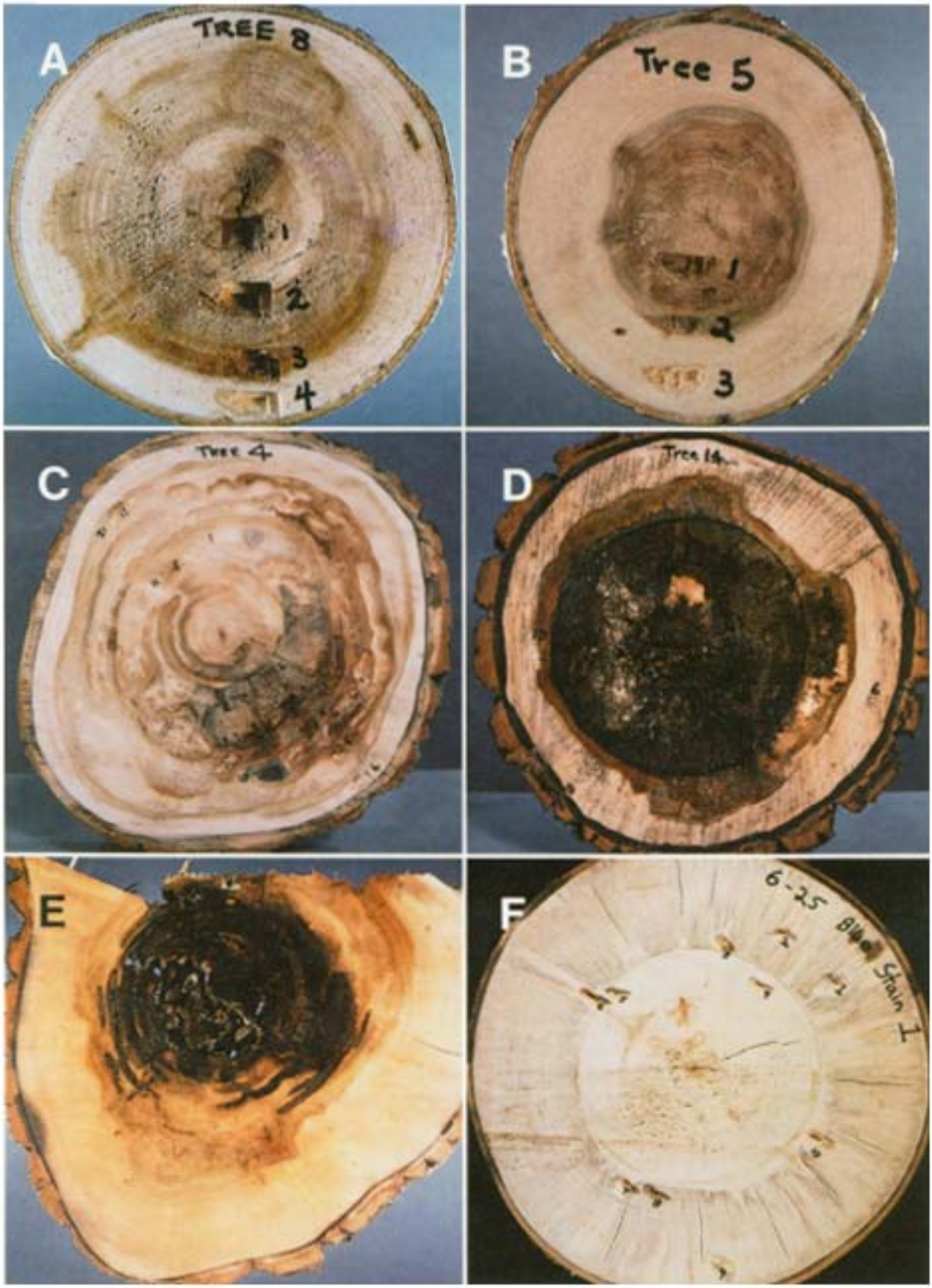
The impact of Type A and B defects is twofold. During the chipping process most of the decay is reduced to fines that are lost. Because the decayed wood must be cut, transported, and handled without a resultant increase in yield, the overall wood costs are higher. Decay that does enter the pulp results in decreased strength and requires additional bleach.

Type C and D defects present the greatest problem for the CTMP process. Bleaching costs are increased, and high brightness levels may not be attainable. If large amounts of scattered decay are present, pulp strength can be decreased.

The Type E defect characterized by sapwood discoloration (blue stain) seems to affect bleaching efficiency in the CTMP process and thus adds to the cost of bleaching. Since this defect develops mainly after logging and during storage of the wood, damage can be controlled or prevented to some extent.

Figure 7.

Stem cross sections of various defect types.
A, B. Type A defect caused by *Phellinus tremulae.*
C, D. Type C defect caused by *Peniophora polygonia.*


A
TREE 8
1
2
3
4
B
Tree 5
1
2
3
C
Tree 4
D
E
F
6-25 Blue Stain 1

Oriented Strand Board

Stain (Type D and E defects) at levels of up to 20% have very little effect on oriented strand board (OSB). Technically, higher levels of stain are acceptable, but current market conditions allow for a maximum of only 20% (Breck 1987; Denny 1987).

Most decay shatters during the cutting process, producing fines that are usually lost. Fines that are incorporated into the OSB absorb more resin and affect the bulk density of the material. At high levels of decay, OSB strength can be reduced (Anderson 1987).

Lumber and Solid Wood Products

The presence of stain in more than trace amounts is not acceptable in furniture, moldings, and other specialty products because of the reduction in esthetics and strength (Breck 1987). Stain is allowed in all grades of hardwood factory lumber recognized by the National Hardwood Lumber Association. The presence of stain and decay, however, reduces the grade and subsequent value of the lumber (Petro 1987).

DEVELOPMENT OF MEASUREMENT METHODS

The following sections outline the development of a standardized method for characterizing the extent of decay. The initial identification of defects was visual, relying on the characteristic discoloration associated with stain and decay. Wood hardness was subsequently used to distinguish between defect types.

Defect Measurement in the Field

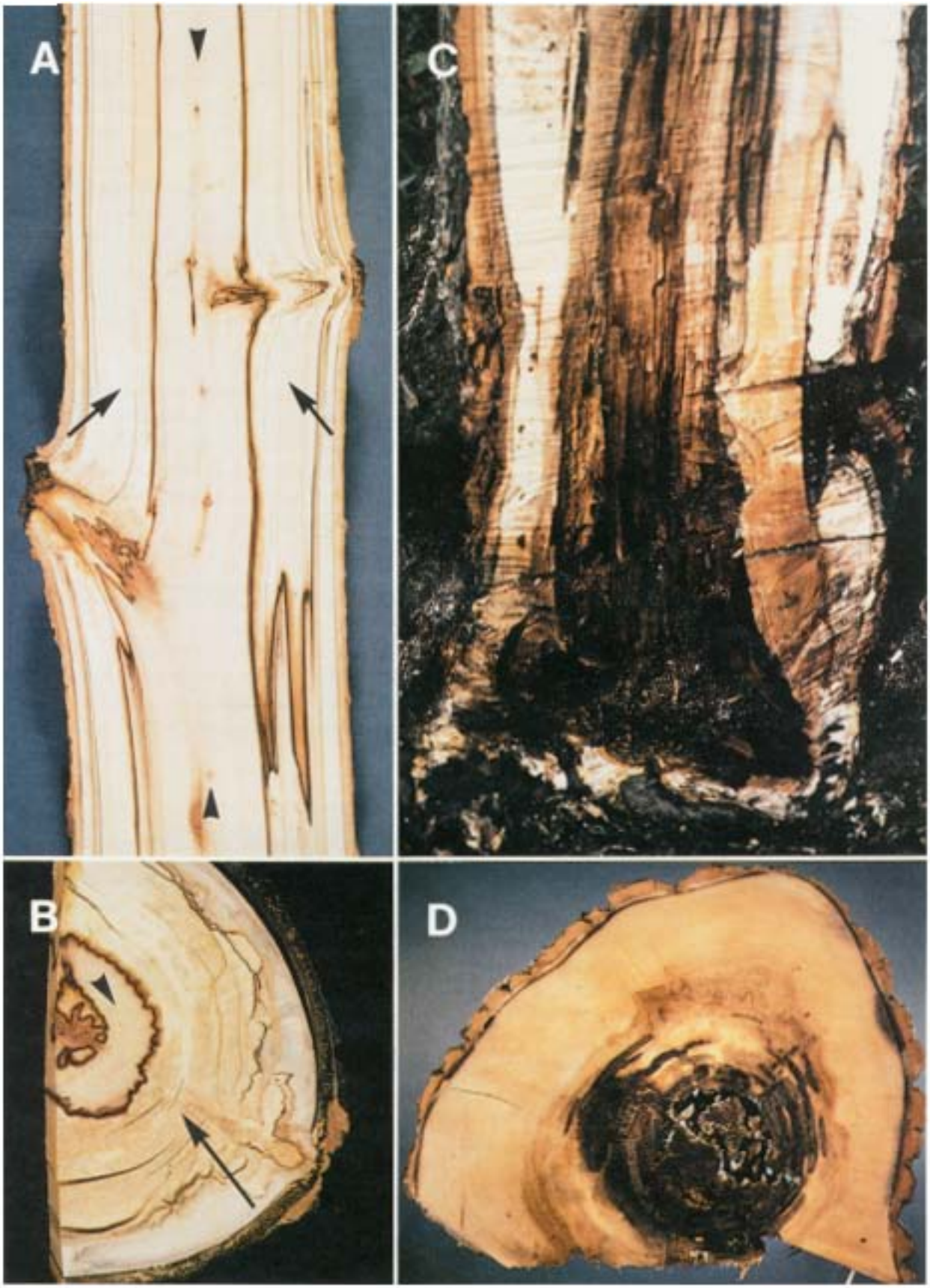
It is important to be able to easily measure the relative hardness of wood to categorize defects in the field before harvesting decisions are made. Traditional defect categorization has relied on subjective estimates of hardness utilizing knives or other sharp instruments. Several mechanical devices to measure hardness of wood and other material are commercially available, but they are expensive and inappropriate for field use.

In order to determine if defect types affect wood hardness, a prototype device called the Hoffmann-Gun or H-Gun (Fig. 12B-E) was designed specifically for measurement of aspen wood hardness[2]. The device is spring loaded, and when triggered, it releases a pin that penetrates the wood. The depth of pin penetration is related to the wood hardness, pin diameter, and spring strength. A scale measures the resistance of the wood to penetration

Figure 8.

Stem cross sections of various defect types. **A-C.** Various types of stain (Type D defect). **D, E.** Type B defect caused by *Armillaria* sp. **F.** Sapwood stain caused by blue stain fungi (Type E defect).

[2] The H-Gun was developed for this project by Walter Hoffmann of the Northern Alberta Institute of Technology, Edmonton, Alberta.


A
C
B
D

by the pin. Low readings indicate little resistance, which coincides with decayed wood.

A combination of the wood's color, cut-surface texture, and trends in H-Gun readings were used to delineate the various defect types. Initially, the defects were identified using the traditional categories of advanced, incipient, and stain. Volumes of sound and defective wood were calculated based on these classes. Fortunately, the traditional classification coupled with wood hardness and defect-causing organism information could be used to categorize defects according to the system recommended in this publication.

To reduce the complexity of measurements and the confusion associated with the rather subjective incipient category of defect, we attempted to determine if a quantitative estimate of hardness could be used to distinguish decayed and sound wood. The distribution of the H-Gun readings from cross-sectional samples from each tree were plotted to determine if a logical break in readings occurred on what was classed as advanced decay, incipient decay, stain, and sound wood. The H-Gun readings for incipient decay wood did not show a clearly defined pattern. The readings ranged from 0 (minimum) to 25 (40 is maximum) and effectively covered the range of readings associated with advanced decay and stained wood.

As an arbitrary goal, we wanted to ensure that at least 75% of the readings made on incipient decay samples were categorized correctly (i.e., they were not classed as decay that would result in volume loss). The distribution of H-Gun readings on incipient samples indicated the H-Gun value of 7 was appropriate. To test this as a reliable division between advanced defects and stains, the incipient readings were divided into two groups. Samples with H-Gun values of 6 or less were put into the advanced category and those of 7 or more were combined with the stain category. Distributions of H-Gun readings indicated a high degree of accuracy (93% or greater) could be achieved if the H-gun was used to determine whether the wood should be categorized as sound or decayed.

Figure 9.

Type A, B, and C defects. **A.** Column with Type A defect (arrows) surrounding Type C defect (arrowheads). **B.** Cross section of column shown in A. **C.** Decay column of Type B defect (*Armillaria* butt rot). **D.** Cross section of Type B defect.

Reconciling Field and Laboratory Measurements

Wood product testing laboratories typically provide clients with an estimate of defect based on the traditional classification of advanced and incipient decay and stain. Their assessment is based on recoverable chips and involves manually grading chips or portions of chips on the basis of color and a subjective estimate of hardness. The results are presented as a percentage of ovendry weight.

Significant discrepancies in recoverable volume derived from sound and stained wood samples were found between the field sampling and the laboratory chipping exercise. This can be attributed to three factors. The first and most important factor is likely that the criteria used in the chipping


A
C
E
B
D
F

exercise to differentiate between defect types were different from those used in the field measurements. Secondly, in the calculation of internal decay from stem analysis measurements, certain assumptions were made about the shape of the decay inside the bolt. These assumptions may not have been applicable to individual trees, but they would be reasonable over a large enough sample. Finally, field decay measurements were based on log volume, while laboratory results were determined on the basis of the ovendry weight of pulp chips.

The assumptions used in the calculation of internal defect volume from stem analysis (*Tree sectioning manual*; Alberta Forest Service 1988) were shown to be appropriate. Fifteen 2.5-m sample bolts were cut longitudinally and defect size was measured at 31-cm intervals. Comparison of these detailed volume calculations with those determined from the log end measurements revealed no significant differences ($P = 0.10$) in volumes of stained and decayed wood.

Despite the differences in defect volumes, fairly strong correlations were found between laboratory and field estimates of defect (with the exception of incipient decay). Figure 13 shows scatter plots of laboratory estimates versus field estimates of defect. Correlations between the two estimates were as follows:

Type	Correlation
Percent sound	0.52
Percent stain	0.60
Percent incipient	0.28
Percent advanced	0.79

The consistently high laboratory estimates of stain (Fig. 13B) relative to field estimates indicate that the criteria used to differentiate between defect types differed. The cause of the difference is not known but may be related to the natural variability in color or the subjective determination of wood hardness of manually graded pulp chips.

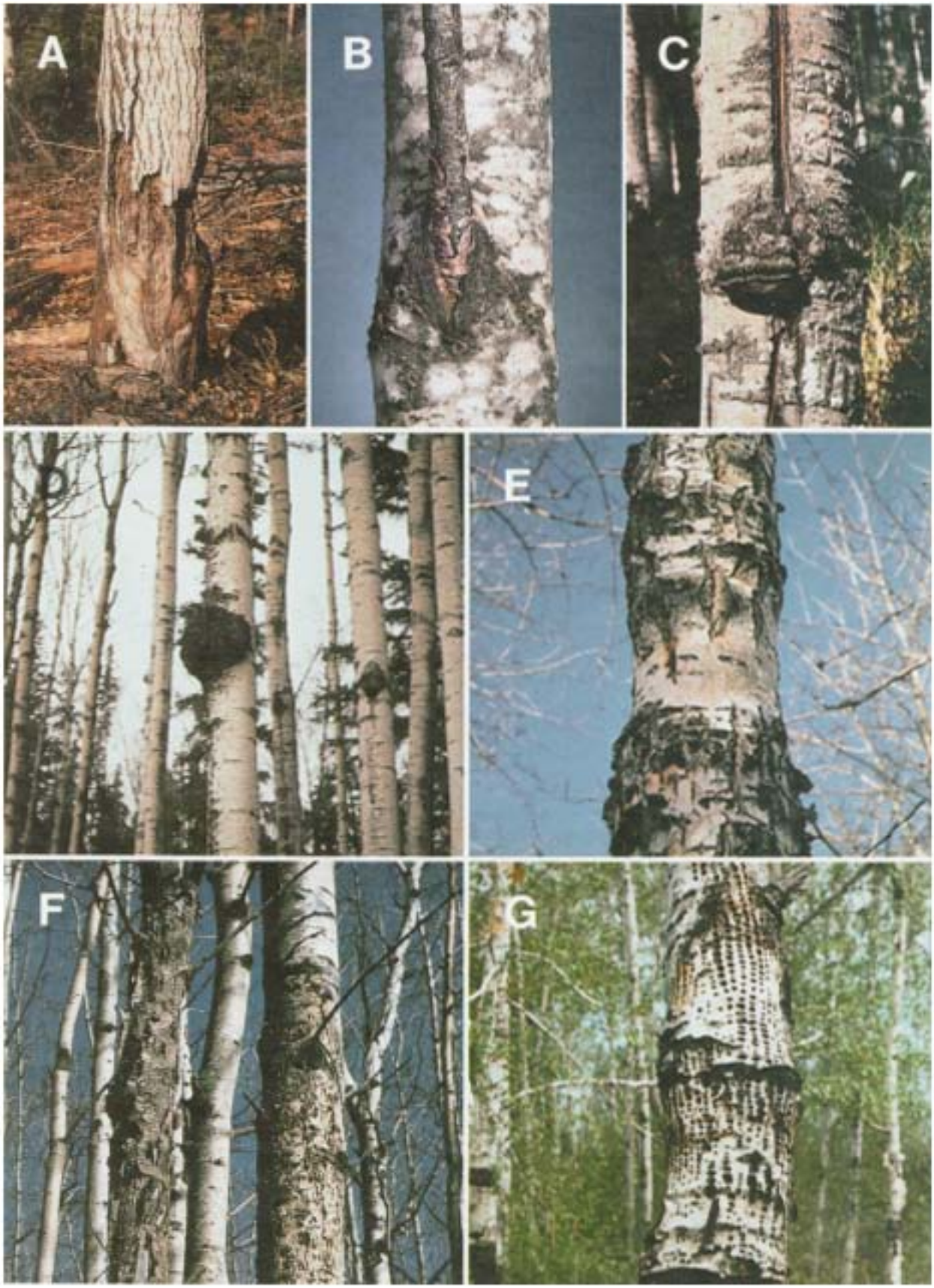
SAMPLING AND MEASUREMENT GUIDELINES

The objective of this section is to provide guidelines for future aspen defect sampling and measurement. The use of this methodology will provide some standardization for identification and measurement of wood defects in aspen and removes much of the subjectivity involved in such work. The guidelines are a first approximation; refinements and revisions to the methodology are anticipated as additional work and testing is completed.

Figure 10.

A–F. Decay and stain columns and cross sections of Type C defect.

The methods described assume the user has access to an H-Gun. The spring strength and pin thickness both influence the depth of penetration of the H-Gun pin. Because of this, the ratings used to identify decay Types A and B are dependent on the H-Gun being constructed to the same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specifications as the prototype used in this investigation[3]. Any H-Gun being used for decay assessments should be calibrated against the standard to ensure the hardness criterion is appropriate.

Sampling Design

There is no standard methodology for selecting sites or trees for defect sampling. The use of external indicators can signal the presence of internal decay, but their use as a predictor of decay is limited (LeMay 1986; Maier and Darrah 1989). The exception is the presence of *Phellinus tremulae* conks, which is the only reliable indicator of internal decay that would lead to a reduction in usable volume. Indicators such as *Peniophora* fruiting bodies (Type C defect) may reveal problems with stain but likely will not result in a reduction in usable wood volume.

There is a weak relationship between aspen decay and age (Basham 1958; Black and Kristapovich 1954; LeMay 1985) and diameter (Maier and Darrah 1989). Due to the high variation in decay occurrence throughout individual stands, it is unlikely that decay estimates can be tied to stand cover type descriptions.

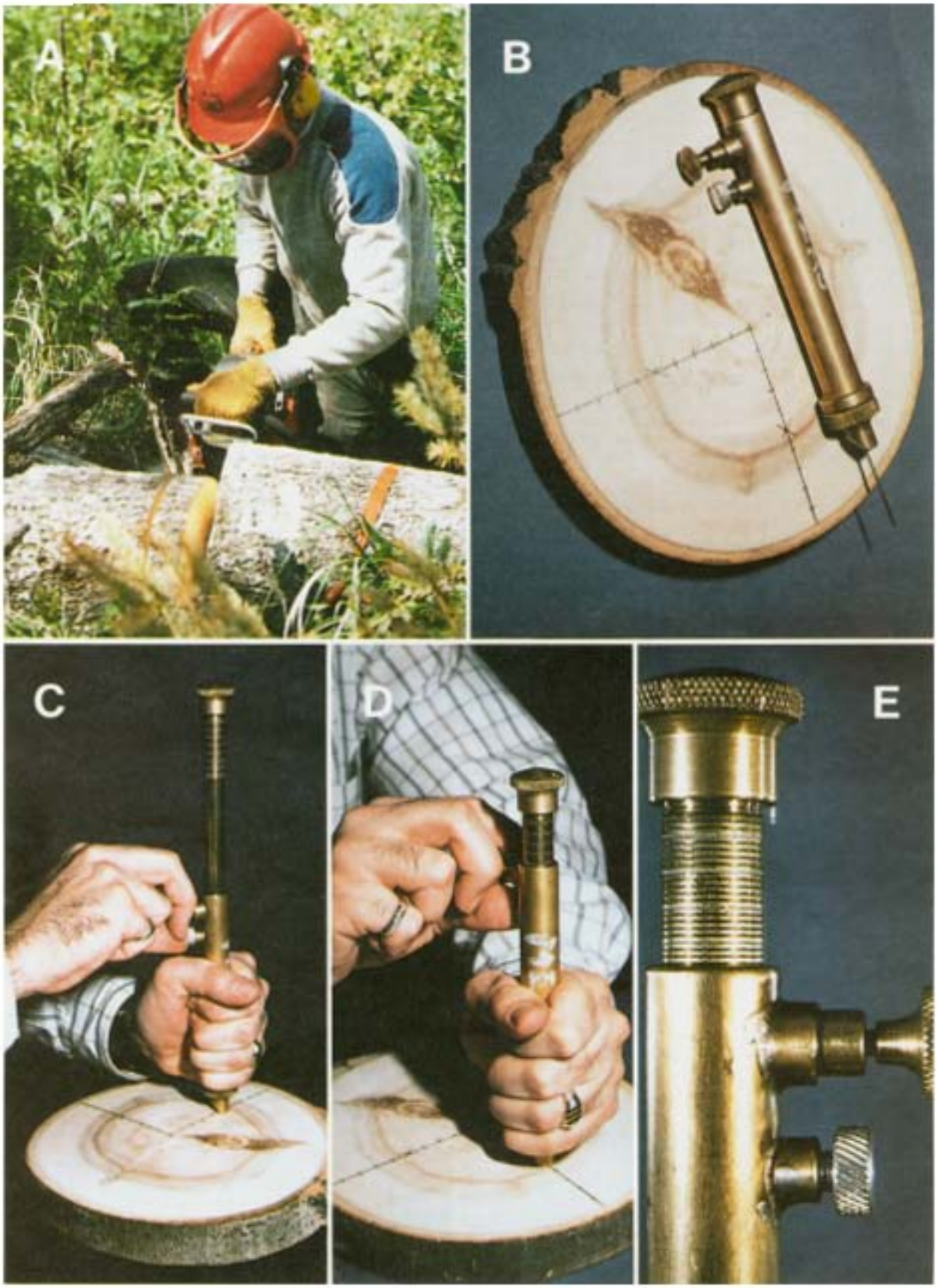
The primary consideration, then, is to sample across the range of growing conditions, stand structures, and tree sizes that are of interest. A sample of trees balanced over the geographic area of interest and over the range of tree sizes is the best approach to account for the large decay and stain variability that will be encountered. The total number of sample trees necessary to estimate decay will depend on the purpose of the survey and the size of the survey area. For an operational survey, the area of interest may be four to five townships. In this case, a minimum of 100 trees collected across the range of tree sizes will provide a reasonable estimate; however, these samples should be collected on a random basis throughout the entire survey area.

Through an efficient sample design, maximum value can be obtained from a decay survey. Individual stands representing average types should be selected. Then within each selected stand a sample plot should be established, and each tree within the plot boundary should be destructively sampled. This method has distinct advantages over sampling individual trees throughout the study area. Generally, there will be more confidence in the results, because defect estimates can be averaged to the stand level; incidences of specific defect factors (such as *Phellinus* or *Peniophora*) can be based on the stand survey; and travel costs will be reduced by sampling on a plot basis.

Figure 11.

Various external stem abnormalities of aspen. **A.** Basal stem damage. **B.** Dead branch stub with fruiting bodies of *Peniophora polygonia*. **C.** Stem crack with a conk of *Phellinus tremulae*. **D.** Black gall of unknown cause. **E.** Rough bark symptom caused by *Diplodia tumefascience*. **F.** Cankers caused by *Hypoxylon mammatum*. **G.** Stem damage caused by yellow-bellied sapsucker (*Sphyrapicus varius varius*).

[3] H-Gun specifications are available from the Timber Management Branch of the Alberta Forest Service. The device is not yet being produced commercially.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Field Measurement Guidelines

Much of the recommended field methodology that follows is taken from the *Tree sectioning manual* (Alberta Forest Service 1988).

Felling and Sectioning

Tree attributes are tallied, with special note being taken of decay indicators, disease, stem form, and stem condition. External indicators should be assessed both prior to and after felling to ensure all indicators are detected.

Stump height and breast height are marked on the stem. The felling cuts are made below the stump mark, using standard felling techniques.

Tree length is measured and marked off in 2.5-m sections starting at the stump height. Cross-sectional samples (cookies) are taken at each mark, including at stump and breast height (Fig. 12A). All defects are noted, and their extent is determined.

To identify defect type and assist with determining the extent of defects (chasing), hardness testing should be performed in the field at the tree sectioning site.

Cookies from each tree are then bagged so that age, diameter, and defect measurements can be determined later. It was during this last phase that hardness testing took place in this study.

Determining Defect Volume

A cookie from each sectioned bolt is used in the calculation of defect volume. Because hardness testing is conducted on each cookie, these cookies must be a minimum of 4 cm thick.

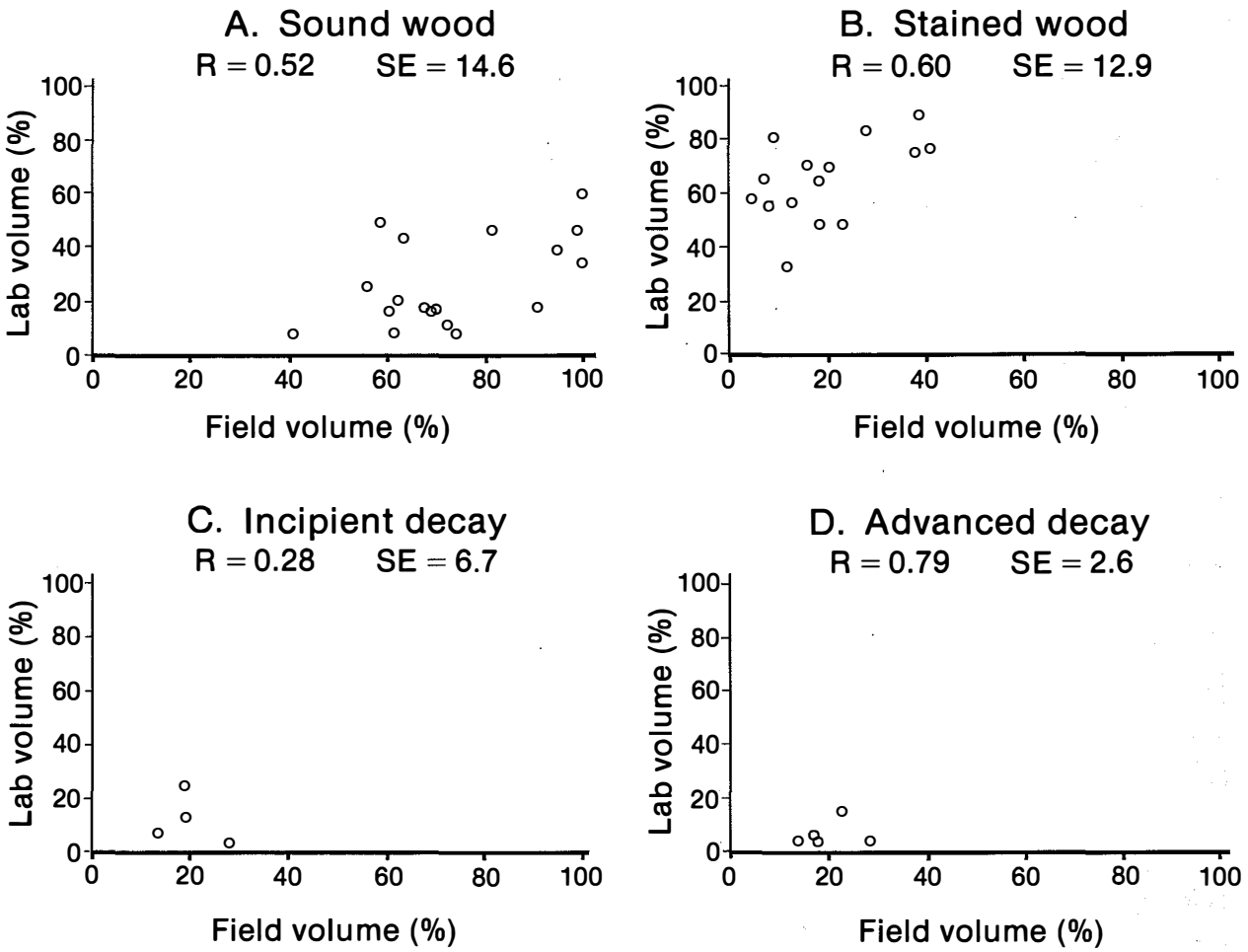
Figure 12.

Field measurement methods. A. Cutting cookies in the field. **B.** H-Gun and a cookie marked for testing. **C.** Hardness testing showing the H-Gun in the cocked position. **D.** Hardness testing showing the H-Gun after an application. **E.** The H-Gun scale after an application.

The extent of decay and stain is measured along two perpendicular radii, which are marked on the cookie (Fig. 12 B-D). These radii should be selected so that, between the two, they represent the average radius.

Hardness measurements should be taken at various intervals along the marked radii. Measurements are taken approximately every 3 cm along obviously sound or obviously decayed areas. H-Gun readings in these areas should be relatively consistent. In areas where a transition between defect types occurs, more-frequent measurements are necessary (0.5 cm apart). The objective of the H-Gun readings is to identify the transition from readings of 7 and above to those below 7.

Once the extent of each defect type has been determined for each sample cookie, the defect volumes can be calculated using the procedure outlined in the *Tree sectioning manual.*



Several options for calculating volumes exist. Each defect type (A to E) can be treated separately; alternatively, those types that cause structural decay (A and B) can be aggregated, as can the stains (D and E).

The user has several options for the treatment of Type C defect. Defects known to be caused by *Peniophora* or *Radulum casearium* but that do not contain small pockets of soft wood should usually be included with Type D defect. For chip-based products, the volume of structural defect in Type C may be insignificant; therefore, Type C defect could be included with the remaining stains (Type D and E). For solid wood products, however, scattered pockets of soft wood can make the entire wood volume unusable. In this case, Type C defect might be aggregated with Type A and B defects. In all instances, the treatment of Type C and other defects should be documented.

ACKNOWLEDGMENTS

This project was funded by the Canada-Alberta Forest Resource Development Agreement of 1984-89, which was administered by the

Northern Forestry Centre of Forestry Canada's Northwest Region. Fieldwork and hardness testing were conducted by staff of the Alberta Forest Service. Laboratory isolations, examination of microorganisms, and photographic work were conducted at the Northern Forestry Centre. Chip and pulping property assessments were conducted by Econotech Services Limited (New Westminster, B.C.).

We would like to thank the following persons for helping in the preparation of this publication:

Walter Hoffmann (Northern Alberta Institute of Technology) for developing the hardness measurement device (Hoffman-Gun or H-Gun);
Darrel Panas, Axel Winter and his field crew, and the Whitecourt Forest staff (Alberta Forest Service) for their assistance with fieldwork;
Debbie Zandbelt (Alberta Forest Service) for assisting with measurement;
Paul Maruyama (Forestry Canada) for field and laboratory assistance;
Colin Myrholm and Pat Crane (contract technologists) for assisting with word processing, laboratory work, and fieldwork;
Phil Debnam (Forestry Canada) and Jim Baker (contract photographer) for photographic work; and
Ken Mallett and Bob Newstead (Forestry Canada) for reviewing the manuscript.

Figure 13.

Comparisons of laboratory and field estimates of defect volumes.

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