ROOT ROT OF SPRUCE AND BALSAM FIR IN NORTHWESTERN ONTARIO

I. DAMAGE AND IMPLICATIONS FOR FOREST MANAGEMENT

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ABSTRACT

Examination of the root systems of 650 balsam fir (*Abies balsamea* [L.] Mill.), 570 black spruce (*Picea mariana* [Mill.] B.S.P.) and 280 white spruce (*P. glauca* [Moench] Voss) in northwestern Ontario averaging 66, 75 and 64 years of age, respectively, revealed that averages of 28%, 26%, and 25% of root, stump, and lower stem cross sections were decayed or stained by root-rotting fungi. Four types of damage resulted, the two most serious being windfall and dead standing trees which, combined, resulted in average losses in all stands of 20%, 15%, and 7%, respectively, of the dominant and codominant trees of the above species. Whether these dead and windfallen trees can be considered entirely as losses depends on their utilization and on the growth responses of the remaining trees. There were additional losses in the merchantable volume of 11%, 11% and 8% as a result of butt rot in living crop trees, and of 10%, 12% and 5% of the annual increment as a result of growth reduction associated with root rot, in each of these species, respectively.

The extent of root rot per tree increased with tree age. In the 51- to 70-year age class, losses due to windfall, dead standing trees and butt cull combined averaged 21% in balsam fir and black spruce, and 14% in white spruce. Above 71 years, these losses were much greater for balsam fir than for the two spruces. Losses due to root rot can be minimized by cutting stands before extensive damage develops, but utilization and the overall management plan must also be considered in determining the rotation age.

Average stand root rot intensity varied inversely with soil moisture regime in black spruce and white spruce, and there was a similar tendency in balsam fir. All species tended to have higher root rot on the better sites. Root rot intensity was higher on sandy soils than on aeolian silt over glacial till, and in balsam fir stands previously defoliated by the spruce budworm (*Choristoneura fumiferana* [Clem.]). Models were developed for estimating levels of root rot intensity in each species on the basis of percentages of stump surfaces affected by root rot in 10 sample trees.

RÉSUMÉ

L'examen des systèmes racinaires de 650 sapins baumiers (*Abies balsamea* [L.] Mill.), de 570 épinettes noires (*Picea mariana* [Mill.] B.S.P.) et de 280 épinettes blanches (*P. glauca* [Moench] Voss) dans le nord-ouest de l'Ontario, arbres dont la moyenne d'âge était de 66, 75 et 64 ans respectivement, a révélé qu'en moyenne, 28%, 26% et 25% des racines, des souches et des parties inférieures de la tige étaient pourries ou encore attaquées par des champignons pourrissant les racines. On a dénombré quatre types de dommages, les deux plus graves étant les chablis et les arbres morts debout. Ces dommages combinés ont indiqué des pertes de 20%, 15% et 7% respectivement dans tous les peuplements, parmi les arbres dominants et codominants des espèces précitées. Ces arbres morts ou abattus par le vent peuvent ou non être considérés comme une perte, selon qu'on les utilise ou non et selon le degré de croissance des arbres restants. Des pertes additionnelles de l'ordre de 11%, 11% et 8% du volume marchand sont à signaler à cause de la pourriture des souches chez les arbres de coupe vivants, ainsi qu'une réduction de 10%, 12% et 5% de l'augmentation de volume annuelle, causée par la diminution de la croissance, qui peut être associée à la pourriture des racines, pour chacune de ces espèces respectivement.

La pourriture des racines a augmenté en fonction de l'âge des arbres. Dans la classe de 51 à 70 ans, les arbres chablis ou morts debout et ceux dont la souche était à rejeter produisaient des pertes moyennes de 21% parmi les sapins baumiers et les épinettes noires et de 14% parmi les épinettes blanches. Pour les arbres âgés de plus de 71 ans, ces pertes étaient beaucoup plus considérables chez le sapin baumier que parmi les deux espèces d'épinettes. On peut réduire les pertes causées par la pourriture de la racine en procédant à la coupe des peuplements avant que les dommages prennent de l'ampleur, mais il faut considérer l'utilisation des arbres et le plan d'aménagement global lorsque l'on détermine la révolution.

L'intensité moyenne de pourriture de la racine dans les peuplements a varié inversement à la teneur en humidité du sol, chez l'épinette noire et l'épinette blanche; on a constaté la même tendance chez le sapin baumier. C'est dans les meilleures stations que toutes les espèces semblaient avoir subi les plus graves dommages causés par la pourriture de la racine. L'intensité de la pourriture de la racine était plus grande sur les sols sableux que sur les limons éoliens recouvrant le till glaciaire et aussi dans les peuplements de sapin abumier antérieurement défoliés par la Tordeuse des bourgeons de l'Epinette (*Choristoneura fumiferana* [Clem.]). On a mis au point des modèles afin d'évaluer le niveau d'intensité de la pourriture de la racine dans chaque espèce, à partir des pourcentages de surfaces de section des souches avariées par la pourriture des racines et ce, sur 10 arbres-échantillons.

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Cover photo: Top - Butt rot in 100-year-old black spruce and jack pine, Lake of Bays, Ontario.
Bottom - Parasitic attack of *Armillaria mellea* in 39-year-old balsam fir.

INTRODUCTION

Information is needed on root rot and its role in contributing to losses in the pulpwood species of Ontario's boreal forests. Losses attributed to decay in Canada have been estimated (Prebble 1959) as some 12% of the annual depletion by all factors including fire, logging, and pests. This estimate excludes tree mortality, windfall, and growth reduction from root and butt rot, which are considerable in some natural stands (Whitney 1962). Many root- and butt-rotting fungi are present in the major pulpwood species in Ontario (Basham 1950, 1966, 1973b, Basham et al. 1953, Basham and Morawski 1964, Gross 1970, Morawski et al. 1958, Whitney et al. 1974). However, information on damage caused by these fungi is limited largely to knowledge of the stains and decays resulting from their upward extensions into the commercial portion of the stem, i.e., above stump height. Nordin (1959) has stated that the appraisal of damage by important classes of diseases, including root and butt rots, is one of the most neglected aspects of forest pathology. The paucity of information on root rot damage is due to several factors including lack of methods of assessing damage, physical difficulties in examining roots, complexities of relating root rot to increment losses or other damage, and lack of aboveground symptoms until root rot is well advanced. In one of the few reports (Whitney 1973) on losses due to root rot in Canada, damage in the form of dead standing and windfallen trees was as high as 45% of the cubic volume in spruce stands near Candle Lake, Saskatchewan. Recent information has been published on fungi causing stem defects and on site relationships in Ontario black spruce (*Picea mariana* [Mill.] B.S.P.) (Basham 1973a, b); however, estimates of damage resulting from root rot in this and other Ontario conifers were not available when the present study was conducted.

Experience in root rot investigations has shown that a considerable amount of root decay develops before it reaches stump height and that a high proportion of roots may be killed by fungi before the decay reaches stump level. Death of roots results in loss of height and diameter increments in white spruce (*P. glauca* [Moench] Voss) (Whitney 1962). Cull in the butt log due to the upward extension of root rot is considered at least as important as that in the higher portions of the trunk (Basham and Morawski 1964), not only because the butt log is the largest and hence most valuable part of the tree, but also because butt rot weakens the base of the tree and contributes to breakage and windfall. Losses due to root and butt rot are thus a composite of losses from mortality, windthrow, growth reduction, and reduction in value of butt logs.

Information on the relation of root rot to tree age, species, stand composition and site would undoubtedly contribute to more efficient management of pulpwood stands. Adjustment of cutting priorities and logging techniques to reduce losses from root rot could result in greater profits to both owners and operators. Stumpage values would also be more realistic. The determination of comparative amounts of root rot in various species and on different sites would enable better selection of species for regeneration of successive stands. For these reasons a comprehensive root rot investigation was undertaken in pulpwood stands of northwestern Ontario. Identification of the causal organisms and information on entrance courts in the roots are also essential for development of control procedures, and these are to be included in a future report.

Studies were begun in 1971 to determine the extent of mortality, windthrow, growth reduction, and net volume loss due to root rot in black spruce, white spruce, and balsam fir (*Abies balsamea* [L.] Mill.) in northwestern Ontario. Studies of the relations between these losses and tree age, site type, site index, and geographic location were also undertaken.

MATERIALS AND METHODS

During three years of field work (1971-1973), 76 stands in the spruce and balsam fir forest types of northwestern Ontario were sampled in five major areas (Muskrat Lake, Kabitotikwia Lake [commonly known as Kab Lake], Spruce River Road, Dog River, and Lake of Bays) (Fig. 1). Most stands sampled had regenerated following fires. Some of the younger stands in the Muskrat Lake area had developed from advance regeneration that was left after logging 20 to 40 years earlier. Stands considered to be representative of each area were selected to include ranges of sites, age classes (mostly 40-100 years), stand composition, and root rot, as judged from an examination of roots of windfallen or dead standing trees. This meant that some stands were young, healthy, and on good sites, while others were older, decadent, and on poor sites. An attempt was made to sample a cross section on healthy through decadent stands in approximately 20-year age classes. Stands including large numbers of trees damaged by current insect defoliation, fire, high water tables, porcupines or other agents, but excluding root rot, were avoided.

In each stand to be sampled an area considered representative of the stand was selected and the percentages of dominant and codominant trees (potential crop trees) of each of black spruce, white spruce and balsam fir that were dead standing, windfallen, or unhealthy (as indicated below) were determined as a measure of root rot damage in each stand. The basal area per acre of each species was determined by tallying trees with a Cruz-all and multiplying by the appropriate basal area factor. Throughout this report the percentage of volume affected by root rot in a stand is considered equivalent to the proportion of dominant or codominant trees affected by root rot.

In each stand to be sampled 10 dominant or codominant trees of each of the above three species (when present) were selected as root rot sample trees, and the irregular area on which the sample trees occurred was referred to as a "plot". Where possible, a range of vigor classes

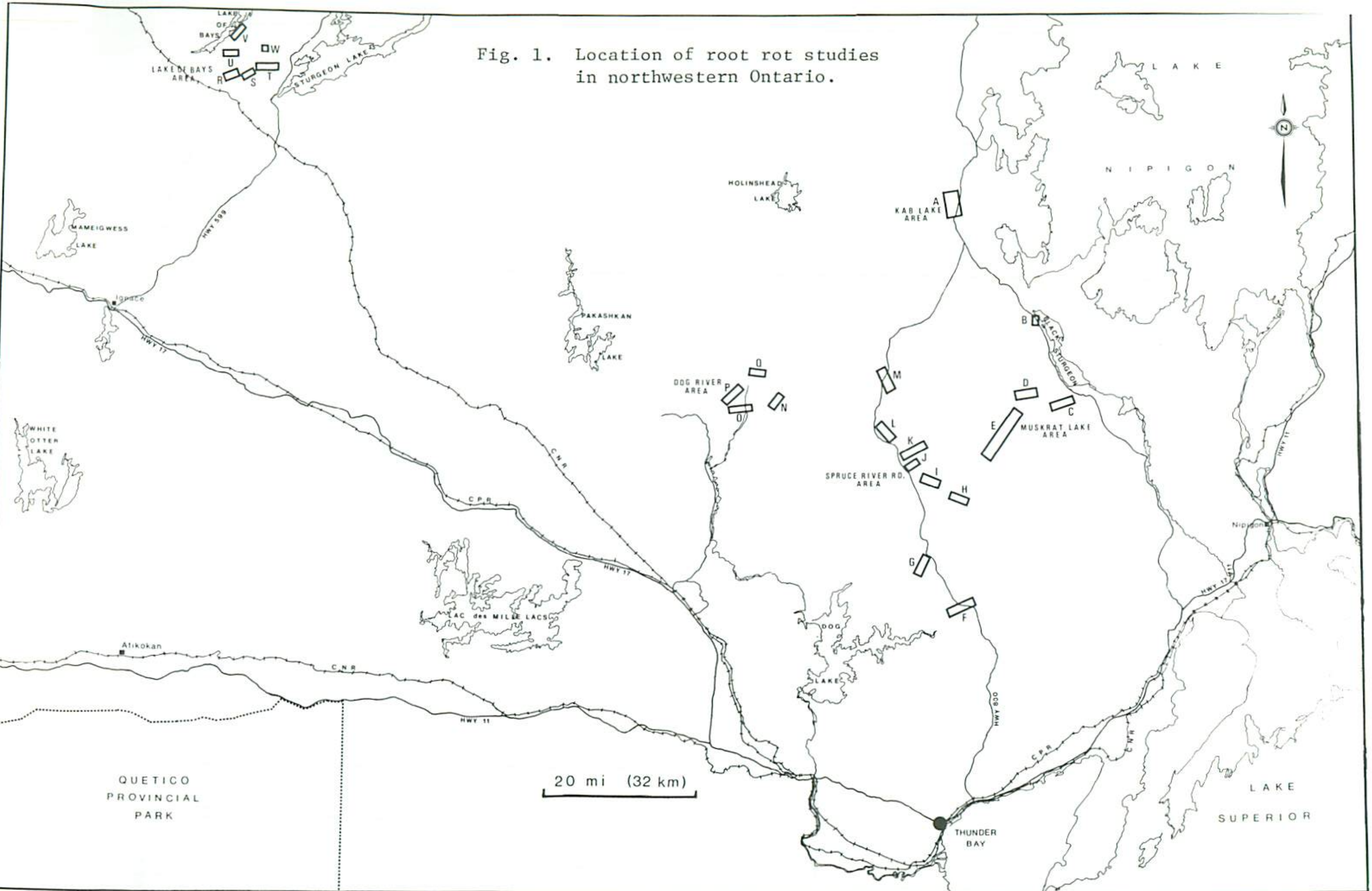

Fig. 1. Location of root rot studies in northwestern Ontario.

KAB LAKE
A– K1, K3, K4, K5, K6, K7, K8

MUSKRAT LAKE
B– K9, K10
C– M23, M24, M25, M30, M31, M32, M35
D– M41, M42, M43, M44, M51
E– M46, M47, M48, M49, M50

SPRUCE RIVER ROAD
F– A10, A11, A12, A27
G– A13, A14, A14a
H– A15, A15a, A16
I– A5, A6, A17
J– A7, A8, A9
K– A18, A19, A20
L– A21, A22, A23
M– A24, A25

DOG RIVER
N– D1, D2
O– D3, D4, D5, D6
P– D7, D8, D9, D 0
Q– D11, D12

LAKE OF BAYS
R– A53, A54
S– A55, A56
T– A57, A58, A59
U– A52, A63
V– A60, A61, A62
W– A64

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was selected within each species in order to test the relationships between tree decline and root rot. Tree vigor was classified as follows: 1 - healthy, leaves green, crown full, fully extended leader 15 cm or longer; 2 - unhealthy, leaves green, crown thinning and leader less than 15 cm, *or* scars, resinosis, and excessive dead branches; 3 - dying, leaves chlorotic and falling; leader much reduced, most of crown dead; 4 - dead, tree standing; 5 - live windfall.

Within each plot the landform, soil moisture regime (MR) based on Hills' (1952) classification, soil texture, soil depth to parent material or water table, stoniness, and any other apparently significant site feature such as extreme slope, were determined in cooperation with personnel of the Land Classification Division of the Ontario Ministry of Natural Resources. Stand history of fire, logging, and storm damage was recorded. In order to investigate the effect of previous spruce budworm (*Choristoneura fumiferana* [Clem.]) defoliation on susceptibility of trees to root rot, the intensity of tree growth reduction as a result of budworm damage, over a 1- to 5-year period at the time of the outbreak was determined from growth ring analysis at breast height (4.5 ft, or 1.37 m above ground). Each tree was allocated to one of four growth reduction classes as a result of budworm defoliation: 1, none; 2, slight; 3, moderate; and 4, severe. A Budworm Damage Index (BDI) was then calculated for each tree by multiplying the magnitude of the growth slowdown by its duration in years.

The roots of sample trees were exposed by pulling trees over with the winch of a skidder (Fig. 2). Total tree height, DBH, and age at 1-ft (0.3-m) height were determined. Height increment during each of the last 5 years was measured and a disc from breast height was cut for growth ring measurements using an Addo-X-Ring Counter. These two growth measurements formed the basis for determining relationships between root rot and tree growth. Trees were bucked into 8-ft (2.4-m) lengths and the linear extent of stem decay was determined to the nearest 2 ft (0.6 m).

For measurement and diagnosis of root rot, the roots were cleaned with a water jet from a Wajax fire pump (Fig. 3), and large roots were bucked with chain saws near the root collar (Fig. 4). If a water supply was not reasonably close to the plot (max. of 1,500 ft, or 450 m), soil was removed from the roots with hand tools. The proportion of each root larger than 2 in. (5 cm) in diameter that was stained or decayed was estimated and expressed as a percentage of the volume of that root. This procedure was also carried out on the longitudinal section of the stump below ground level (designated as the "tap" root), on the cross section of the tree at ground level, and on the cross section at 1 ft (0.3 m) above ground. The root rot intensity in each tree was then calculated by averaging the values from all the roots and averaging this figure with that from the "tap" root section plus the average of the value from the cross sections at ground level and at

Fig. 2. Pulling trees over with skidder.

1 ft (0.3 m) above ground. The average of the decay and stain values from the sample of 10 trees was then used as an expression of the root rot intensity for each species and age class per plot.

All data were placed on computer cards for sorting and compilation. Programming was conducted by personnel of the Biometrics Unit, Great Lakes Forest Research Centre.

RESULTS

Over the 3 years of the study a total of 1,500 trees were analyzed on 76 plots. All three species studied were present on 13 plots, two species were sampled on 32 plots, and single species were sampled on 31 plots. Of the 48 plots on which balsam fir were sampled, 15 were in two-storied stands in which two size classes were sampled and one was in a three-storied stand in which three size classes were sampled. Three of the 54 plots on which black spruce were sampled had two age classes sampled. The 28 plots on which white spruce were sampled had only one age class of this species. By species, 650 balsam fir, 570 black spruce and 280 white spruce trees were sampled.

Although the fungi causing root rot in northern Ontario conifers are not virulent parasites that kill trees rapidly in large numbers, they do cause a slow but relentless decay that can eventually kill trees.

Fig. 3. Cleaning roots with water jet from fire pump.

Fig. 4. Bucking roots with chain saw for root rot examination.

Many of the dead standing trees commonly seen in virgin uncut stands (Fig. 5-8) have died from the development of root rot throughout the roots and lower bole of the tree (Fig. 9-12). These trees eventually fall over; indeed, many are blown over prior to death as a result of a weakened root system. Windfallen merchantable trees, singly (Fig. 6) or in groups that cause quite distinct stand openings (Fig. 7-8), can be seen in almost any spruce-fir stand older than 30 years, especially where soils are thin. Windfall occurs, of course, during hurricane-force winds (72 mph or greater on the Beaufort Scale) regardless of the soundness of the root system. However, trees weakened by root rot are the first to be blown over by winds of lesser force. Root-rotted trees blown over by winds of less than hurricane force are usually crisscrossed (Fig. 7) and interspersed among standing trees, either living or dead. Windfalls resulting from hurricane-force winds usually lie parallel to one another, and all are blown over. In this report only windfallen trees of the former type are considered, and they were always found to be heavily root-rotted.

Both dead standing and windfallen trees can be utilized if logged prior to extensive deterioration, but this is seldom feasible except in massive blowdowns. Therefore, dominant and codominant dead standing and crisscrossed windfallen trees are usually not utilized and in this report are considered as volume losses to the stand.

When a dominant or codominant tree is killed or windfallen, adjacent trees might be expected to benefit from increased growing space. This would probably be so if only single trees or groups of two or three were attacked. Unfortunately, however, root-rotting fungi usually affected larger groups of trees (Fig. 7). Where one or two trees were dead or windfallen in this study, the nearby trees were almost invariably severely attacked, and were often in a moribund state. The root contact method of spreading major root-rotting fungi leads to patchiness of affected trees, and in this study large openings developed in some stands. The trees that remained free of heavy root rot and could respond to additional growing space were too far removed from the opening to benefit from it. Any beneficial thinning effect, therefore, by death or windfall of dominant or codominant trees as a result of root rot was negligible. In fact, the reverse occurred in the stands examined, in that nearby trees suffered a growth reduction as a result of heavy root rot.

In living coniferous trees, certain types of wood stains such as reddish brown, brown, or yellow stains, are known to be the incipient stage of forthcoming decay. In the present study, culturing proved this to be so in most trees. Incipient decay is implied wherever stain is mentioned in this report and root rot refers to the combination of decay (Fig. 10-12) and stain (incipient decay). Other types of stain, which will not be mentioned further in this report, such as pink,

Fig. 5. Dead standing black spruce killed by root rot.

orange, yellow-brown, or faint brown, are apparently not the incipient stage of decay because decay fungi were not isolated from them. Non-decaying fungi such as Fungi Imperfecti, certain Ascomycetes, and Phycomycetes are apparently associated with many of these stains, but their role in tree damage and their relation to decay fungi are largely unknown.

Damage

(a) <u>Dead Standing Trees and Windfalls</u>: Trees with heavy root rot may remain standing for many years after death or they may fall over even before they are completely dead. Factors such as spatial position with respect to other trees, occurrence of gale-force winds, soil type and moisture, slope position, and type of decay all play a part in tree stability. Since all these factors were not studied in detail, dead standing and

Fig. 6. Root-rotted balsam fir blown over in wind.

windfallen trees were grouped for purposes of analysis and discussion. Root rot in the remaining living trees is also discussed in this section to relate root rot abundance to dead trees and windfall damage.

Analysis of all trees on all plots revealed that balsam fir was affected most by root rot, black spruce was moderately affected, and white spruce was least affected. Averages of 20%, 15%, and 8% of the dominant and codominant trees of each of the species sampled were dead or windfallen as a result of root rot (Table 1). In the remaining living trees, averages of 28%, 26%, and 25% of the wood of roots and lower stem were decayed or stained in balsam fir, black spruce, and white spruce, respectively. In all three species fewer than 8% of the trees were completely free of root rot.

Both root decay alone and decay plus stain (incipient decay) were correlated with stand damage of dead and windfallen trees (Table 2). Decay and stain together are used as a measure of root rot in all discussions in this study except that decay alone is used in dealing with tree growth relationships for reasons that will be explained later. The low "r" values in Table 2 indicate that root rot does not account for all the variation in stand damage; however, root rot intensity can be used as a measure of potential damage in the stand.

By age classes (Tables 3, 4, 5) the losses in the form of dead standing trees or windfalls were negligible in balsam fir and white spruce below 50 years of age. However, 7% of dominant and codominant

Fig. 7. Stand opening resulting from root rot damage in 90- to 100-year-old black spruce.

Fig. 8. Blowdown in 60-year-old balsam fir due to heavy wind on root-rotted trees.

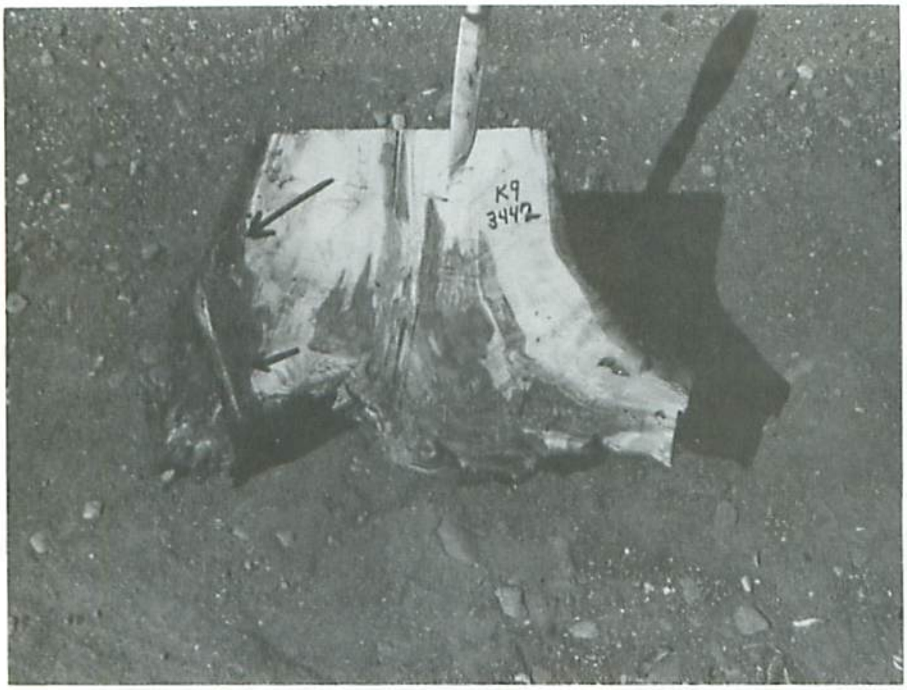

Fig. 9. Reddish brown stain and decay caused by *Armillaria mellea* (Vahl ex Fr.) Kummer in the lower stump of a 40-year-old black spruce. Arrows point to sections of killed bark.

Fig. 10. Brown cubical decay in the lower stump of a 35-year-old balsam fir.

Fig. 11. White pocket decay caused by *Polyporus tomentosus* Fr. in the base of a white spruce, 103 years old.

Fig. 12. Yellow stringy decay caused by *Scytinostroma galactinum* (Fr.) Donk in the base of a 54-year-old balsam fir.

Table 1. Proportion of dominant and codominant trees dead standing or windfallen, percentage of trees having root rot, percentage of root wood decayed or stained, and merchantable volume reduction due to root and butt rot in three conifers in northwestern Ontario

Species	No. of plots	Avg age[a]	Root rot: Trees infected (%)	Root rot: Root wood affected (%)	Dead and windfallen trees (%)	Merchantable volume reduction[b]: Actual butt rot (%)	Merchantable volume reduction[b]: Scaled cull (%)
Balsam fir	48	66	97	28	20	2.7	11
Black spruce	54	75	93	26	15	3.1	11
White spruce	28	64	96	25	7	2.5	8

[a] Measured at height of 30 cm (1 ft).

[b] Proportion of gross merchantable volume of living trees lost as a result of the upward extension (beyond 1/2 ft, or 15 cm) of root rot into the butt of the tree. Actual butt rot -- Smalian formula. Scaled cull -- Ontario Scaling Manual (Anon. 1970).

Table 2. Correlation between root rot intensity (average per plot of 10 trees) and stand damage (dead or windfallen dominant and codominant trees) of three pulpwood species

Species	No. of plots	Correlation coefficient	
		Decay plus stain	Decay alone
Balsam fir	48	.58**	.40**
Black spruce	54	.42**	.42**
White spruce	28	.58**	.58**

** Correlation significant at .01 level.

black spruce in this age class were dead standing or windfallen. In the next age class (51-70), an average of 13% of dominant and codominant balsam fir trees were dead or windfallen and this is the age class in which losses due to root rot became significant in balsam fir. Losses due to mortality and windfall were still quite low in black spruce (9%) and had started to occur in white spruce (6%). In this age class, average root rot intensity per plot remained about the same (22%), for white and black spruce, as in the previous age class (below 50 yr), but increased to 32% in balsam fir.

In the next age class (71-90) almost one-quarter (23%) of the dominant and codominant balsam fir trees and 14% of the black spruce were either dead or windfallen; there was still only a comparatively small amount of loss due to mortality and windfall (8%) in white spruce. Balsam fir was greatly affected by mortality resulting from root rot, and mortality was becoming an important factor in black spruce. In this age class, average root rot intensity in the trees sampled was 37% and 35% in balsam fir and black spruce, respectively, which was close to the maximum average intensity of root rot observed in these two species in all age classes. If only living trees were sampled, a significantly greater intensity of root rot could probably not be attained because of mortality or windfall of the trees most heavily attacked. White spruce was not as heavily attacked as the other two species in this age class: only 25% of the average root system was decayed or stained (Table 5).

Table 3. Averages (per plot) of dead standing and windfallen dominant and co-dominant balsam fir trees, root rot intensity, and merchantable volume reductions due to root and butt rot, by age classes

Age class	No. of plots	Avg age[a]	Root rot (%)	Dead and wind-fallen trees (%)	Merchantable volume reduction[b]	
					Actual butt rot (%)	Scaled cull (%)
31-50	18	39	23	3	2.0	7
51-70	6	62	32	13	1.6	8
71-90	8	79	37	23	3.4	16
91-110	10	100	39	44	4.5	14
111+	6	125	35	37	3.8	12

[a] Measured at height of 30 cm (1 ft).

[b] Proportion of gross merchantable volume of living trees lost as a result of the upward extension (beyond 1/2 ft, or 15 cm) of root rot into the butt of the tree. Actual butt rot--Smalian formula. Scaled cull--Ontario Scaling Manual (Anon. 1970).

Table 4. Averages (per plot) of dead standing and windfallen dominant and co-dominant black spruce trees, root rot intensity, and merchantable volume reductions due to root and butt rot, by age classes

					Merchantable volume reduction[b]	
Age class	No. of plots	Avg age[a]	Root rot (%)	Dead and wind-fallen trees (%)	Actual butt rot (%)	Scaled cull (%)
31-50	11	43	21	7	1.6	6
51-70	13	61	22	9	3.0	12
71-90	13	77	35	14	4.7	14
91-110	12	101	25	24	2.5	8
111+	5	132	34	23	4.4	13

[a] Measured at height of 30 cm (1 ft).

[b] Proportion of gross merchantable volume of living trees lost as a result of the upward extension (beyond 1/2 ft, or 15 cm) of root rot into the butt of the tree. Actual butt rot--Smalian formula. Scaled cull--Ontario Scaling Manual (Anon. 1970).

Table 5. Averages (per plot) of dead standing and windfallen dominant and co-dominant white spruce trees, root rot intensity, and merchantable volume reductions due to root and butt rot, by age classes

Age class	No. of plots	Avg age[a]	Root rot (%)	Dead and wind-fallen trees (%)	Merchantable volume reduction[b]	
					Actual butt rot (%)	Scalled cull (%)
31-50	7	43	22	0	2.4	7
51-70	11	60	22	6	2.6	8
71-90	7	75	25	8	1.9	6
91-110	3	101	42	42	3.7	10

[a] Measured at height of 30 cm (1 ft).

[b] Proportion of gross merchantable volume of living trees lost as a result of the upward extension (beyond 1/2 ft, or 15 cm) of root rot into the butt of the tree. Actual butt rot--Smalian formula. Scaled cull--Ontario Scaling Manual (Anon. 1970).

In the next 20-year age class (91-110 years), more than two-fifths of the balsam fir trees were dead or windfallen. Successful management of this species to this age is impracticable on most sites. Root rot damage to black spruce was also heavy in this age class where 24% of the trees were dead or windfallen. There was a rapid increase in mortality and windfall of white spruce above 90 years of age (to 42%). However, there were only three plots in this age class and these figures require confirmation. Above 110 years of age, dead trees and windfall appeared to level off in balsam fir and black spruce stands that were sampled. Most black spruce trees above 110 years of age were on sites of very high moisture regime which will be shown later to be associated with a much slower development of root rot.

In the areas sampled there was a great deal of variation, in both average root rot per tree and damage in terms of mortality and windfall, among plots in any of the age classes for all species. The intensity of root rot varied with site as will be seen later.

(b) Volume Reduction Due to Decay: The upward extension of root rot into the merchantable portion of the tree resulted in a reduction of usable wood. The resultant cull depends on factors such as use of the wood, stage of decay, and pattern and type of rot. Reduction in value of the butt log due to root rot can be considered in direct proportion to the distance above ground that the rot column progresses. If it extended to only 1/2 ft (15 cm) above ground there would be no loss, as this is about where the cut is made in logging operations either by chain saw or by mechanical harvester. If utilization is such that no decay can be allowed, then the base of the tree must be butted to remove decay above 1/2 ft (15 cm).

Ontario scaling regulations for pulpwood allow for cull of the entire 8-ft (2.4-m) log if more than 50% of the cross-sectional area is stained or decayed at the end that is scaled. For lesser amounts, tables have been devised that reduce the diameter of the log according to the diameter of the decay column at the butt or the log end being scaled (Anon. 1970).

Both actual cubic foot volumes[1] affected by decay or stain and volume of cull in terms of diameter reduction according to Table 8 of the Ontario Scaling Manual (ibid.) were calculated for each tree species and age class (Tables 1, 3, 4 and 5).

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[1] Volume of basal decay column was computed using Smalian's formula and tree volumes were from Honer's tables (Honer 1967).

Actual wood affected by butt rot in the merchantable portion of the trees, as a percentage of the gross merchantable volume, averaged 2.7%, 3.1%, and 2.5% in balsam fir, black spruce, and white spruce, respectively (Table 1). Application of scaling rules for pulpwood resulted in cull averaging 11%, 11%, and 8% in the above three species, respectively, or three to four times the volume of decayed wood (Table 1).

As with mortality and windfall, butt rot increased with age to a maximum of 3.8%, 4.7%, and 2.6% in balsam fir, black spruce, and white spruce, respectively (Tables 3 to 5). The maximum average butt rot in the trees sampled was not always in the oldest age classes, probably owing to previous mortality or windfall of the most heavily butt-rotted trees. Thus, high butt rot such as occurred in the 71-90 age class in black spruce was accompanied by comparatively low mortality and windfall in this age class. The decrease in average butt rot of black spruce in the next age class (91-110 years) very likely reflects the high percentage of trees being killed or windthrown in this age class. Above 110 years, black spruce butt rot again increased, probably because all of the older plots were on high moisture regimes where mortality and windfall due to root rot were low. In white spruce, butt rot volumes remained quite constant up to 90 years of age (Table 5). In trees older than 90 years there was an abrupt increase in the occurrence of butt rot as with dead trees and windfall.

(c) <u>Growth Reductions Due to Root Rot</u>: Living trees that are heavily infected with root rot are usually cut during harvesting, and they may be quite usable following butting of the basal decay. However, root-rotted trees were often stunted owing to poor growth over a period of years. As the development of rot gradually reduces the efficiency of affected roots, the vital functions of the tree are interfered with, and growth slows considerably prior to tree death. The growth slowdown in heavily infected trees was usually over a 5- to 20-year period in trees that were initially growing well, while the trees would have been infected for a considerably longer period of at least 30 or 40 years to have developed this amount of root rot. This indicates that the growth slowdown was indeed due to the root rot. Only dominant and codominant trees were sampled for this purpose, and their large size indicated that they competed well with their neighbors until the heavy root rot severely affected the root system. A measure of these losses was approximated by comparing the growth rate of trees with varying degrees of root rot. Very few trees in this study were free of stains in root wood, but over 100 of each species were free of advanced decay. Therefore, for estimating height and diameter reductions due to root rot, trees with stains or incipient decay only were considered to be healthy, and trees grouped into various intensities of root decay (rather than decay and stain) were compared with these healthy trees.

(i) Height Increment: In all three tree species the average annual height growth over the last 5 years was highest for trees with no root decay, and there was a gradual reduction in height growth with an increase in root decay, until the lowest height increments were reached for trees with more than 80% of the root wood decayed (Table 6). In balsam fir, large reductions in height growth coincided with increases in root decay from light to heavy; there was a further large reduction when root decay became very severe. In black spruce the largest reductions occurred as root decay increased from moderate to heavy; however, loss in height growth was more uniform with increases in root decay than it was in balsam fir. In white spruce the largest reductions in height increment occurred as root decay increased from light to moderate. In trees with heavy to very severe root decay, weighted average height reductions of 33%, 29%, and 27% occurred in balsam fir, black spruce, and white spruce, respectively. These reductions were 10%, 8%, and 4% when trees with moderate and light root decay were included in the weighted averages.

(ii) Diameter Increment: Current annual diameter increments (CADI) at breast height, over the last 5 years, were expressed as a ratio of current average annual increments to the total average annual increment of the tree excluding the last 20 years. This is an expression of current annual diameter increment compared with the long-term average for the tree. As the current diameter growth rate decreased compared with the long-term average for the tree, the CADI ratio also decreased. CADI ratios are thus a more direct measure of growth *slowdown* in the tree than the above current annual height increments.

Table 7 shows that, as with height increments, CADI ratios decreased for all three species as root decay increased. The first large reduction in 5-year CADI of balsam fir occurred as root decay increased from moderate to heavy, but the largest reduction occurred as root decay became very severe, where the CADI of trees averaged only 33% of that of the healthy trees. In black spruce, CADI decreased sharply in trees with heavy to very severe root decay when CADI was only 40% of that of healthy trees. In white spruce the greatest reduction in CADI occurred as root decay increased from light to moderate. As root decay increased further, growth reductions were quite uniform except that trees with very severe root decay produced only 44% of the increment added by healthy trees. Average CADI was not reduced in white spruce trees with only light root decay. In trees with heavy to very severe root decay, weighted average CADI reductions of 33%, 40%, and 43% occurred in balsam fir, black spruce, and white spruce, respectively. These reductions were 10%, 12%, and 5% when trees with moderate and light root decay were included in the weighted averages. It is evident that diameter increment in the trees sampled was decreased to a greater extent by root decay than height increment in black spruce, while the

Table 6. Average annual height increment of 600 balsam fir (bF), 524 black spruce (bS), and 264 white spruce (wS) with varying amounts of root decay

Root decay class	No. of trees			Avg annual height increment[a] cm			Reduction in height growth (%) compared with healthy class		
	bF	bS	wS	bF	bS	wS	bF	bS	wS
Healthy (0)[b]	125	182	106	31	23	28	0	0	0
Light (1-20)	301	195	122	29	21	27	6	6	1
Moderate (21-40)	104	61	18	26	20	19	18	13	30
Heavy (41-60)	55	32	7	21	17	25	32	25	10
Severe (61-80)	12	27	8	21	16	18	31	29	35
Very severe (81-100)	3	27	3	15	15	16	53	33	43
Weighted avg[c]	600	524	264	27	20	26	10	8	4

[a] Average over last 5 years.

[b] Percentage of root wood and stump affected.

[c] Of light to very severe combined, except for the figures under No. of trees, which are totals.

Table 7. Current annual diameter increment[a] (CADI) of 632 balsam fir (bF), 558 black spruce (bS), and 273 white spruce (wS) with varying amounts of root decay

Root decay class	No. of trees			Avg annual diam increment last 5 yr			Reduction in diam growth (%) compared with healthy class		
	bF	bS	wS	bF	bS	wS	bF	bS	wS
Healthy (0)[b]	126	182	106	1.7	1.3	2.2	0	0	0
Light (1-20)	324	213	125	1.5	1.2	2.2	9	8	0
Moderate (21-40)	111	66	21	1.5	1.1	1.7	12	17	22
Heavy (41-60)	55	35	7	1.2	1.1	1.5	31	19	31
Severe (61-80)	14	29	9	1.0	0.8	1.2	38	41	46
Very severe (81-100)	2	33	5	0.6	0.5	0.9	67	60	56
Weighted avg[c]	632	558	273	1.5	1.1	2.0	10	12	5

[a] Ratio of the current average annual increment (5 yr) to the total average annual increment excluding the last 20 years.

[b] Percentage of root wood and stump affected.

[c] Of light to very severe combined, except for the figures under No. of trees, which are totals.

average reduction of the two types of increment was similar in balsam fir and white spruce.

Effect of Geographic Location on Root Rot

Direct comparisons cannot be made among all of the areas owing to differences in average tree age which itself has been seen to affect root rot considerably. Root rot intensity and damage in the form of dead and windfallen trees and butt cull are listed in Tables 8 to 10 for the five areas sampled.

Balsam fir at Kab Lake was apparently much more subject to root rot attack and resultant damage than it was at Muskrat Lake. Although the average balsam fir age was 14 years greater at Muskrat Lake, both the proportion of roots decayed or stained and resultant damage in the form of dead and windfallen trees and butt cull were less than in balsam fir at Kab Lake (Table 8). It was also evident that damage was higher in this species in the Spruce River Road area than in the Dog River area, even though the average age of trees in the former area was 27 years less.

In black spruce, root rot attack independent of age did not appear to differ greatly among the five areas. Root rot intensity and damage due to butt cull were low, however, at Lake of Bays compared with those at Kab Lake where trees were slightly younger (Table 9).

In white spruce it was evident that at Lake of Bays, although the average age of trees was slightly higher, both the level of root rot and butt cull were lower than in the Spruce River Road area (Table 10).

Statements concerning variation between areas in root rot and resultant stand damage must be considered as tentative, owing to the small number of plots per age class in each area. When age is taken into account balsam fir was more defective in all areas than were the other two species, with the possible exception of white spruce at Muskrat Lake. Also on this basis, balsam fir and black spruce appeared to be more defective in the Kab Lake area than in most other areas. White spruce appeared least defective in the Lake of Bays area. Both age and site are known to affect the development of root rot and these are probably the main factors involved in the differences among areas.

Site Relationships

The amount of root rot per plot varied considerably in stands of comparable ages in all three species (Fig. 13, 14, 15). In black spruce, for example, plot A9 had only about one-third the amount of

Table 8. Percentages of dead standing and windfallen dominant and codominant balsam fir trees, root rot intensity, and average merchantable volume reductions due to root and butt rot at five locations in northwestern Ontario

					Merchantable volume reduction[b]	
Location	No. of plots	Avg age[a]	Root rot (%)	Dead and wind-fallen trees (%)	Actual butt rot (%)	Scaled cull (%)
Kab Lake	6	46	32	8	3.0	15
Muskrat Lake	9	60	26	6	2.8	8
Spruce River Road	8	72	35	34	4.0	14
Dog River	12	99	35	28	2.1	9
Lake of Bays	10	68	31	22	1.8	7

[a] Measured at height of 30 cm (1 ft).

[b] Proportion of gross merchantable volume of living trees lost as a result of the upward extension (beyond 1/2 ft, or 15 cm) of root rot into the butt of the tree. Actual butt rot--Smalian formula. Scaled cull--Ontario Scaling Manual (Anon. 1970).

Table 9. Percentages of dead standing and windfallen dominant and codominant black spruce trees, root rot intensity, and average merchantable volume reductions due to root and butt rot at five locations in northwestern Ontario

Location	No. of plots	Avg age[a]	Root rot (%)	Dead and wind-fallen trees (%)	Merchantable volume reduction[b]	
					Actual butt rot (%)	Scaled cull (%)
Kab Lake	7	67	24	5	3.0	13
Muskrat Lake	11	90	31	22	3.4	9
Spruce River Road	16	82	29	18	4.3	15
Dog River	9	70	25	9	2.5	7
Lake of Bays	7	71	19	13	1.5	6

[a] Measured at height of 30 cm (1 ft).

[b] Proportion of gross merchantable volume of living trees lost as a result of the upward extension (beyond 1/2 ft, or 15 cm) of root rot into the butt of the tree. Actual butt rot--Smalian formula. Scaled cull--Ontario Scaling Manual (Anon. 1970).

Table 10. Percentages of dead standing and windfallen dominant and codominant white spruce trees, root rot intensity, and average merchantable volume reductions due to root and butt rot at five locations in northwestern Ontario

					Merchantable volume reduction[b]	
Location	No. of plots	Avg age[a]	Root rot (%)	Dead and wind-fallen trees (%)	Actual butt rot (%)	Scaled cull (%)
Kab Lake	5	62	22	4	1.0	7
Muskrat Lake	7	63	22	12	2.2	8
Spruce River Road	4	65	30	17	3.9	7
Dog River	5	55	23	1	2.3	3
Lake of Bays	2	70	14	0	2.6	6

[a] Measured at height of 30 cm (1 ft).

[b] Proportion of gross merchantable volume of living trees lost due to the upward extension (beyond 1/2 ft, or 15 cm) of root rot into the butt of the tree. Actual butt rot--Smalian formula. Scaled cull--Ontario Scaling Manual (Anon. 1970).

root rot that was present on plot A7, although they were only about 200 m apart, and both were about 84 years old and were of a common fire origin. Similarly, plots of widely varying ages had like amounts of root rot. For example, balsam fir root rot was at least as heavy on plot K6 (average of 51% of root wood decayed or stained per tree) at 70 years of age, as on any of the older balsam fir plots, such as M44 or A20, that were up to 50 years older. Differences in root rot intensity in stands of the same age class were often related to differences in site as seen below. Owing to the small number of stands sampled, the plots were divided into broad (30-yr) age classes for site analysis.

(a) Moisture Regime: When plots were divided into moisture regime (MR) classes, black spruce plots on wet sites (MR 7-8) invariably had less root rot than those on moist or drier sites in age classes I and III (Table 11). In age class II, plots on wet and moist sites had less root rot than those on drier plots. When all age classes were grouped, black spruce root rot was highest on the fresh sites and lowest on the wet sites. Net productivity of black spruce was probably best on moist sites where root rot was comparatively low, and soil moisture was not excessive, especially in the younger age classes.

In white spruce, root rot—soil moisture relationships were similar to those of black spruce but less pronounced (Table 11). In age class I, the one white spruce plot on each of the wet and moist sites had much less root rot than plots on drier sites. White spruce in age class II had similar root rot on the dry, fresh and moist sites. In age class III white spruce was represented only on fresh sites where the average root rot intensity was high (41%). The maximum net productivity of white spruce was probably on the moist sites where growth rate was the nearest to optimal, but average root rot over all age classes was somewhat less than on fresh sites.

In balsam fir, root rot appeared to be higher on the driest sites in age class II, and figures in age classes I and III indicate that root rot in this species was somewhat higher on fresh and dry sites than on moist sites (Table 11). When all age classes were considered, however, there was little difference in root rot of balsam fir on dry, fresh or moist sites. Balsam fir was not present on any of the wet sites.

(b) Site Index: Analysis of the effects of moisture regime on intensity of root rot suggested that root rot was most severe on the better sites and least severe on the poorer sites, particularly with black spruce. Root rot intensity was therefore compared on plots within 30-year age classes in stands of various site indexes. The site index for each species was averaged from the three best dominant trees on each plot.

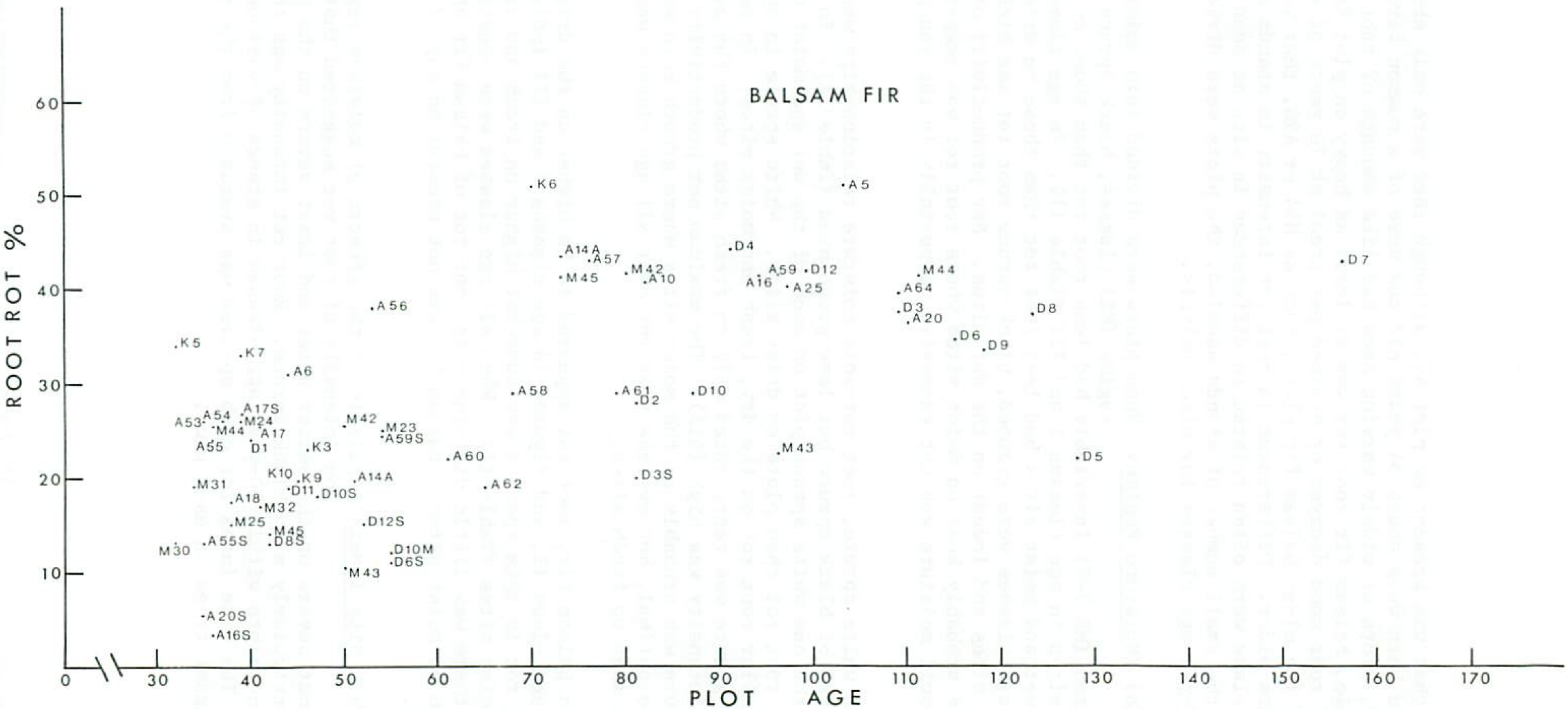

Fig. 13. Average percentage of balsam fir root and stump wood decayed or stained per plot (10 trees) by age classes.

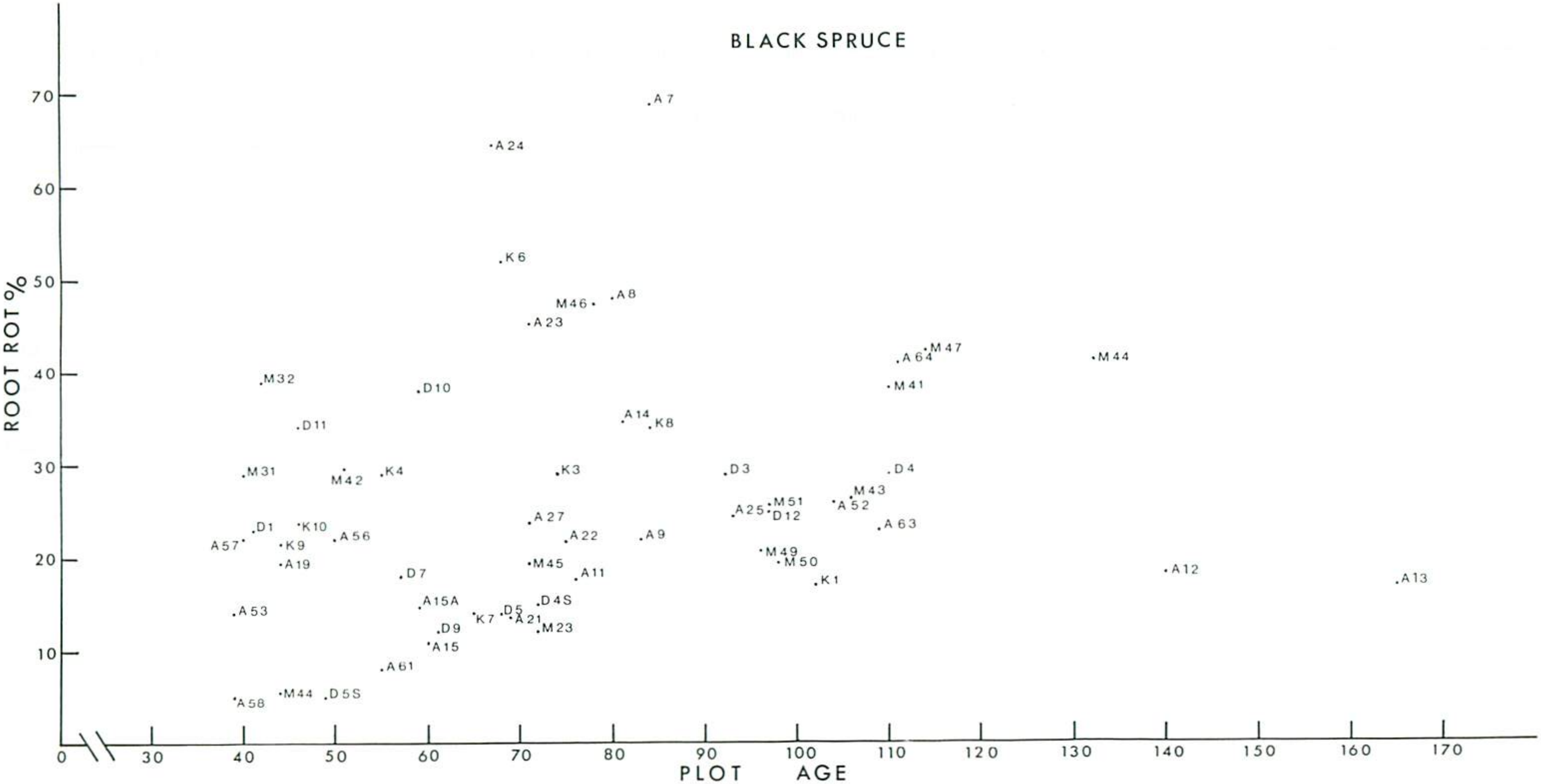

Fig. 14. Average percentage of black spruce root and stump wood decayed or stained per plot (10 trees) by age classes.

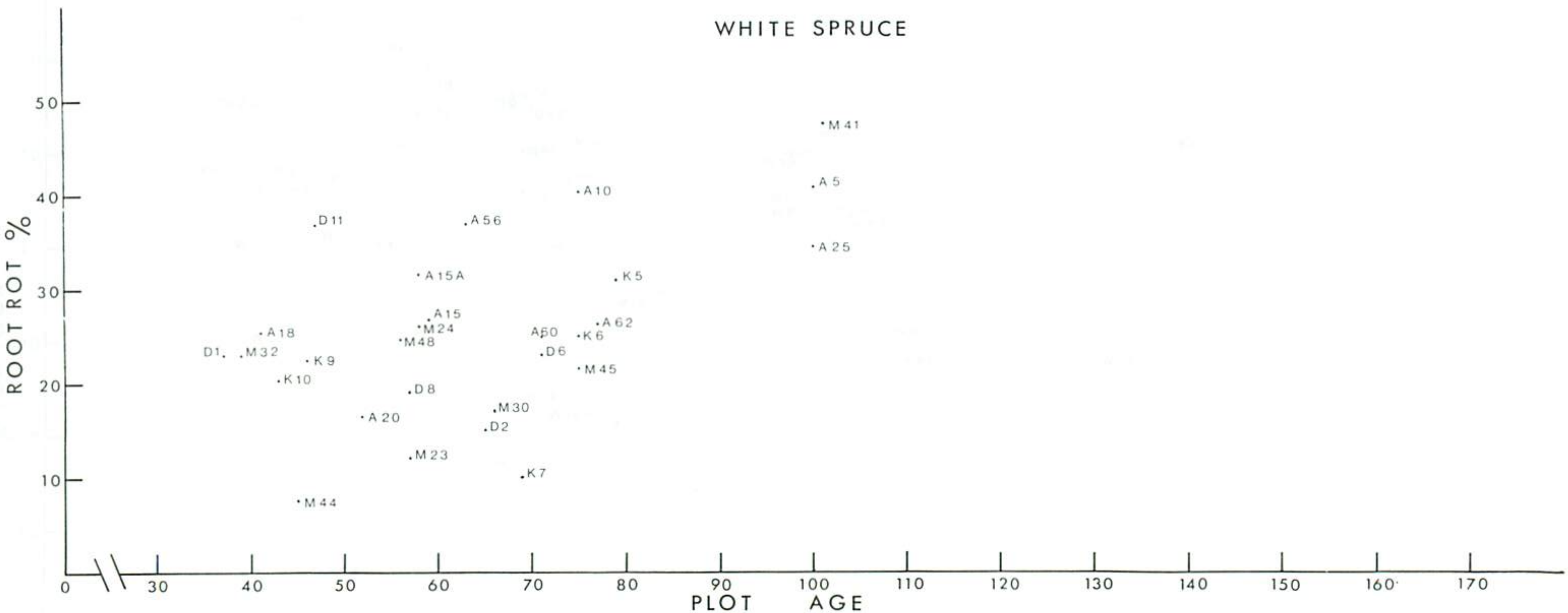

Fig. 15. Average percentage of white spruce root and stump wood decayed or stained per plot (10 trees) by age classes.

Table 11. Average intensity of root rot per plot on various moisture regimes by tree species and broad age classes

	Moisture regime											
	0-1 (Dry)			2-3 (Fresh)			4-6 (Moist)			7-8 (Wet)		
Age class	wS[a]	bS	bF	wS	bS	bF	wS	bS	bF	wS	bS	bF
I (30-60 yr[b])												
Avg root rot	25	18	19	24	29	22	12	14	17	8	6	-
No. of plots[c]	5	6	8	7	8	20	1	5	7	1	1	-
II (61-90 yr)												
Avg root rot	26	34	42	23	34	28	27	23	33	-	22	-
No. of plots	3	4	4	5	9	5	3	6	4	-	1	-
III (91+ yr)												
Avg root rot	-	29	40	41	32	41	-	31	37	-	23	-
No. of plots	-	3	1	3	3	7	-	5	8	-	6	-
I-III (30+ yr)												
Avg root rot	26	25	28	27	32	27	23	23	29	8	20	-
No. of plots	8	13	13	15	20	32	4	16	19	1	8	-

[a] wS - white spruce; bS - black spruce; bF - balsam fir.

[b] avg age at 30-cm stump of 10 sample trees per plot.

[c] 10 trees per plot.

There were no strong relations between root rot intensity and site index; however, trends towards a positive correlation were evident in some age classes of each species. In balsam fir, plots with the lowest site indexes in age classes I and II had less root rot than those with higher site indexes (Table 12). There was no relation between site index and root rot in stands of age class III. In black spruce, root rot tended to increase as site index increased in age class I, except for the one plot in the highest site index class. In age class II, plots in the lowest site index class had less root rot than plots in the next two higher site index classes, but the lowest root rot ratings were in plots with intermediate site indexes. The highest root rot rating of all was on the plot with the highest site index. In age class III, as with balsam fir, there was no relation between site index and root rot. In white spruce the lower site indexes were least subject to root rot in age class II, except for one plot in an intermediate site index class. For age classes I and III there appeared to be no relation between site index and root rot.

(c) Soil Type: Soil horizon development varied tremendously so that almost no two of the 76 plots were on identical soils. However, certain characteristics such as soil texture and landform were sufficiently similar on some plots to allow grouping. Root rot comparisons were made for different values of these factors.

The average percentage of root wood attacked per tree was higher for all three tree species growing on deep, medium-to-fine sands of outwash or ponded origin than for those growing on aeolian silt (silt loam or silty sand) 24 to 40 in. (61-102 cm) thick over glacial till (Table 13). Stones were sparse and did not restrict the rooting layer on either type of site. All plots on aeolian silt soils were in the Dog River area while the deep sands were mostly in the Kab Lake area, with one each in the Spruce River Road and Lake of Bays areas. The possible contribution of other factors such as stand history and age could not be evaluated. Tree ages were comparable on the two site types for balsam fir and black spruce; however, the greater average age of white spruce on the sandy soils undoubtedly accounted for some of the increased root rot on this site type because of the strong positive correlation between tree age and root rot. The average moisture regime and site index were similar on the two sites for all three species.

Stem Decay

Stem decay differs from root rot mainly in that it begins in the aboveground parts of the tree, and it is usually caused by different species of fungi than is root rot. It is known to be very severe

Table 12. Average intensity of root rot per plot by site index classes and broad age classes

Species	Age class[a]	Site index class 31-35	35-40	41-45	46-50	51-55	56-60	61-65	66-70	All sites
		(Average % of root wood decayed or stained per tree)								
Balsam fir	I	-	-	11 (3)[b]	19 (6)	23 (9)	18 (5)	20 (4)	24 (8)	20 (35)
	II	-	-	24 (4)	42 (2)	37 (5)	35 (2)	-	-	34 (13)
	III	-	-	39 (9)	35 (3)	39 (4)	-	-	-	38 (16)
Black spruce	I	-	-	17 (2)	13 (2)	19 (4)	23 (7)	25 (4)	14 (1)	21 (20)
	II	26 (3)	38 (6)	38 (3)	16 (3)	20 (4)	-	64 (1)	-	30 (20)
	III	26 (3)	29 (6)	26 (3)	26 (3)	26 (2)	-	-	-	27 (17)
White spruce	I	-	21 (2)	-	27 (1)	19 (4)	21 (2)	30 (2)	23 (3)	23 (14)
	II	-	13 (2)	26 (4)	-	31 (4)	15 (1)	-	-	25 (11)
	III	-	-	48 (1)	34 (1)	41 (1)	-	-	-	41 (3)

[a] Average age at 30-cm stump of 10 sample trees per plot: I = 30-60 yr; II = 61-90 yr; III = 91+ yr.

[b] Number of plots.

Table 13. Root rot intensity in three species of trees growing on deep sandy soils of outwash or ponded origin, compared with those on aeolian silt, 24 to 40 in. (61-102 cm) thick, over glacial till, in northwestern Ontario

	Deep sand			Aeolian silt		
Species	No. of plots	Avg age[a]	Avg root rot per tree (%)	No. of plots	Avg age	Avg root rot per tree (%)
Balsam fir	9	54 (32-96)[b]	32	10	58 (40-87)	19
Black spruce	7	73 (55-85)	39	9	67 (46-92)	21
White spruce	4	75 (69-79)	27	3	64 (57-71)	19

[a] Measured at height of 30 cm (1 ft).

[b] Range of plot ages.

in balsam fir (Basham 1950, Basham et al. 1953, Basham and Morawski 1964, Morawski et al. 1958) and is the main reason for poor acceptance of this species by wood-using industries. Stem decay, however, usually has a less devastating effect on the stability of the tree than has root rot, as it is in a less vital structural part of the tree. Furthermore, the living sapwood and bark are less frequently invaded by stem decay fungi than by root-rotting fungi. Since extensive stem decay studies on these three tree species have already been conducted by Basham (Basham 1950, 1973a, 1973b, Basham et al. 1953, Basham and Morawski 1964) stem decay was not examined in detail in the present investigation. The average length of the stem decay column in all trees in this study was 4.0, 2.0, and 2.2 m (13.0, 6.6, and 7.2 ft), respectively, in balsam fir, black spruce, and white spruce and averages of 39%, 10%, and 9% of the stems were infected (Tables 14-16). In black spruce and white spruce, stem decay increased with age to the 51-70 age class, where it levelled off. In balsam fir, stem decay increased to the 71-90 age class, beyond which there was no further increase. Levelling off is probably due to mortality and windfall of heavily decayed trees, so that in older stands decay levels were based on the surviving, relatively decay-free trees.

Volume losses due to stem decay would be dependent on the extent and stage of decay and end use of the wood. Stained wood can be accepted for kraft pulping (Hunt and Whitney 1974) and small amounts are used in other processes. Assuming that about 60% of the stem decay was in an advanced stage in black spruce, and close to 80% in the other two species (Basham and Morawski 1964), averages of 3.2, 1.2, and 1.8 lineal m (10.5, 3.9, and 5.9 lineal ft) of the merchantable stem would be culled, according to the diameter of the decay column, in relation to the log diameter indicated in the Ontario Scaling Manual. Again assuming that about one-half of the lineal measure with decay would be sound wood, the three species would average, 1.6, 0.6, and 0.9 lineal m (5.3, 2.0, and 3.0 lineal ft) of actual cull per tree for stem decay. With an average merchantable tree length of 8.5 m (27.9 ft), these lineal losses would amount to approximately 19%, 7%, and 11% of the merchantable volume in balsam fir, black spruce, and white spruce, respectively.

Root Rot in Relation to Spruce Budworm Damage

The effects of previous defoliation by the spruce budworm on tree growth were detected by noting abrupt reductions in diameter growth that coincided with, or closely followed, severe budworm outbreaks of the late 1940s and early 1950s. The average Budworm Damage Index (BDI) for all trees in each root rot class, from areas affected by spruce budworm, is listed in Table 17. In balsam fir the average BDI increased

Table 14. Average length of decay or stain columns in stems of 632 balsam fir trees by age classes in northwestern Ontario

Age class	No. of plots	Avg age[a]	Trees infected (%)	Avg length of decay or stain column (m)
31- 50	18	39	15	1.7
51- 70	6	62	42	3.5
71- 90	8	79	60	5.7
91-110	10	100	59	6.0
111+	6	125	50	5.9
Weighted avg[b]	48	71.4	38.7	4.0

[a] Measured at height of 30 cm (1 ft).

[b] Except for the figure under No. of plots, which is a total.

Table 15. Average length of decay or stain columns in stems of 558 black spruce trees by age classes in northwestern Ontario

Age class	No. of plots	Avg age[a]	Trees infected (%)	Avg length of decay or stain column (m)
31- 50	11	43	6	.8
51- 70	13	61	6	2.0
71- 90	13	77	12	2.7
91-110	12	101	12	2.3
111+	5	132	20	2.5
Weighted avg[b]	54	76.7	10.0	2.0

[a] Measured at height of 30 cm (1 ft).

[b] Except for the figure under No. of plots, which is a total.

Table 16. Average length of decay or stain columns in stems of 273 white spruce trees by age classes in northwestern Ontario

Age class	No. of plots	Avg age[a]	Trees infected (%)	Avg length of decay column (m)
31- 50	7	43	34	.9
51- 70	11	60	10	2.9
71- 90	7	75	11	1.7
91-110	3	101	10	4.1
Weighted avg[b]	28	62.3	8.9	2.2

[a] Measured at height of 30 cm (1 ft).

[b] Except for the figure under No. of plots, which is a total.

steadily with increasing root rot. The decrease in BDI in trees with more than 70% of root wood decayed or stained is probably a reflection of other factors such as tree age or site. This indicates that increased severity and duration of budworm defoliation had the effect of increasing the susceptibility of balsam fir trees to root rot. In black spruce there was an increase in average BDI in the first three root rot classes; beyond this, root rot was not related to BDI in black spruce. In white spruce, where growth reduction due to spruce budworm defoliation was apparently greater than in balsam fir or black spruce, there was possibly a slight negative relationship between budworm-caused growth reduction and root rot.

Predicting Root Rot Losses

The intensity of root rot in a stand must be known in order to predict expected losses accurately. Since root examination and root rot diagnoses are not common forestry activities, some method of determining the root rot intensity in a stand from aboveground information is required to improve estimates of root rot losses in management plans. A correlation was found between the intensity of root rot in a stand and the average percentage of the basal area decayed or stained of a 10-tree sample at 1/2 ft (15 cm). Correlation coefficients of .82, .91, and .77 for each of balsam fir, black spruce, and white spruce, respectively, were found. Assuming a straight line relationship between the two variables, a regression analysis produced the following formula for each tree species on a plot basis.

For balsam fir $X = 1.32Y - 4.78$

For black spruce $X = 1.16Y - 6.83$

For white spruce $X = 1.43Y - 8.10$

Where:

X = mean root rot intensity of the stand and

Y = mean percentage of basal area of 10 sample trees decayed or stained at 1/2 ft (15 cm) (stump height).

Using these formulas and the existing data on 76 plots, estimates of root rot intensity based on measurements of decayed or stained area at stump height were made for each species. Plots were grouped into root rot categories of light (0-15% of root wood decayed or stained), medium

Table 17. Average spruce budworm damage index (BDI)[a] in various root rot classes of balsam fir, black spruce, and white spruce

	Balsam fir		Black spruce		White spruce	
Root rot class[b]	No. of trees	BDI	No. of trees	BDI	No. of trees	BDI
0	12	1.0	32	3.3	13	7.1
1-10	42	4.3	124	4.7	41	11.9
11-20	70	6.8	75	6.5	55	10.6
21-30	71	8.2	61	6.0	45	11.0
31-40	66	6.8	40	4.8	35	9.9
41-50	48	6.9	29	5.9	15	10.0
51-60	35	9.0	23	6.9	7	8.3
61-70	17	9.1	11	3.5	6	9.8
71-80	9	5.5	16	4.0	5	9.6
81-90	2	7.0	16	2.5	3	9.0
91-100	1	5.0	12	0.9	3	9.3

[a] See text.

[b] Percentage of root wood decayed or stained.

Table 18. Proportion of balsam fir, black spruce, and white spruce stands that were correctly placed in broad root rot classes from estimates made 1/2 ft (15 cm) above ground on a 10-tree sample in each stand

	Balsam fir		Black spruce		White spruce	
Root rot intensity (plot avg)	No. of plots	Plots correctly estimated[a] (%)	No. of plots	Plots correctly estimated (%)	No. of plots	Plots correctly estimated (%)
Light (0-15%)	11	82	12	75	4	75
Moderate (16-30%)	28	86	31	65	16	50
Severe (31% +)	24	79	14	86	8	75
Total/Avg	63	83	57	72	28	61

[a] Compared with actual root rot that was measured in this study.

(16%-30%), or severe (31%+). The proportion of plots that were correctly placed within these root rot categories after substituting the plot values of stain and decay at stump height (1/2 ft, or 15 cm) in the formulas for each species varied from 50% to 86% (Table 18). The averages for each species were 83%, 72%, and 61% of estimates falling into the correct root rot severity class for each of balsam fir, black spruce, and white spruce, respectively.

DISCUSSION AND CONCLUSIONS

Root rot sampling in 76 representative spruce—fir or spruce stands in northwestern Ontario revealed a startling amount of root rot. On the basis of a thorough examination of the large roots and stumps of 1,500 living dominant or codominant trees from 26 to 227 years old, the average proportion of root and stump wood decayed or stained was 28% in balsam fir, 26% in black spruce, and 25% in white spruce. These averages were composed of individual trees varying in root rot intensity from 0% to 95% in all three species.

The effect of various intensities of root rot on individual trees in the study was as follows. Trees with 60% or more of the root wood decayed or stained were much weakened structurally and, if the sapwood was affected, physiologically as well. Such trees are prone to windfall and they may be killed outright if decay continues in the sapwood and adjacent root bark is killed, a condition frequently seen in this study. Butt cull was also heavy in trees with 60% or more of the root wood decayed or stained. Trees with 41%-60% of the root wood decayed were also more susceptible to windthrow than were healthy trees. They may live on for many years, but annual increments became progressively smaller as larger proportions of the root system were killed. Butt cull was present in many trees that had 41% to 60% of the root wood decayed or stained. Trees with 21% to 40% of the root wood decayed or stained had reduced growth rates compared with trees with healthy roots. In the present study, slightly more than 50% of the trees averaged 21% or more of the root system and lower butt affected by root rot, and the trees were subjected to the above early windfall, butt cull, and growth reduction. It is thus evident that a high proportion of the living crop trees is adversely affected and root rot is of vital importance in the management of stands of these three species.

In balsam fir, dead and windfallen trees accounted for an average of 20% of the merchantable volume in these stands which averaged 66 years of age, with an additional 11% lost due to scaled cull. The average reduction in height and diameter increment apparently due to root rot in all merchantable balsam fir trees was about 10%. These losses total 41% (20 + 11 + 10) of the gross merchantable volume for stands averaging 66 years of age. The average stem decay column of 4 m (13.0 ft) per tree in balsam fir would increase the volume losses to well over 50% of the gross merchantable volume if stem decay must be culled. As is seen in Table 3, losses from dead and windfallen trees and from butt cull rapidly increase with age so that stands above the average age of 66 years can average well over half the merchantable volume lost as a result of root rot, and even more if stem rot is included. It cannot be too strongly emphasized, therefore, that balsam fir under average conditions must be cut at an age well below 66 years if heavy losses from root rot are to be averted. This is similar to Prielipp's (1957) conclusion for balsam fir in upper Michigan, where he recommended a quality rotation age of 65-70 years on swamp site, 55-60 years on transitional sites, and 45-50 years on upland sites. He based this on balsam fir management that aimed to prevent butt rot rather than deal with rot after it has developed. Spaulding and Hansbrough (1944) suggested a rotation age of about 70 years to keep cull losses at a relatively low figure for balsam fir in the northeastern United States, and Kaufert (1935) indicated that balsam fir cull increased rapidly after 70 years in Minnesota. McCallum (1928) stated that cull losses in balsam fir in Quebec became heavy between 70 and 100 years of age, and Basham (1950) showed that the net periodic increment fell rapidly after 80 years, and that this should be the maximum rotation age in Ontario. Most of the above studies considered only decay and cull in residual trees. The pathological rotation age of 70-80 years, which has been suggested for balsam fir (Bakuzis and Hansen 1965, Gevorkiantz and Olsen 1950), is based on equalization of increments of decay and tree increments, but if mortality and windfall losses were considered, the rotation would be shortened (Basham 1950). In the present study, mortality, windfall, and growth reduction volumes resulting from decay in the roots were all taken into account. As a result, much larger total losses from root rot were indicated and they can be prevented or reduced only by harvesting at an earlier age.

It may be argued that a portion of the trees must die as the stand matures to provide growing space for the remaining trees. Only dominant and codominant trees have been considered in compiling damage in this report, and death of these large trees in stands 40-100 years old represents productivity losses. There undoubtedly are portions of some stands where the thinning effect of mortality and windfall results in improved growth of the remaining trees, but unfortunately the large gaps created, and the decadent condition of many of the remaining trees due to root rot, do not allow this to happen in most stands. The losses could be reduced by logging dead and windfallen trees prior to their deterioration.

In black spruce an average of 15% of dominant and codominant trees were dead or windfallen from predisposition by root rot in stands averaging 75 years of age. Eleven percent of the merchantable volume of the remaining trees was culled because of butt rot and an average of 12% was apparently lost from the annual diameter increment because of root rot in the growing stock. This resulted in a total loss from gross merchantable volume of 38% (15 + 11 + 12%), and the 12% growth reduction is cumulative. Stem decay is minimal in black spruce and white spruce and seldom exceeds 5% of gross merchantable volume in stands less than 100 years old (Morawski et al. 1958). Thus, more than one-third of the volume of average upland black spruce stands, 75 years of age, was lost because of root rot unless windfall and/or dead standing trees were salvaged before they began to deteriorate. Black spruce trees on upland sites should be harvested before they are 75 years old to prevent such losses. Johnson (1971) has recommended rotations of not more than 70 years for black spruce on mineral soil in Minnesota because of butt rot and windfall. As with balsam fir, older trees had more defect from root rot; however, black spruce stands averaging 9 years older than balsam fir suffered slightly lower total losses. The lower proportion of black spruce roots affected by root rot at a comparable age indicates that black spruce can be harvested at an age at least 20 years older than balsam fir and not suffer more loss (compare Tables 3 and 4).

Of the three species analyzed in this study, white spruce suffered the least loss from root rot. At an average age of 64 years, losses were 7% from dead and windfallen dominant and codominant trees, and 8% from butt cull. An additional 5% of the increment was lost annually. Thus, total losses in white spruce were 20% (7 + 8 + 5) of the gross merchantable volume in stands averaging 64 years of age. It is evident that, because average root rot in white spruce was about one-third less at 71-90 years of age than in black spruce (compare Tables 4 and 5), white spruce harvested at an age considerably older (10-20 years) than black spruce would have about the same losses from root rot.

Site conditions greatly affect the severity of root rot and resultant damage in these three species. Basham (1973a, 1973b) found that black spruce butt rot infections caused by most fungi were much higher on upland than on lowland sites, and that butt rot in this species increased with a decrease in moisture regime. These findings have been confirmed in this study. A similar relationship was found between moisture regime and root rot in white spruce and to a lesser extent in balsam fir. Whitney and Denyer (1970) found that inoculated fungi caused more infections and grew significantly faster in upland than in lowland black spruce. Prielipp (1957), Spaulding and Hansbrough (1944), Kaufert (1935), Heimburger and McCallum (1960), and Zon (1914) all found more cull in upland (drier) than in lowland (moister) balsam fir. The greater amounts of root rot found in this study on sandy soils compared with finer textured soils could be indirectly related to lower soil moisture contents generally prevalent in sandy soils. Prielipp (1957) and Peacock (1968) also found decay in balsam fir to be heavier on sandy soils than on finer textured soils.

Where trees were growing fastest there was a tendency toward greater development of root rot in all three species, especially in black spruce younger than 60 years. Zon (1914) found balsam fir to be most defective on sites where it grew best, and McCallum (1928) and Basham (1950) found culled volumes to be slightly higher in fast-grown balsam fir than in slow-grown trees. However, Rankin (1920) found the more rapidly growing balsam fir to have less butt rot. Spaulding and Hansbrough (1944) found no correlation between percent of cull and rate of growth. They found, however, that decay volumes are much larger in fast-grown balsam fir, but that the percentage of wood decayed is actually slightly less in fast-grown than in slow-grown trees. Kaufert (1935) found essentially the same in Minnesota. Basham (1973a) found faster growing black spruce to be much more defective than slower growing trees of the same age. Conflicting evidence and lack of definite relationships between tree vigor and infection by decay fungi suggest a complex relationship. Additional information on the subject can probably best be acquired by studying individual fungi. Arvidson (1954) concluded that *Fomes annosus* Fr. attacked mainly fast-growing trees in a study on Norway spruce (*Picea abies* [L.] Karst.). Fungus—tree relationships in the current root rot study will be published separately.

There were apparently significant reductions in tree increment by root-rotting fungi in the present study. Trees that had been infected for many years (40 or more) had diameter increment reductions during the last 5 to 20 years. Many of the major roots were dead and much sapwood and bark in the area of the root collar and lower stump were dead. Diameter increments were reduced by 19% or more compared with healthy trees (no root decay) in all three species with heavy root decay (41%-60% of root wood decayed). Annual increment of trees with severe or very severe root decay was reduced even more, by as much as two-thirds in balsam fir with very severe root decay. Height increments were also less in trees with root decay than in healthy trees, but the percentage reduction was somewhat less than with diameter increment. The largest growth reductions occurred in a comparatively low percentage of the growing stock, the proportions of trees with 41% or more of root wood decayed being 12%, 18%, and 4% in balsam fir, black spruce, and white spruce, respectively. The average annual increment of trees with less root decay was also reduced, though to a lesser degree, so that the overall average diameter increment reduction was 10%, 12%, and 5% in the above species, respectively. These figures must be considered as conservative, since trees with stain only were grouped with the healthy trees, but the stained trees themselves might also have had some growth reduction. Significant growth reductions due to root rot have also been found in Norway spruce infected with *Fomes annosus* Fr. (ibid.), and Arvidson surmises that this fungus conceivably reduces tree growth at a very early stage of attack.

Spruce budworm defoliation that was sufficient to reduce markedly the diameter growth rate of trees was related to root rot intensity in balsam fir, and to a lesser extent in black spruce. Root rot was apparently heavier in trees that had been severely defoliated for a number of years, but later recovered. The fact that balsam fir and black spruce trees having little or no root rot had earlier been subjected to less growth reduction, as a result of budworm defoliation, than those having moderate or heavy root rot, strongly suggests that budworm defoliation increased tree susceptibility to root rot in these species. Sterner (1970) found that former suppression due to budworm defoliation resulted in increased root rot in balsam fir in New Brunswick, and Redmond (1957) indicated that existing root and butt infections of balsam fir may spread more quickly because of the reduction in tree growth and vigor caused by previous budworm defoliation. Peacock (1968), working in one of the areas covered in this report (Spruce River Road), found an inverse relationship between the percentage of stem wood rotted (much of it butt rot) in balsam fir averaging 79 years of age, and distance (1 to 18 miles, or 1.6 to 29 km) from an area severely attacked by the spruce budworm 20 to 25 years earlier. McCallum (1928), however, found no relationship between previous budworm damage and decay in balsam fir in Quebec.

Independent of tree age, root rot was generally high at Kab Lake and Spruce River Road, and low at Lake of Bays. No single factor was found that would account for these differences, but it is assumed that variation in site and stand history would be important. Soils at Kab Lake were deep alluvial sands, while soils at Lake of Bays were mostly silts or clays of glacial till origin. Stands on deep, fine or medium sands were found in this study to have higher root rot intensity than those on aeolian silt over glacial till. Soil differences might therefore account for some of the root rot variation between Kab Lake and Lake of Bays. Defoliation by the spruce budworm was known to be heavy in the Spruce River Road area, while it was much lighter in the Lake of Bays area. Budworm defoliation, another factor found associated with root rot in this and other studies (Redmond 1957, Peacock 1968, Sterner 1970), could account for some of the differences in root rot between the Lake of Bays and Spruce River Road areas.

Detailed calculations of economic losses resulting from root and butt rot have been made in the much more intensively managed Norway spruce in northern Europe (Arvidson 1954, Kallio 1972, Rattsjo and Rennerfelt 1955, Kallio and Tamminen 1974). Studies in both Finland (Kallio and Tamminen 1974) and Sweden (Arvidson 1954) showed that butt-rotted trees suffered economic losses from reduction in growth, as well as from butt cull. Arvidson (ibid.), working in Sweden, concluded that root rot from the economic standpoint is "a far more serious matter than has earlier been assumed". These European studies also showed that stumpage prices fell as much as 23% (Rattsjo and Rennerfelt 1955) when trees were downgraded from sawtimber to pulpwood because of butt cull.

Similar stumpage losses would undoubtedly be experienced in Ontario if optimum tree utilization were practised, and these losses would compound the volume losses stated earlier.

Productivity from Ontario forest lands could be greatly increased if root rot could be prevented or largely reduced in future stands. Little experimentation on direct control has been undertaken because of the difficulties of getting control materials to the site of the fungi in roots, and because of the high cost of application over large, relatively inaccessible areas. Control measures designed to prevent infection have been developed, however, for some root rot fungi such as *Fomes annosus* (Myren and Punter 1972), and stump removal as a means of reducing inoculum has been experimented with (Weir and Johnson 1970). If root rot control would even partly reduce timber volume losses of the magnitude indicated in this report--and it surely would--then intensified investigation and experimentation in this field would appear to be amply justified.

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