ROOT ROT OF SPRUCE AND BALSAM FIR
IN NORTHWESTERN ONTARIO
II. CAUSAL FUNGI
AND SITE RELATIONSHIPS

R. D. WHITNEY

GREAT LAKES FOREST RESEARCH CENTRE

SAULT STE. MARIE, ONTARIO

REPORT O-X-284

CANADIAN FORESTRY SERVICE
DEPARTMENT OF THE ENVIRONMENT
DECEMBER 1978

ACKNOWLEDGMENT

Cover Photo: Base of 60-year-old black spruce with heavy root rot caused by *Polyporus tomentosus*. The tree, near Longlac, Ontario, was living when pulled out with a skidder for root examination.

ABSTRACT

Culturing of decay or stain from the roots of 1,497 balsam fir (*Abies balsamea* [L.] Mill.), black spruce (*Picea mariana* [Mill.] B.S.P.) and white spruce (*P. glauca* [Moench] Voss) from 76 locations in northwestern Ontario revealed that *Armillariella mellea* (Vahl ex Fr.) Karst. was present in 42%, 31% and 36% of the trees in each species, respectively. *Polyporus tomentosus* Fr. was isolated from 18% and 14% of black spruce and white spruce, respectively; and *Scytinostroma galactinum* (Fr.) Donk, *Odontia bicolor* (Alb. & Schw. ex Fr.) Quél., *Coniophora puteana* (Schum. ex Fr.) Karst. and *Stereum sanguinolentum* (Alb. & Schw. ex Fr.) Fr. were isolated from 10%, 9%, 9% and 6% of the balsam fir trees, respectively. These six fungi caused a combined average of about 65% of the infections in all three tree species. Twenty other identified and four unidentified basidiomycetes were isolated. An average of 20% of the infections in each tree species yielded no decay-causing fungus. *Armillariella mellea* infections remained in tissues chiefly below ground while those of other important root-rotting fungi such as *P. tomentosus*, *S. galactinum*, *O. bicolor*, and *C. puteana* extended into the wood several metres above ground. Infections by *A. mellea* and *P. tomentosus* decreased with increasing tree age while those by *S. galactinum*, *O. bicolor*, and *C. puteana* increased with increasing tree age. *Ascocoryne sarcoides* (Jacq. ex Gray) Groves & Wilson, a non-decay fungus reported to be antagonistic to some decay fungi, was frequently isolated from black spruce trees as young as 30 years measured at a 30 cm stump.

The number of infections by *A. Mellea*, *P. tomentosus*, and *S. galactinum* in black spruce, and by *A. mellea*, *S. galactinum*, *Merulius himantioides* Fr., and *Stereum sanguinolentum* in balsam fir, tended to decrease as the moisture regime of the site increased. Those by Unknown F and *A. sarcoides* in black spruce, and by *C. puteana* and *O. bicolor* in balsam fir, increased with an increase in moisture regime.

Armillariella mellea, *P. tomentosus*, *Poria subacida* (Peck) Sacc., and *Fomes pini* (Fr.) Karst. attacked more trees on sandy soils than on silty soils, while *S. galactinum*, Unknowns F, S2, and S3, and *A. sarcoides* were more prevalent in trees on silty soils. Infections by *S. galactinum* tended to increase with increasing site index.

RESUME

L'auteur effectua des cultures de pourridiés et de colorations dans les racines de 1,497 Sapins baumiers (*Abies balsamea* [L.] Mill.), Epinettes noires (*Picea mariana* [Mill.] B.S.P.) et Epinettes blanches (*Picea glauca* [Moench] Voss) récoltées dans 76 lieux dans le nord-ouest de l'Ontario, et il trouva qu'*Armillariella mellea* (Vahl ex Fr.) Karst. était présente dans 42, 31 et 36% des arbres de chaque espèce, respectivement. Le *Polyporus tomentosus* Fr. fut isolé de 18 et 14% des Epinettes noires et blanches, respectivement. Et *Scytinostroma galactinum* (Fr.) Donk, *Odontia bicolor* (Alb. & Schw. ex Fr.) Quél., *Coniophora puteana* (Schum. ex Fr.) Karst. et *Stereum sanguinolentum* (Alb. & Schw. ex Fr.) Fr. furent respectivement isolés de 10, 9, 9 et 6% des Sapins baumiers. Ces six Champignons ensemble causèrent en moyenne environ 65% des infections dans toutes les espèces d'arbres. L'auteur isola en outre vingt autres Basidiomycètes identifiés et quatre Basidiomycètes non identifiés spécifiquement. Une moyenne de 20% des infections dans chaque espèce d'arbre ne causa pas de pourriture. L'*Armillariella mellea* infecta les tissus surtout en bas du collet, tandis que notamment *P. tomentosus*, *S. galactinum*, *O. bicolor* et *C. puteana* s'étendirent dans le tronc jusqu'à plusieurs mètres au-dessus du sol. Les infections par *A. mellea* et *P. tomentosus* diminuèrent chez les arbres plus âgés tandis que *S. galactinum*, *O. bicolor* et *C. puteana* infectèrent plus les arbres plus âgés. L'*Ascocoryne sarcoides* (Jacq. ex Gray) Groves & Wilson, Champignon qui ne cause pas de pourriture et rapporté l'ennemi de certains Champignons de pourritures fut fréquemment isolé d'Epinettes noires âgées d'aussi peu que 30 ans mesurés à 30 cm au-dessus du sol.

Certaines infections causées par *A. mellea*, *P. tomentosus* et *S. galactinum* chez l'Epinette noire, et par *A. mellea*, *S. galactinum*, *Merulius himantioides* Fr. et *Stereum sanguinolentum* chez le Sapin baumier avaient tendance à diminuer lorsque le régime d'humidité de la station augmentait. Par contre, les Champignons non identifiés et *A. sarcoides* chez l'Epinette noire et *C. puteana* et *O. bicolor* chez le Sapin baumier devinrent plus abondants avec un régime d'humidité plus élevé.

L'*Armillariella mellea*, le *P. tomentosus*, *Poria subacida* (Peck) Sacc., et *Fomes pini* (Fr.) Karst. attaquèrent plus d'arbres en sol sableux (moins en sol limoneux) tandis que *S. galactinum*, les Inconnus F, S2 et S3 et *A. sarcoides* devinrent plus abondants chez les arbres en sol limoneux. Les infections causées par *S. galactinum* tendirent à augmenter avec l'indice de la station.

TABLE OF CONTENTS

INTRODUCTION

The importance of black spruce (*Picea mariana* [Mill.] B.S.P.) and white spruce (*P. glauca* [Moench] Voss) to the pulpwood industry in Ontario is indicated by the fact that the combined annual harvest of these species was 7.6 million m^3 in 1975 (Anon. 1976). Balsam fir (*Abies balsamea* [L.] Mill.), on the other hand, is utilized to a lesser extent (0.44 million m^3 in 1975), and it is considered a less desirable species by the pulp companies in Ontario, largely because of excessive internal defect. However, balsam fir, which has already proven itself a valuable pulping species in the Maritime provinces, will undoubtedly become more prominent in Ontario mills in the coming decades, because of its persistence in regenerating on cutover lands.

Losses due to above-ground defects in these three pulpwood species have been determined (Morawski et al. 1958, Basham and Morawski 1964). More recently Basham (1973) indicated that consideration of root and butt rot is important in the management of black spruce in Ontario. He found 21 decay fungi in the above-ground portions of Ontario black spruce, most of which apparently originated in the roots. In black spruce, white spruce and balsam fir, losses resulting from root rot, in the form of dead trees, windthrow, butt cull, and growth reduction have been found to average from 25 to 40% of the merchantable volume in natural stands averaging 65 to 75 years of age (Whitney 1976).

Among the root-rotting fungi known to kill coniferous trees (Patton and Vasquez Bravo 1967), *Armillariella mellea* (Vahl ex Fr.) Karst. occurs extensively in several Ontario species (Huntley et al. 1961, Gross 1970, Sippell et al. 1971, 1972, Whitney et al. 1974). *Polyporus tomentosus* Fr., also known to kill trees (Whitney 1962), has recently been found associated with mortality of white spruce and black spruce in Ontario (Whitney 1972, Whitney et al. 1974). Windthrown green trees are frequently found to have root rot caused by one or both of these fungi. Other fungi have been classed as butt-rotting fungi that probably entered through roots or the root collar area in Ontario conifers (Faull 1922, Haddow 1941, White 1953, Basham and Morawski 1964, Basham 1973). These species contributed to volume loss in the butt log of the tree as revealed in cull studies (Morawski et al. 1958), and they undoubtedly weaken the root systems to varying degrees, making the trees more susceptible to windfall. Many of the butt-rotting fungi, as well as other species, have recently been isolated from tree roots (Whitney et al. 1974), but a comprehensive examination and analysis of root-rotting fungi in Ontario has not been made.

To improve our understanding of the root-rotting fungi as they affect Ontario pulpwood species, a study was begun in 1971 in which roots were excavated and root rot examined on about 1,500 trees. Objectives included the determination of root rot damage and causal fungi in various age classes of black spruce, white spruce, and balsam fir, and

interactions of root rot with site, stand history, stand composition, or other factors that can be manipulated in managing these species. Information on damage has been published recently (Whitney 1976), and the present report includes the causal fungi and their site relationships.

MATERIALS AND METHODS

In the spruce and balsam fir forest types of northwestern Ontario, 1,497 trees ranging in age from 26 to 227 years were examined for root rot over a three-year period (1971-1973). Data from the trees were used to compile a report on root rot damage (Whitney 1976), in which details of all field procedures may be seen. The trees were in 76 stands grouped in five areas (Fig. 1). Stands considered 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. In each stand to be sampled, ten dominant or codominant trees each of black spruce, white spruce, and balsam fir (when all were present) were sampled for root rot, and the irregular area on which the sample trees occurred was referred to as a "plot".

The roots of sample trees were exposed by pulling trees over with the winch of a skidder. Total height, DBH, and age determined at a 30-cm stump were measured in the field. Site information on landform, soil moisture regime (M.R.) according to Hills (1952), soil texture, depth to parent material, and humus thickness was obtained from soil pits on each plot by J.W.R. Williams and J. Jackson, Ontario Ministry of Natural Resources.

Samples for measurement and diagnosis of root rot were obtained from roots cleaned with a water jet from a Wajax fire pump, and roots larger than approximately 5 cm in diameter were bucked with chainsaws about 15-30 cm from the root collar. The stump, including the portion below ground, was sawn longitudinally to expose decays and stains which were described, classified, and measured. Samples of each decay and stain type were sawn from the root system and shipped to the laboratory in Sault Ste. Marie, where they were cultured as soon as possible after arrival. If, for any reason, culturing could not be undertaken immediately, the samples were placed in storage at a temperature near 0° until they were cultured.

Four cultures were made from each sample, but more were taken when it was considered necessary to ensure the isolation of all decay fungi present, such as in samples having two or more decays or stains. Four to ten triangular wood chips, about 3 mm on a side, were removed aseptically from each decay or stain in each wood block, placed on sterile malt (1½%) agar (2%) in test tubes, and allowed to incubate in the dark at room temperature for six weeks. By this time those that were either sterile or contained bacteria, Actinomycetes, or Phycomycetes were

Fig. 1. Location of root rot studies in northwestern Ontario.
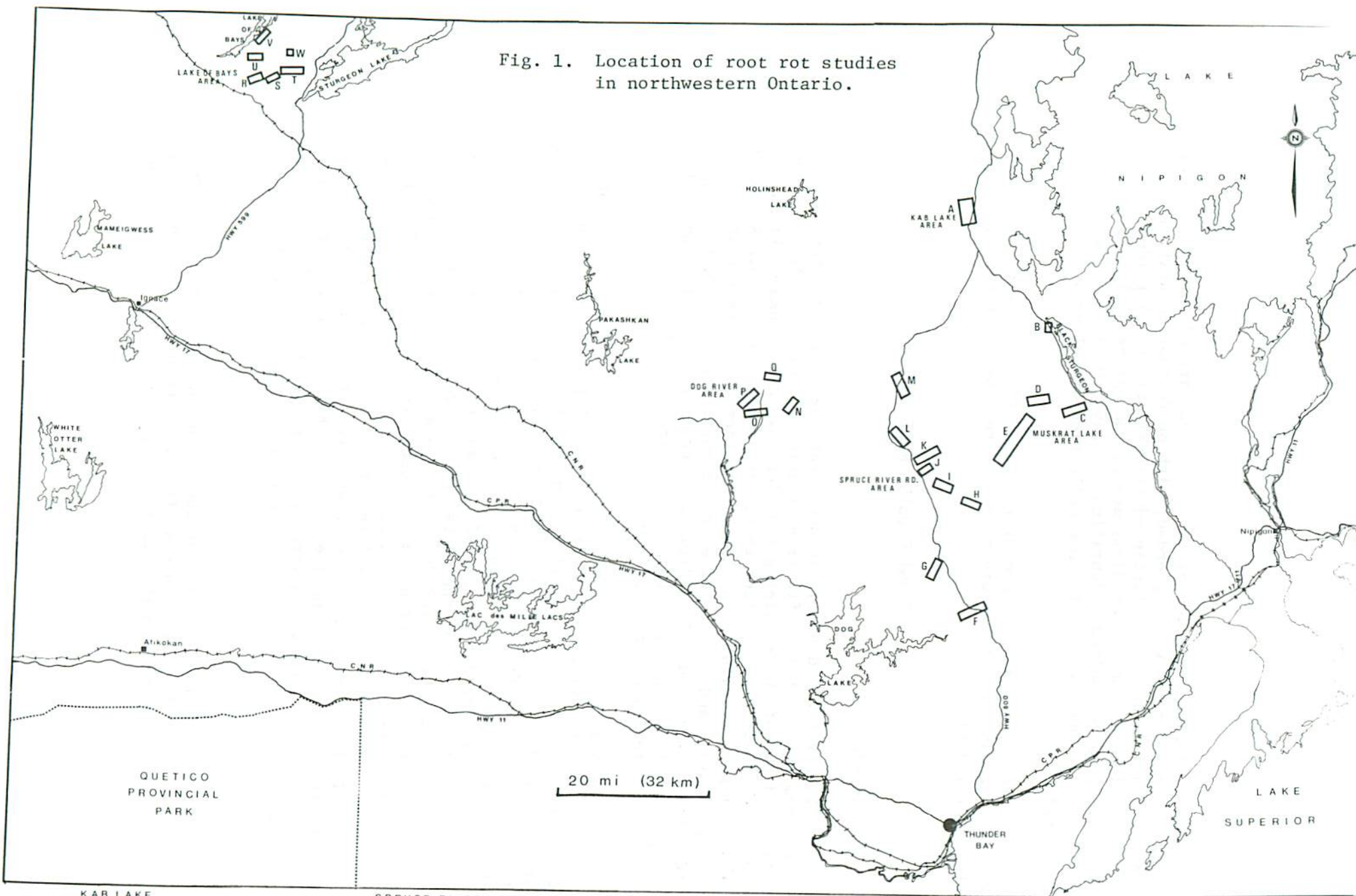
KAB LAKE
A— K1,K3,K4,K5,K6,K7,K8

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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JUNE 9,1975

recorded, and identification of these was not carried further. Cultures
yielding Hyphomycetes were recorded, with no further identification un-
less it could be done with little additional effort. For identification
of the wood-decay fungi (Basidiomycetes), the extensive literature on
the subject was consulted; identification keys (Davidson et al. 1938,
Nobles 1948, 1965) and a reference collection of cultures of wood decay
were used.

Data were placed on computer cards for sorting and compilation.
Programming was done at the Great Lakes Forest Research Centre, Sault
Ste. Marie, Ontario.

FUNGI CAUSING ROOT ROT

a) Balsam Fir

Twenty-five identifiable decay-causing Basidiomycetes were iso-
lated from the 650 balsam fir trees (Table 1). Of these, 21 were iden-
tified and two of the remaining four (Unknown C and Unknown F) have been
recognized in wood decay literature. The other two (Unknown S2 and Un-
known S3) have mycelium with clamp connections, a characteristic of
Basidiomycetes, and members of each are sufficiently alike to be grouped
under one designation. In addition, 14 trees (2%) yielded fungi with
clamp connections that were not characterized, and 148 trees (23%) had
decay that yielded no apparent causal fungus.

The well known *Armillariella mellea* was by far the most abundant
fungus associated with balsam fir root rot (Fig. 2). It was present in
42% of the sample trees, on all but one of the 48 plots, and in all five
areas sampled. *Scytinostroma galactinum* (Fr.) Donk, *Odontia bicolor*
(Alb. and Schw. ex Fr.) Quél., *Coniophora puteana* (Schum. ex. Fr.) Karst.,
and *Stereum sanguinolentum* (Alb. and Schw. ex Fr.) Fr. were next in abun-
dance, being isolated from 12%, 9%, 9%, and 6% of the trees, and from
69%, 67%, 42%, and 38% of the plots, respectively (Fig. 3-6). The first
three of these were isolated from all five areas. These five fungi com-
bined accounted for almost 65% of all decay infections in balsam fir, and
all except *C. puteana* and *S. sanguinolentum* occurred on more than half of
the plots. More than 12% of all infections were caused by the next five
fungi in Table 1 combined, and each was present in about 25% of the plots.
Most of the remaining 14 fungi each caused fewer than 1% of the infec-
tions and most of this group were present on fewer than 10% of the plots.
No causal fungus was isolated from over 18% of the infections.

b) Black Spruce

Almost as many species of decay-causing Basidiomycetes were iso-
lated from the 570 black spruce as from the balsam fir. However, only
18 species were common to the two trees (Table 2). *Armillariella mellea*

Table 1. The percentage of trees and plots infected by various Basidiomycetes in 650 balsam fir trees from 48 plots in northwestern Ontario

Fungus	Trees infected (%)	% of all infections	Plots infected (%)
Armillariella mellea (Vahl ex Fr.) Karst.	42.0	33.6	96
Scytinostroma galactinum (Fr.) Donk	12.5	10.0	69
Odontia bicolor (Alb. & Schw. ex Fr.) Quél.	9.2	7.4	67
Coniophora puteana (Schum. ex Fr.) Karst.	9.1	7.3	42
Stereum sanguinolentum (Alb. & Schw. ex Fr.) Fr.	6.2	4.9	38
Xeromphalina campanella (Batsch ex Fr.) Kuehn & Maire	3.7	3.0	29
Merulius himantioides Fr.	3.7	3.0	21
Poria subacida (Peck) Sacc.	3.2	2.6	33
Unknown S2[a]	2.6	2.1	25
Polyporus tomentosus Fr.	2.2	1.7	29
Unknown S3[a]	1.5	1.2	15
Unknown F[b]	1.1	0.9	13
Polyporus balsameus Peck	0.8	0.6	10
Stereum chailletii (Pers. ex Fr.) Fr.	0.8	0.6	8
Flammula alnicola (Fr.) Kummer	0.3	0.3	4
Coriolellus sinuosus (Fr.) Sarker	0.3	0.3	4
Stereum murraii (Berk. & Curt.) Burt	0.1	0.1	2
Fomes pini (Fr.) Karst.	0.1	0.1	2
Polyporus guttulatus Peck	0.1	0.1	2
Gloeocystidiellum citrinum (Pers.) Donk	0.1	0.1	2
Stereum purpureum (Pers. ex Fr.) Fr.	0.1	0.1	2
Gloeocystidiellum karstenii (Bourd. & Galz.) Donk	0.1	0.1	2
Asterodon ferruginosus Pat.	0.1	0.1	2
Trechispora brinkmannii (Bres.) Rog. & Jackson	0.1	0.1	2
Unknown C[b]	0.1	0.1	2
Unknown Basidiomycetes	2.0	1.7	27
Decay (no Basidiomycetes isolated)	23	18.2	85
Total infections (812)	123[c]	100.3	

[a] All isolates within each unknown fungus were sufficiently similar for each group to be considered as one species.

[b] Recognized as individual species (Denyer and Riley 1954).

[c] Totals more than 100% because some trees had more than one root-rotting fungus; others had no fungus.

Table 2. The percentage of trees and plots infected by various Basidiomycetes in 570 <u>black spruce</u> trees from 54 plots in northwestern Ontario

Fungus	Trees infected (%)	% of all infections	Plots infected (%)
Armillariella mellea (Vahl ex Fr.) Karst.	30.9	30.3	81
Polyporus tomentosus Fr.	18.2	17.9	65
Scytinostroma galactinum (Fr.) Donk	7.2	7.1	37
Coniophora puteana (Schum. ex Fr.) Karst.	4.0	3.4	31
Unknown F[a]	3.5	3.3	24
Merulius himantioides Fr.	2.3	2.2	22
Odontia bicolor (Alb. & Schw. ex Fr.) Quél.	1.8	1.7	13
Fomes pini (Fr.) Karst.	1.6	1.6	15
Xeromphalina campanella (Batsch ex Fr.) Kuehn & Maire	1.6	1.6	15
Poria subacida (Peck) Sacc.	1.4	1.4	11
Polyporus borealis Fr.	1.2	1.2	9
Flammula alnicola (Fr.) Kummer	1.1	1.0	11
Stereum sanguinolentum (Alb. & Schw. ex Fr.) Fr.	0.9	0.9	6
Peniophora pseudopini Weresub & S. Gibson	0.7	0.7	4
Unknown C[a]	0.5	0.5	6
Fomes pinicola (Sw. ex Fr.) Cooke	0.5	0.5	4
Coriolellus sinuosus (Fr.) Sarker	0.4	0.3	4
Trechispora brinkmannii (Bres.) Rog. & Jackson	0.2	0.2	2
Polyporus schweinitzii Fr.	0.2	0.2	2
Trechispora raduloides (Karst.) Rogers	0.2	0.2	2
Stereum chailletii (Pers. ex Fr.) Fr.	0.2	0.2	2
Lenzites saepiaria Wulf. ex Fr.	0.2	0.2	2
Unknown S2[b]	0.2	0.2	2
Unknown Basidiomycetes	2	1.6	13
Decay (no Basidiomycetes)	23	22.2	87
Total infections (583)	102.9[c]	100.2	

[a]Recognized as individual species (Denyer and Riley 1954).

[b]All isolates within each unknown fungus were sufficiently similar for each group to be considered as one species.

[c]Totals more than 100% because some trees had more than one root-rotting fungus; others had no fungus
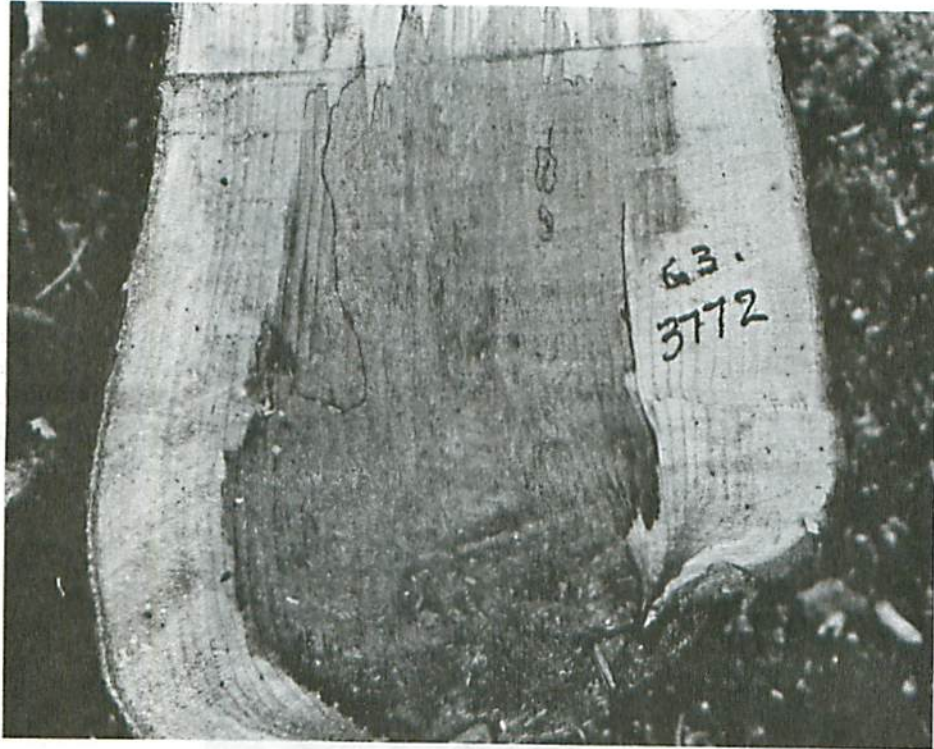
Fig. 2.   Yellow stringy decay and zone lines of *Armillariella mella* in a 41-year-old black spruce.   The decay column originated in dead area at bottom of stump and extends to a little above ground level which is about 5 cm above the photo (X 1/3).

and *Polyporus tomentosus* Fr. (Fig. 7) were the two most abundant fungi in black spruce, being isolated from 30% and 18% of the trees, and 81% and 65% of the plots, respectively.   These two fungi together accounted for 48% of all infections in this species, and they each occurred on all five study areas.   *Scytinostroma galactinum* was a distant third in both percentage of trees (7%) and percentage of plots (37%) infected.   Six other fungi combined caused infections in an additional 15% of the trees. A total of nine fungi, therefore, accounted for almost 70% of the infections in black spruce.   The other 14 fungi each accounted for 1% or fewer of the infections.   As in balsam fir, a large percentage of trees (23%) were infected by fungi that were not isolated from the decay or stain.

Fig. 3

Advanced yellow stringy decay caused by *Scytinostroma galactinum* in base of a 38-year-old balsam fir (X 1/5).

Fig. 4

Yellow string decay caused by *Odontia bicolor* in central wood and sapwood of stump of a 112-year-old black spruce (X 1/6).

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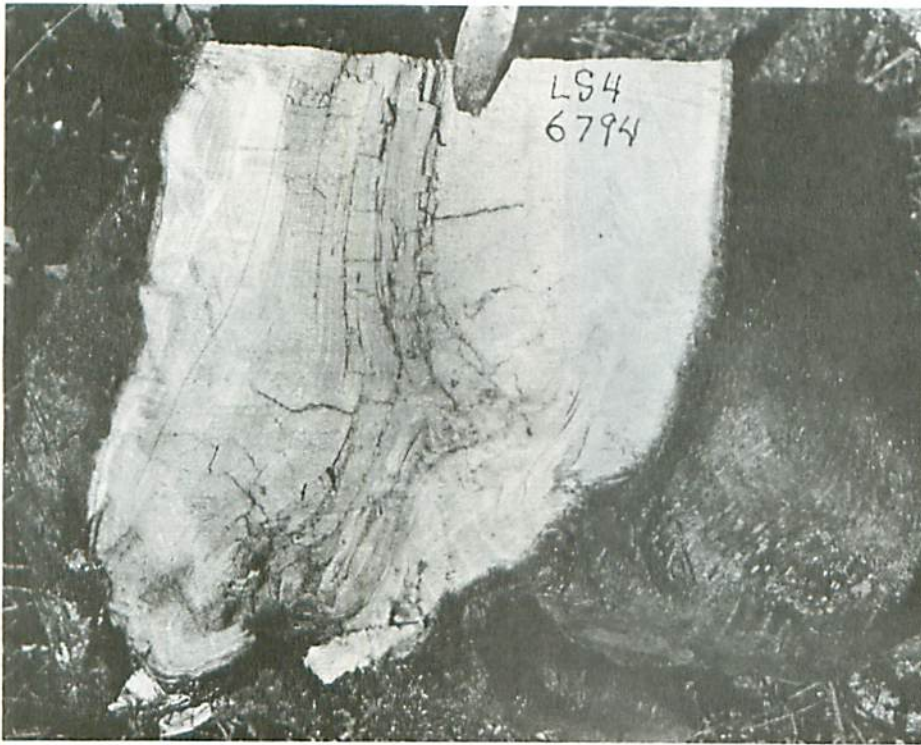
Fig. 5

Brown cubical decay
caused by *Coniophora
puteana* chiefly in
central wood of
69-year-old balsam
fir stump (X 1/4).

Fig. 6

Greyish brown streaks
caused by *Stereum sanguino-
lentum* extending from the
stem into the stump of a
47-year-old balsam fir
(X 1/3).
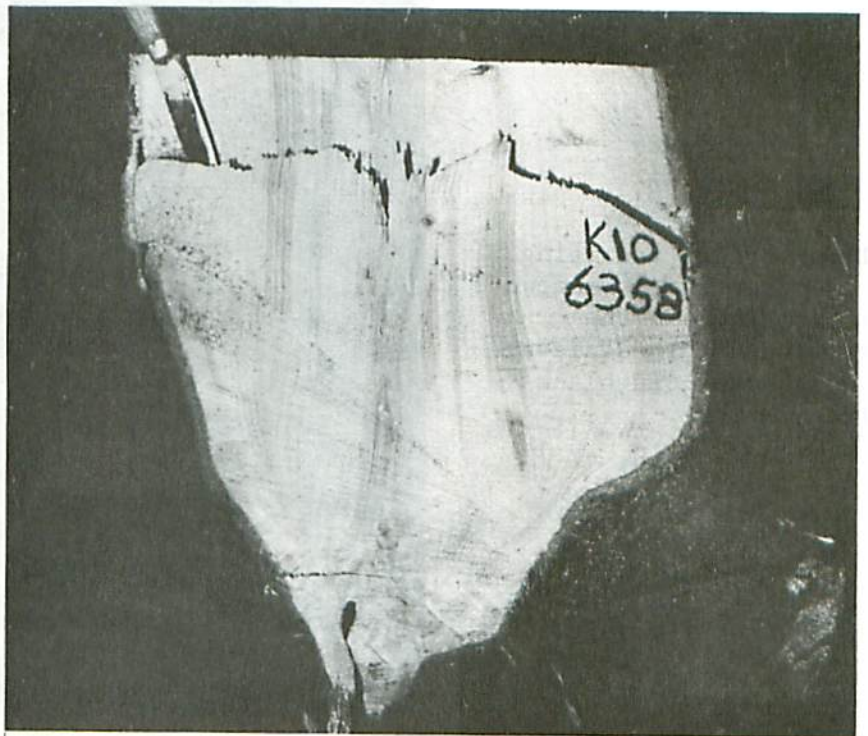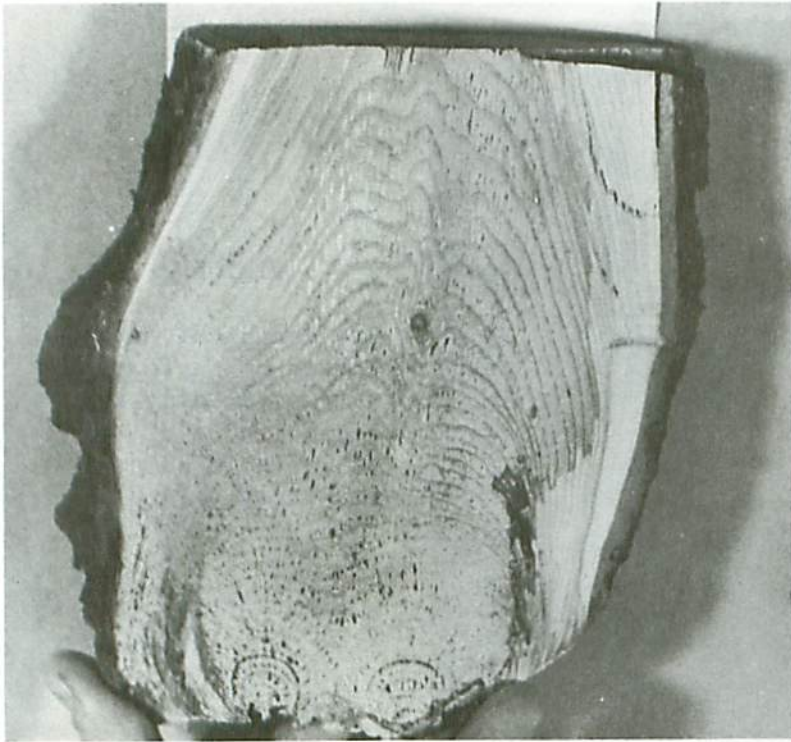
Fig. 7

White pocket decay and
zone lines caused by
Polyporus tomentosus in
central wood and sapwood
of lower stump of an
83-year-old black spruce.
Much bark had been killed
by the fungus (X 1/4).

Fig. 8

Yellow stringy radiating
decay, from which Unknown F
was isolated, in the
heartwood at ground level
in a 140-year-old black
spruce (X 1/5).

c) White Spruce

Only fourteen identifiable decay-causing Basidiomycetes were isolated from the 277 white spruce trees. As in black spruce, *A. mellea* and *P. tomentosus* were most important, causing decay in 36% and 14% of the trees, and occurring on 89% and 64% of the plots, respectively (Table 3). These two fungi also occurred in white spruce on all five study areas. As in black spruce, *S. galactinum*, *C. puteana* and Unknown F (Fig. 8) were next in frequency of occurrence in white spruce, being isolated from 6%, 2% and 2% of the trees, respectively. These five fungi caused a combined total of 71% of all infections in white spruce. The remaining nine fungi occurred in 1% or fewer of the trees. Thirteen of the fourteen identified fungi causing decay in white spruce were also isolated from black spruce, and 12 of these were isolated from balsam fir. *Peniophora pseudopini* Weres. and S. Gibson was the only fungus common to the two spruces that was not isolated from balsam fir. On the other hand, Unknown S2 was isolated from white spruce and balsam fir but not from black spruce.

d) All Tree Species

On the basis of numbers of infections, three fungi, *Armillariella mellea*, *Scytinostroma galactinum*, and *Coniophora puteana*, were important in all three tree species, accounting for a combined average of 48% of all infections. *Polyporus tomentosus* was also important in the two spruces, causing an additional average of 17.5% of all infections in these two species. Many trees, and often individual roots, were infected by two decay-causing Basidiomycetes; some trees had decay or stain caused by as many as four fungi in the roots (Fig. 9).

AGE RELATIONSHIPS

It is obvious that the longer a tree exists, the greater are its chances of being attacked by root-rotting fungi; hence, for a given site and set of pathogen virulence and tree susceptibility conditions, infections increase with tree age. Another general principle accepted in the following discussions is that the trees with the heaviest root rot damage are the first to be windthrown or to die; hence, the causal fungi are withdrawn from the living portion of the stand. Only living trees were sampled for causal fungi because secondary saprophytic organisms quickly invade dead or windfallen trees, making isolation of the fungi causing the original root rot very difficult or impossible.

a) Balsam Fir

The main root-rotting fungus, *A. mellea*, was present in about the same percentage of trees in each 10-year age class between 30 and 90

Table 3. The percentage of trees and plots infected by various Basidiomycetes in 277 <u>white spruce</u> trees from 28 plots in northwestern Ontario

Fungus	Trees infected (%)	% of all infections	Plots infected (%)
Armillariella mellea (Vahl ex Fr.) Karst.	36.1	42.6	89
Polyporus tomentosus Fr.	13.7	16.2	64
Scytinostroma galactinum (Fr.) Donk	6.1	7.2	39
Coniophora puteana (Schum. ex Fr.) Karst.	2.2	2.6	21
Unknown F[a]	1.8	2.1	18
Xeromphalina campanella (Batsch ex Fr.) Kuehn & Maire	1.4	1.7	14
Stereum sanguinolentum (Alb. & Schw. ex Fr.) Fr.	0.7	0.9	7
Merulius himantioides Fr.	0.7	0.9	7
Poria subacida (Peck) Sacc.	0.7	0.9	7
Peniophora pseudopini Weresub & S. Gibson	0.7	0.9	4
Unknown S2[b]	0.7	0.9	4
Fomes pini (Fr.) Karst.	0.4	0.4	4
Odontia bicolor (Alb. & Schw. ex Fr.) Quél.	0.4	0.4	4
Polyporus schweinitzii Fr.	0.4	0.4	4
Unknown Basidiomycetes	1.4	1.7	14
Decay (no Basidiomycetes)	17.7	20.9	86
Total infections	85.1[c]	100.7	

[a]Recognized as individual species (Denyer and Riley 1954).

[b]All isolates within each unknown fungus were sufficiently similar for each group to be considered as one species.

[c]Some trees had more than one root-rotting fungus; others had no fungus.

Fig. 9. Badly decayed root system of a 98-year-old black spruce from which four root-rotting fungi (*A. mellea, C. puteana, Xeromphalina campanella*, and Unknown F) were isolated (X 1/16).

years of age (Table 4). From 90 to 120 years the percentage of trees infected increased, but lower percentages of both younger (21-30 years) and older trees (above 120 years) harbored root rot caused by *A. mellea*. Probably fewer of the younger trees had been attacked, while in the oldest age classes, the most severely attacked trees had died or succumbed to windfall, leaving only the healthiest trees for sampling.

In intermediate age classes of 51 to 80 years, the numbers of trees infected with *S. galactinum* were well below the overall average, but trees older than 80 years generally had above-average numbers infected by this fungus. The reasons for lower average percentages of trees being infected by this fungus in the intermediate age classes are possibly associated with site conditions. Proportionately more trees in the oldest age classes were attacked by *S. galactinum* than by *A. mellea*. This might reflect the habit of *A. mellea* to concentrate in the lower stem and roots where it attacks living tissues (Fig. 10). *Scytinostroma galactinum* spreads further up the stem and appears to be less active in killing living sapwood and bark than *A. mellea*, thereby allowing trees to survive to an older age, even though they are infected by this fungus.

Table 4. Percentages of <u>balsam fir</u> trees, by age classes, from which the most frequently occurring fungi were isolated in northwestern Ontario

Age class (year)	No. of trees	*Armillariella mellea*	*Polyporus tomentosus*	*Coniophora puteana*	*Scytinostroma galactinum*	*Odontia bicolor*	*Stereum sanguinolentum*	*Merulius himantioides*	*Poria subacida*	*Xeromphalina campanella*	Unknown S2	Unknown S3	*Ascocoryne sarcoides*
				Fungi	isolated	(% of	trees	infected)					
21 – 30	29	28	0	–	14	4	4	4	4	–	–	–	4
31 – 40	147	42	0	7	8	7	5	3	2	1	1	1	1
41 – 50	123	43	1	2	12	7	11	2	1	1	1	–	2
51 – 60	70	39	1	1	4	11	14	1	4	3	3	1	6
61 – 70	38	40	11	16	5	13	11	5	5	8	–	3	5
71 – 80	46	44	9	13	4	7	7	7	7	7	–	4	9
81 – 90	49	39	6	14	18	8	–	6	6	4	2	6	2
91 – 100	49	47	2	12	22	10	–	8	4	2	2	2	8
101 – 110	31	65	3	13	26	10	–	3	–	3	–	–	–
111 – 120	22	50	–	23	18	14	–	5	–	9	5	–	9
121 – 130	25	36	–	20	44	20	–	4	4	4	–	–	12
131 – 180	21	29	5	19	10	10	–	–	5	29	5	5	19
Average for all trees		42	3	9	13	9	8	4	3	4	1	2	5

Fig. 10

Bottom or underside
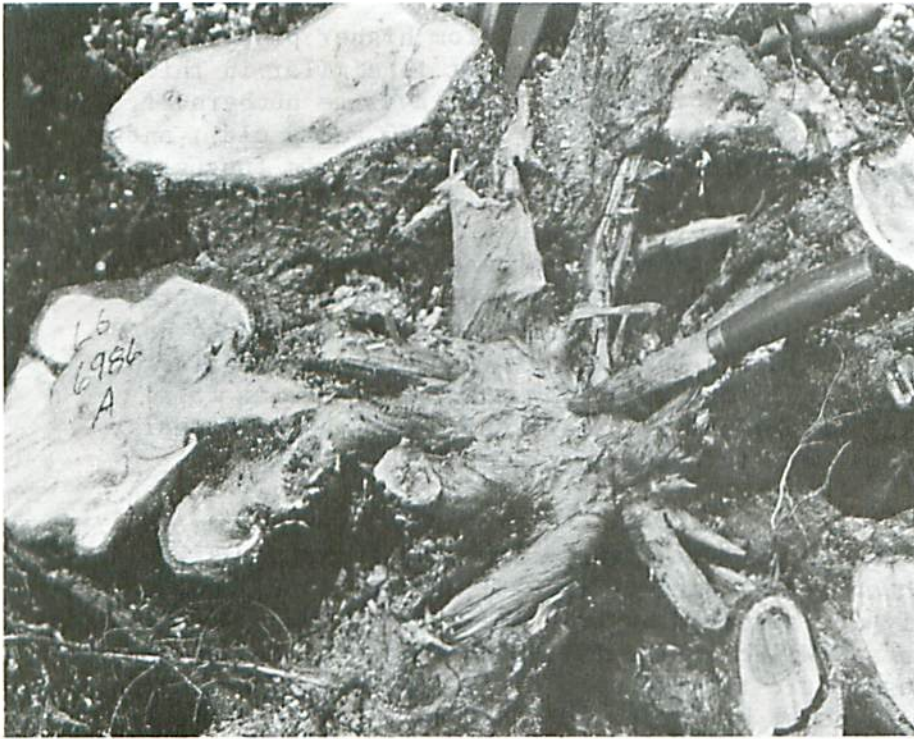of 88-year-old
balsam fir tree in
which much of the
sapwood of the
stump and larger
roots had been
killed by *A. mellea*
(X 1/6).

Fig. 11

Grey advanced decay from
which *X. campanella* was
isolated in heartwood
76.2 cm above ground level
in 98-year-old black
spruce. The thin black
rhizomorphs seen in the
darkest part of the decay
are typically present in
decay caused by this
fungus (X 1/2).
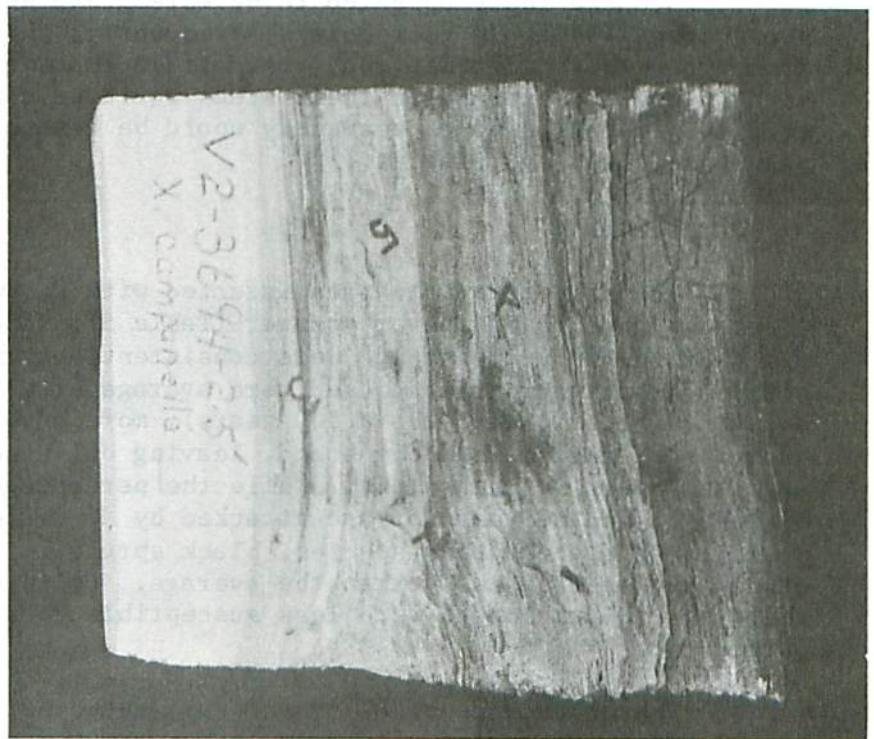
Odontia bicolor was generally isolated from higher proportions of trees in the age classes above 90 years, and it is similar in this respect to S. galactinum. It was present in above average numbers of trees in some intermediate age classes (trees 51 to 70 years old), and this suggests, as with S. galactinum, that infection by this fungus varies with site conditions.

Infections by Coniophora puteana were generally very low in balsam fir younger than 60 years of age. This fungus definitely infects higher proportions of trees older than 60 years, and it appears to be less influenced by site conditions than the previous two fungi. There was a pronounced increase in Xeromphalina campanella (Batsch ex Fr.) Kuehn. & Maire (Fig. 11) infections in balsam fir older than 130 years, and below average numbers were infected in trees 50 years old and younger (Table 4).

Infections by Polyporus tomentosus, Merulius himantioides Fr. (Fig. 12), Poria subacida (Peck) Sacc. (Fig. 13), Unknowns S2, and S3 (Fig. 14) are evidently not affected by tree age. Ascocoryne sarcoides (Jacq. ex Gray) Groves and Wilson (Fig. 15), a non-decaying fungus that is believed to be antagonistic to some wood decay fungi, was present in balsam fir in all age classes, but appeared to be most prevalent in the oldest age classes.

Infections by the trunk fungus, Stereum sanguinolentum, that had spread into the roots appeared to be more prevalent in comparatively young trees (41 to 70 years old). Frequently, this fungus was isolated from trees that had other root rot. Trees that were heavily infected both in their roots and in their stems would be expected to die or succumb to windfall, and consequently would be removed from the living tree sample in older age classes.

b) Black Spruce

The proportion of trees infected with A. mellea was below average in trees 70 years of age or younger (Table 5). Above average numbers of trees 71 to 100 years of age were consistently attacked, and at still older ages the numbers attacked were average or below average. As in balsam fir, the older (above 100 years), more adversely affected trees had died or fallen from the stand, leaving only the less frequently attacked trees in the sample. While the percentage of balsam fir trees between 31 and 60 years of age attacked by A. mellea was the same as the overall average for this species, black spruce in these age classes were attacked less frequently than the average. Up to 60 years of age, therefore, black spruce were less susceptible to A. mellea attack than balsam fir.

The occurrence of P. tomentosus, the other abundant fungus in black spruce, increased with tree age up to 90 years. In all age classes above 90 years, below average numbers of sampled trees were infected with this fungus. It appeared that trees were attacked by P. tomentosus at an early age (above average numbers at age 31-40) and mortality or

Table 5. Percentages of <u>black spruce</u> trees, by age classes, from
which the most frequently occurring fungi were isolated
in northwestern Ontario

Age class (year)	No. of trees	*Armillariella mellea*	*Polyporus tomentosus*	*Coniophora puteana*	*Scytinostroma galactinum*	*Merulius himantioides*	Unknown F	*Ascocoryne sarcoides*
		Fungi isolated (% of trees infected)						
21 - 30	3	33	–	–	33	–	–	–
31 - 40	53	26	23	2	13	2	–	30
41 - 50	85	26	16	–	7	2	1	31
51 - 60	56	21	16	2	2	2	–	27
61 - 70	76	29	26	–	5	1	1	30
71 - 80	87	40	18	5	2	–	–	24
81 - 90	53	40	36	6	8	2	–	19
91 - 100	51	37	8	8	6	2	2	43
101 - 110	42	29	12	2	7	2	2	36
111 - 130	22	36	9	9	18	9	–	32
·131 - 150	32	25	13	6	13	9	–	44
151 - 230	10	10	10	10	10	–	–	50
Average for all trees		31	19	3	7	2	1	31

Fig. 12

Brown cubical decay from which *Merulius himanti-oides* was isolated in below-ground stump portion of 72-year-old black spruce (X 1/5).

Fig. 13

Yellow stringy decay from which *Poria subacida* was isolated in central wood and sapwood of stump of 39-year-old balsam fir (X 1/10).
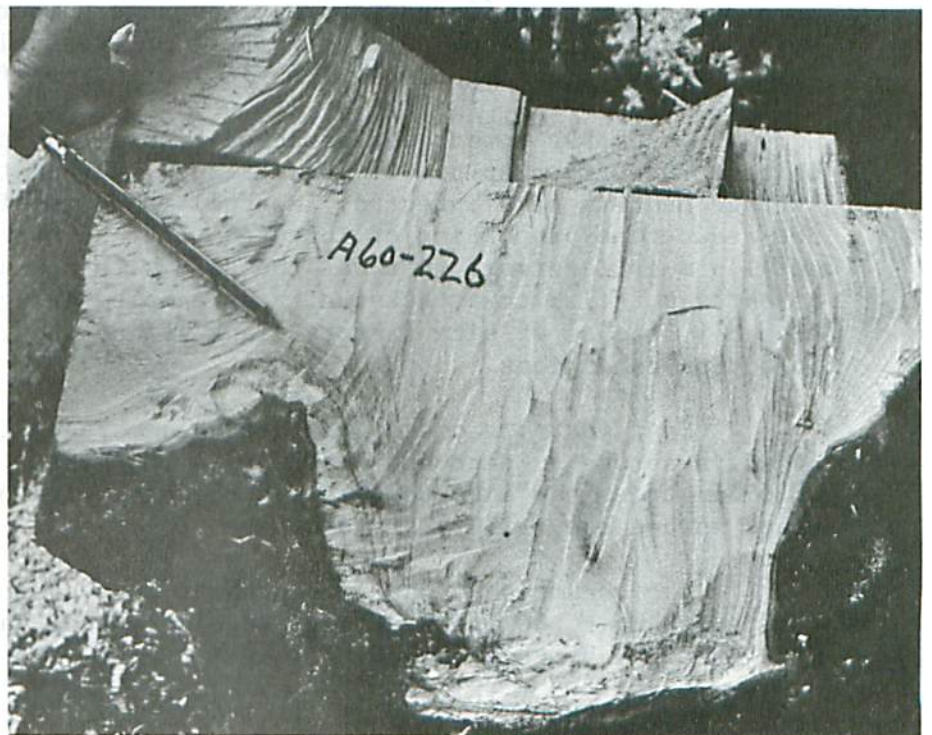
Fig. 14

Yellow string decay from which Unknown S3 was isolated in heartwood at ground level of 57-year-old balsam fir (X 1/8).

Fig. 15

Pinkish stained wood (area near tip of pen) from which *Ascocoryne sarcoides* was isolated, in stump of 81-year-old white spruce (X 1/4).

windfall of trees attacked by this fungus occurred much earlier (begin-
ning noticeably in the 91-100 age class) than in those attacked by
A. mellea.

As in balsam fir, *S. galactinum* was isolated from below aver-
age numbers of trees from 51 to 80 years old. In older trees, average
or above average numbers were found infected with this fungus. As in
balsam fir, the occurrence of *S. galactinum* was unaccountably high in
a young age class (31-40), possibly because the sites on which it was
found were more suitable for the growth of this species.

Coniophora puteana occurred very seldom in black spruce trees
less than 70 years old, and as in balsam fir, it had a tendency to
increase with tree age. *Merulius himantioides* was most prevalent in
trees above 110 years old. The occurrence of Unknown F increased
slightly with tree age, although very few isolations of this fungus
were obtained.

Armillariella mellea and *P. tomentosus* attack black spruce at
early ages and the latter appears to lead to significant mortality or
windthrow of trees beyond 90 years of age, while significant losses of
this type result from *A. mellea* at a somewhat later age. *Coniophora
puteana* appears to attack trees at a much later age than the above two
fungi. *Ascocoryne sarcoides*, much more abundant in black spruce than
in balsam fir, tended to be more frequent in trees older than 90 years.

c) White Spruce

Armillariella mellea infected below average numbers of white
spruce younger than 60 years of age, average numbers of trees 61 to 70
years of age, and above average numbers of trees older than 70 years
(Table 6), a situation almost identical with that found in black spruce.

Polyporus tomentosus attacked average numbers (or fewer) of
white spruce trees up to 90 years of age. Beyond this age, above
average numbers were infected. Mortality and windfall apparently did
not reduce the proportion of infected white spruce in the sample trees
until a much later age than was the case with black spruce. *Polyporus
tomentosus* failed to attack the trees sampled in age class 81 to 90,
probably because of site factors, lack of inoculum, or lack of suitable
infection conditions.

Scytinostroma galactinum attacked more or less average numbers
of white spruce in each age class up to 100 years. A larger proportion
of older trees was infected, as was the case with balsam fir and with
black spruce above 110 years old.

Ascocoryne sarcoides was present in average numbers of trees
(or fewer) up to 80 years of age; in older trees, above average numbers
were infected by this fungus.

Table 6. Percentages of <u>white spruce</u> trees, by age classes, from which the most frequently occurring fungi were isolated in northwestern Ontario

Age class (year)	No. of trees	*Armillariella mellea*	*Polyporus tomentosus*	*Scytinostroma galactinum*	*Ascocoryne sarcoides*
		Fungi isolated (% of trees infected)			
21 - 30	4	-	25	-	-
31 - 40	22	14	9	5	20
41 - 50	60	30	18	2	28
51 - 60	45	24	9	7	24
61 - 70	42	36	5	7	14
71 - 80	56	52	16	3	29
81 - 90	17	65	-	12	41
91 - 100	17	47	29	-	41
101 - 170	14	43	29	29	36
Average for all trees		36	14	6	26

d) All Tree Species

A comparison of the percentage of the three tree species infec-
ted by *A. mellea* reveals that balsam fir is apparently much more suscep-
tible in the younger age classes (up to 60 years old) than either black
spruce or white spruce. The maximum proportion of trees was infected
in balsam fir between 90 and 120 years of age, in black spruce between
70 and 100 years of age, and in white spruce in ages above 70 years.
If we assume that the stand age at which the percentage of infected
living trees starts to decline reflects the age at which significant
tree mortality and windfall begin, these losses due to *A. mellea* become
severe in balsam fir above 120 years, in black spruce older than 100
years, and in white spruce older than those sampled. It would appear,
therefore, that black spruce is damaged most from *A. mellea* attack, and
white spruce the least. *Coniophora puteana* caused root rot primarily
in the older age classes in all three tree species. In the trees
sampled, the proportion infected did not decrease with increasing age;
this indicates that *C. puteana* is lethal only in relatively old trees,
if at all.

There was a slight increase in the proportion of trees yielding
the non-decaying fungus, *Ascocoryne sarcoides*, in black and white spruce
older than 90 years of age (Tables 5 and 6). As trees with root rot
fell from the stands or were killed, a higher proportion of those that
remained were infected by this fungus. The low proportions of balsam
fir from which *A. sarcoides* was isolated apparently fluctuated very
little with tree age.

GEOGRAPHIC LOCATION

a) Balsam Fir

The occurrence of the most abundant fungus, *A. mellea*, was
quite uniform in the five areas sampled (Table 7). *Scytinostroma
galactinum* was more prevalent in the Spruce River Road area than at
Lake of Bays, while the reverse was true with *O. bicolor*. Of the other
frequently occurring fungi in balsam fir, *C. puteana* was uniformly
present in all areas, except at Kab Lake, where it was absent, and
Stereum sanguinolentum occurred in fewer than the average number of trees
at Kab Lake and Lake of Bays. *Xeromphalina campanella* was much more
abundant in balsam fir at Dog River than at any other location.
Merulius himantioides and *Poria subacida* occurred more or less uniformly
in all five areas. The non-decaying fungus, *Ascocoryne sarcoides*,
occurred uniformly in all areas except Kab Lake where it was not iso-
lated.

Table 7. Percentages of <u>balsam fir</u> trees from which the most frequently occurring fungi were isolated at five locations in northwestern Ontario

Location	No. of trees	Armillariella mellea	Coniophora puteana	Scytinostroma galactinum	Odontia bicolor	Stereum sanguinolentum	Merulius himantioides	Poria subacida	Xeromphalina campanella	Ascocoryne sarcoides
		Fungi isolated (% of trees infected)								
Kab Lake	40	50	0	10	13	0	3	5	0	0
Muskrat Lake	160	45	6	12	7	9	6	3	0.5	5
Spruce River Road	140	37	12	18	4	4	4	1	2	5
Dog River	180	37	11	13	11	9	2	2	8	4
Lake of Bays	130	48	9	7	15	2	3	6	4	5
Average of all locations		42	9	11	9	6	4	3	4	4

b) Black Spruce

Unlike balsam fir, *A. mellea* infection of black spruce was far below average in the Dog River plots and above average at Kab Lake (Table 8). On the other hand, *Scytinostroma galactinum* infected more than average numbers of trees in the Dog River plots, but less than average on the Spruce River Road, which was the opposite of balsam fir. *Merulius himantioides* was most abundant at Lake of Bays, while *Stereum sanguinolentum* was much above average at Kab Lake in black spruce. *Polyporus tomentosus*, *Coniophora puteana*, and *Odontia bicolor* were more or less uniformly distributed in black spruce in all the areas. *Ascocoryne sarcoides* was exceptionally abundant on the Muskrat Lake plots, being present in almost half of the trees, while at Kab Lake it was isolated from only 3% of black spruce.

Table 8. Percentages of black spruce trees from which the most
frequently occurring fungi were isolated at five
locations in northwestern Ontario

Location	No. of trees	*Armillariella mellea*	*Polyporus tomentosus*	*Coniophora puteana*	*Scytinostroma galactinum*	*Odontia bicolor*	*Stereum sanguinolentum*	*Merulius himantioides*	*Ascocoryne sarcoides*
		Fungi isolated (% of trees infected)							
Kab Lake	60	50	15	2	7	2	5	2	3
Muskrat Lake	160	34	18	4	9	2	0	2	47
Spruce River Road	160	30	24	3	1	1	0	1	31
Dog River	110	14	14	6	13	2	1	2	24
Lake of Bays	80	38	16	3	9	4	1	6	36
Average of all locations		31	18	4	7	2	1	2	32

c) White spruce

As in black spruce, the proportion of trees infected with
A. mellea was highest at Kab Lake (62%) and lowest on the Dog River
plots (28%) (Table 9). *Polyporus tomentosus* infections were below
average on the Dog River plots. *Scytinostroma galactinum* was most
abundant at Dog River and Lake of Bays and *Xeromphalina campanella*
infected most trees at Lake of Bays. *Coniophora puteana* occurred
fairly uniformly at all five locations. *Ascocoryne sarcoides* was
isolated more frequently from Lake of Bays plots than from all
others, and was not isolated from white spruce at Kab Lake.

Table 9. Percentages of <u>white spruce</u> trees from which the most
frequently occurring fungi were isolated at five locations
in northwestern Ontario

Location	No. of trees	*Armillariella mellea*	*Polyporus tomentosus*	*Coniophora puteana*	*Scytinostroma galactinum*	*Xeromphalina campanella*	*Ascocoryne sarcoides*
		Fungi isolated (% of trees infected)					
Kab Lake	29	62	10	0	0	0	0
Muskrat Lake	105	31	17	3	7	0	30
Spruce River Road	63	39	13	3	3	1	31
Dog River	50	28	8	2	10	0	18
Lake of Bays	30	43	13	0	10	7	47
Average of all locations		37	14	2	6	1	27

d) All Tree Species

The two most prevalent root rotting fungi in spruces,
Armillariella mellea and *P. tomentosus*, were both below average in
occurrence at Dog River in the two spruces, while *S. galactinum*
infected above average numbers of these species at this location.
Coniophora puteana was low in all species at Kab Lake, as was the non-
decaying fungus *Ascocoryne sarcoides*.

MOISTURE REGIME

Root rot damage in black spruce and white spruce was found to
increase as moisture regime (M.R.) decreased (Whitney 1976). Relation-
ships between individual fungi and M.R. were therefore investigated.

a) Balsam Fir

In balsam fir, *A. mellea* infected more than 35% of the trees in all M.R. classes and all age classes, except on moist sites in age class II (Table 10). The highest numbers of *A. mellea* infections tended to be on fresh sites, but there were no marked relationships between *A. mellea* infections and M.R. *Coniophora puteana* infections generally increased with increases in M.R. except in age class II, where none of the 40 trees on moist sites were infected and an average of 7% of trees on fresh and dry sites were attacked. No clear relationship existed between *Odontia bicolor* infections in balsam fir and M.R.; but in age class II, infections by this fungus increased with increasing M.R., whereas the reverse was true for infections by *S. galactinum*. *Merulius himantioides* infections tended to decrease with increases in M.R. *Stereum sanguinolentum* root infections were fewer in age class III, probably because trees fell from the stands as they became older. There was no clear relationship between infections by *S. sanguinolentum* or *Ascocoryne sarcoides* and M.R., although in age class I and in all age classes combined, infections by *S. sanguinolentum* tended to decrease with increasing M.R.

b) Black Spruce

Armillariella mellea and *P. tomentosus* were the only two root-rotting fungi that were present in all M.R.s in all age classes of black spruce (Table 11).

The proportion of trees attacked by *A. mellea* decreased with increasing M.R. in all age classes, although trees on fresh sites were more frequently attacked than those on dry sites in age class I. Attack by *A. mellea* increased from age class I to age class II, but similar increases in age class III were noted only on moist sites (M.R. 4-6). *Polyporus tomentosus*, the second most abundant root-rotting fungus in black spruce, attacked trees most aggressively on fresh sites in age classes I and II. Trees on dry sites appeared to be most susceptible to this fungus in age class III, but this is likely because trees on fresh sites attacked by this fungus had fallen from the stand before reaching age class III. Unlike *A. mellea*, *P. tomentosus* was apparently as severe in age class I black spruce as in older trees. *Scytinostroma galactinum* attacked trees most frequently on fresh sites in age classes I and III, and, as with *P. tomentosus*, it was most frequent on this site when all age classes were combined. Like *A. mellea*, *S. galactinum* increased in abundance in older black spruce, and it decreased considerably on the wet sites.

Coniophora puteana did not vary consistently with M.R., although in age class III there was a tendency for more trees on fresh sites to be attacked. Unknown F was the only decay fungus in black spruce that attacked higher proportions of trees on wet than on dry

Table 10. Percentages of <u>balsam fir</u> trees on various M.R.s in northwestern Ontario, by broad age classes, with roots invaded by six principal root-rotting fungi and *Ascocoryne sarcoides*

Age class	M.R.	No. of trees	Fungi isolated						
			Armillariella mellea	*Coniophora puteana*	*Scytinostroma galactinum*	*Odontia bicolor*	*Merulius himantioides*	*Stereum sanguinolentum*	*Ascocoryne sarcoides*
			(% of trees infected)						
I[a]	Dry[b]	70	36	2	10	4	6	14	0
	Fresh	210	44	3	8	9	0.5	8	2
	Moist	70	39	9	7	4	1	9	6
Avg			41	4	8	7	2	9	2
II	Dry	40	43	5	15	5	13	3	8
	Fresh	50	62	8	8	10	0	12	4
	Moist	40	18	0	8	18	15	0	8
Avg			43	5	10	11	9	6	7
III	Dry	0	-	-	-	-	-	-	-
	Fresh	90	41	21	28	13	5	0	10
	Moist	80	45	25	18	11	4	1	5
Avg			43	23	23	12	5	1	8
I-III	Dry	110	39	3	12	4	9	10	3
	Fresh	350	46	8	13	10	2	7	4
	Moist	190	37	14	12	10	5	4	6
Avg			42	9	13	9	4	6	5

[a]Trees with stump ages of 30 to 60 inclusive are included in age class I; ages 61 to 90 inclusive, age class II; and ages 90+, age class III.

[b]Dry is considered equivalent to M.R. 0 to 1 according to Hills' (1952) classification, fresh = M.R. 2 to 3, moist = M.R. 4 to 6, and wet = M.R. 7 to 8.

27

Table 11. Percentages of black spruce trees on various M.R.s in northwestern Ontario, by broad age classes, with roots invaded by seven principal root-rotting fungi and *Ascocoryne sarcoides*

Age class	M.R.	No. of trees	*Armillariella mellea*	*Polyporus tomentosus*	*Coniophora puteana*	*Scytinostroma galactinum*	*Merulius himantioides*	*Poria subacida*	Unknown F	*Ascocoryne sarcoides*
						(% of trees infected)				
I[a]	Dry[b]	60	27	13	0	8	1	3	1	42
	Fresh	80	35	28	1	14	1	0	1	34
	Moist	60	10	17	0	2	3	2	2	20
Avg			25	20	0.4	9	2	2	1	32
II	Dry	40	63	15	5	0	3	0	3	25
	Fresh	90	44	32	2	4	1	1	1	20
	Moist	60	17	20	7	7	0	2	0	23
	Wet	10	10	20	0	0	0	0	0	50
Avg			38	24	4	4	1	1	1	23
III	Dry	30	50	23	7	10	7	7	7	5
	Fresh	30	40	3	13	30	3	0	3	43
	Moist	50	36	10	4	4	6	0	6	36
	Wet	60	12	3	5	3	2	2	13	40
Avg			31	9	7	9	4	2	8	33
I-III	Dry	130	43	16	3	8	3	3	3	28
	Fresh	200	40	26	3	12	2	1	1	29
	Moist	170	20	16	4	4	4	1	3	26
	Wet	70	12	6	4	3	2	2	11	41
Avg			31	18	4	8	2	1	3	29

[a] Trees with stump ages of 30 to 60 inclusive are included in age class I; ages 61 to 90 inclusive, age class II; and ages 90+, age class III.

[b] Dry is considered equivalent to M.R. 0 to 1 according to Hills' (1952) classification, fresh = M.R. 2 to 3, moist = M.R. 4 to 6, and wet = M.R. 7 to 8.

sites (age class III). Trees attacked by *Merulius himantioides* and *Poria subacida*, though few in number, were well distributed on all sites (Table 11). *Ascocoryne sarcoides* was isolated most frequently from trees on wet sites in age class II and in all ages combined (Table 11).

c) White Spruce

The small number of white spruce plots prevented division into broad age classes, but with all plots grouped, the highest proportion of trees attacked by *A. mellea* occurred on moist sites (Table 12). As in black spruce *P. tomentosus* infections decreased with increasing M.R. Trees on fresh and moist sites were most frequently attacked by *Scytinostroma galactinum* and Unknown F. Attack by *C. puteana* did not appear related to M.R. *Ascocoryne sarcoides* infections tended to increase with increasing M.R.

d) All Tree Species

Armillariella mellea attack was high in all M.R. classes, but was distinctly reduced on wet black spruce sites. Balsam fir and white spruce seldom occur on wet sites. When the combined age classes were compared, *P. tomentosus*, *C. puteana*, and *S. galactinum* were related to M.R. in the same way in black spruce and white spruce. Only *A. sarcoides* increased with increasing M.R. in all three species.

SOIL TEXTURE

For all three tree species, the average amount of root rot in trees of comparable age was considerably higher on deep, outwash, sandy soil (sand) than on aeolean silt over glacial till (silt) (Table 13).

a) Balsam Fir

In balsam fir, *A. mellea*, *O. bicolor*, and *M. himantioides* all attacked more trees on sandy soil than on silty soil, while *S. sanguinolentum*, Unknown S2, Unknown S3, and *A. sarcoides* tended to attack more trees on silty soil (Table 13). Strangely, there were more species causing root rot in silty soil (14 species), where average root rot per tree was low (21%), than on sandy soil (10 species), where average root rot per tree was high (32%). Apparently each infection resulted in more root rot on sandy soil than on silty soil.

b) Black Spruce

Six times as many black spruce trees were infected with *A. mellea* and twice as many with *P. tomentosus* on sandy soil as on silty soil (Table 13). On sandy soil, 7% of trees were infected with

Table 12. Percentages of white spruce trees (21 to 170 years old) on various M.R.s in northwestern Ontario, with roots infected by five principal root-rotting fungi and *Ascocoryne sarcoides*

Age class	M.R.	No. of trees	Fungi isolated					
			Armillariella mellea	*Polyporus tomentosus*	*Coniophora puteana*	*Scytinostroma galactinum*	Unknown F	*Ascocoryne sarcoides*
			(% of trees infected)					
I-III	Dry[a]	60	35	19	2	2	0	17
	Fresh	167	33	15	2	8	2	32
	Moist	40	52	5	5	7	2	25
	Wet	10	30	0	0	0	0	30
Average for all trees			36	14	2	6	2	27

[a]Dry is considered equivalent to M.R. 0 to 1 according to Hills' (1952) classification, fresh = M.R. 2 to 3, moist = M.R. 4 to 6, and wet = M.R. 7 to 8.

Table 13. Percentages of trees with roots invaded by root-rotting fungi and *Ascocoryne sarcoides* on two soil types in northwestern Ontario

	No. of plots [a]	Avg age (30 cm) and range	Avg root rot per tree (%) [b]	Armillariella mellea	Polyporus tomentosus	Coniophora puteana	Scytinostroma galactinum	Odontia bicolor	Merulius himantioides	Poria subacida	Fomes pini	Stereum sanguinolentum	Unknown F	Unknown S2	Unknown S3	Ascocoryne sarcoides
								(% of trees infected)								
Balsam fir																
sand	9	54 (32–96)	32	55	3	11	11	16	3	3	0	1	0	1	0	0
silt	11	61 (40–91)	21	40	2	8	12	9	0	1	0	15	0	5	3	3
Black spruce																
sand	7	73 (55–85)	39	60	29	4	6	1	1	3	7	0	0	0	0	1
silt	9	67 (46–97)	21	10	14	6	13	1	1	0	0	1	0	0	0	19
White spruce																
sand	4	75 (69–79)	27	57	13	0	0	0	0	0	0	3	0	0	0	3
silt	3	64 (57–71)	19	37	3	3	13	0	0	0	0	0	7	0	0	23

[a] Ten trees per plot.

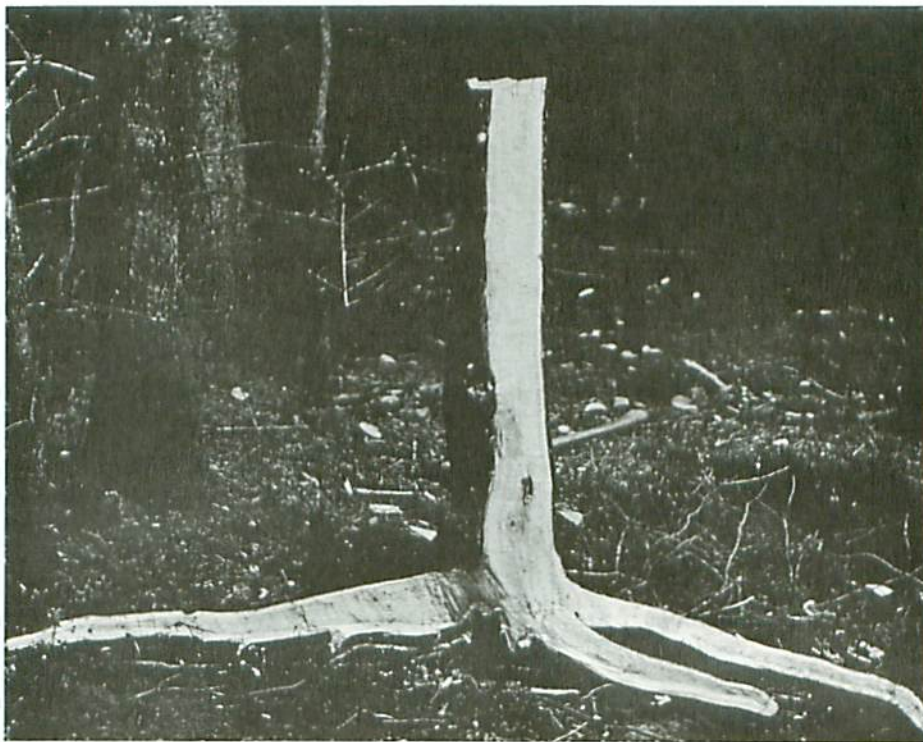[b] Proportion of root wood decayed or stained (see text).

Fig. 16. Reddish-brown stained central root wood in 45-year-old black spruce from which *Fomes pini* was isolated. The fungus had advanced into the roots from the infected stem (X 1/20).

Fomes pini (Fr.) Karst. (Fig. 16), and 3% with *Poria subacida*, while neither of these fungi was isolated from black spruce roots on silty soil. On the other hand, twice as many trees were infected with *S. galactinum* on silty soil as on sandy soil. *Ascocoryne sarcoides*, a non-decaying Ascomycete, was almost 20 times more abundant in trees on silty soil than on sandy soil.

c) White Spruce

In white spruce, where fewer plots were studied, *A. mellea* and *P. tomentosus* also attacked a greater proportion of trees on sandy soil (57% and 13%) than on silty soil (37% and 3%, respectively, Table 13). *Scytinostroma galactinum*, *C. puteana*, and Unknown F attacked white spruce only on silty soil. As it did in black spruce roots, *A. sarcoides* attacked many more white spruce on silty soil than on sandy soil (23% compared with 3%).

d) All Tree Species

Generally, soil texture relationships for each fungus were
similar in the three tree species, i.e., those occurring more
abundantly on sandy soil or on silty soil did so on all three trees.
However, *C. puteana* infected a higher proportion of balsam fir on
sandy soil, while it was more prevalent on black spruce and white
spruce on silty soil. *S. sanguinolentum*, on the other hand, infected
more balsam fir on silty soil, while it was more prevalent on white
spruce on sandy soil.

SITE INDEX

There were tendencies for root rot to increase with site
index (site index being based on the three best trees in the stand)
in all three tree species (Whitney 1976). To analyze the effect of
site index on individual root-rotting fungi, all trees from 31 to 90
years of age were placed in site index classes. The frequency with
which each fungus was isolated is shown in Table 14.

a) Balsam Fir

In balsam fir, infections by *A. mellea* and *S. galactinum* tended
to increase with site index, while those by *P. tomentosus*, *P. subacida*,
and the non-decay fungus, *A. sarcoides*, tended to decrease. *Merulius
himantioides* and *S. sanguinolentum* in the roots tended to be most
severe in trees with intermediate site indexes. Infections by other
root-rotting fungi in balsam fir did not seem to be related to site
index.

b) Black Spruce

Armillariella mellea infections decreased with increasing site
index up to site index 55, then increased again, indicating no clear
trend in black spruce. *Fomes pini* infections tended to decrease with
an increase in site index, while *S. galactinum* and *O. bicolor* increased
with increasing site index. Unknown F tended to be most prevalent in
trees with intermediate site indexes. In black spruce *A. sarcoides*
tended to be more prevalent in trees with higher site indexes.

c) White Spruce

Armillariella mellea infections decreased with increasing site
index in white spruce, although the reverse was true with *P. tomentosus*
and Unknown F (Table 14). *Scytinostroma galactinum* tended to be most
frequent in white spruce trees with intermediate site indexes.

Table 14. Percentages of trees in northwestern Ontario, 30 to 90 years old, infected with various root-rotting fungi (by site index[a] classes)

Site index	No. of plots[b]	Armillariella mellea	Polyporus tomentosus	Coniophora puteana	Scytinostroma galactinum	Odontia bicolor	Merulius himantioides	Poria subacida	Xeromphalina campanella	Fomes pini	Stereum sanguinolentum	Unknown F	Unknown S2	Ascocoryne sarcoides
						(% of trees infected)								
Balsam fir														
41-45	7	30	1	3	3	10	0	4	1	0	3	1	4	7
46-50	8	33	5	10	6	5	4	3	0	0	8	0	1	6
51-55	14	50	4	4	9	12	4	5	1	1	14	1	3	2
56-60	7	44	0	0	14	4	6	1	0	0	9	0	1	3
61-65	4	50	0	3	10	15	0	0	0	0	5	0	5	0
66-70	8	40	0	4	10	3	0	0	1	0	5	0	1	1
Black spruce														
31-35	3	37	37	0	3	0	0	3	0	0	0	0	0	13
36-40	6	43	30	2	3	2	2	0	2	5	0	0	0	18
41-45	5	34	22	6	6	0	2	6	3	4	0	0	0	30
46-50	5	20	10	2	2	0	2	0	4	0	0	2	0	16
51-55	8	21	19	3	4	0	0	0	0	1	0	3	0	19
56-60	7	44	19	1	7	0	1	0	0	0	0	1	0	53
61-65	5	12	30	2	12	6	4	2	5	0	2	2	0	36
66-70	1	70	10	0	40	10	0	0	0	0	0	0	0	10
White spruce														
36-40	4	45	8	5	0	0	0	0	0	0	3	0	0	23
41-45	4	58	13	0	3	0	3	0	3	0	0	0	0	20
46-50	1	30	10	0	0	0	0	0	0	0	0	0	0	30
51-55	8	33	10	4	10	1	0	1	3	1	1	4	2	26
56-60	3	23	20	0	10	0	0	0	0	0	0	5	0	23
61-65	2	5	25	0	5	0	0	0	0	0	0	3	0	35
66-70	3	20	10	0	3	0	0	0	3	0	0	0	0	27

[a] Based on three best trees in the stand.

[b] Ten trees per plot.

d) All Tree Species

S. *galactinum* generally infected more trees as site indexes increased, and *C. puteana* infections generally decreased with increasing site index. *Xeromphalina campanella* and Unknown S2 were unrelated to site index in any of the tree species.

DISCUSSION AND CONCLUSIONS

Armillariella mellea was by far the most prevalent root-rotting fungus in all three species studied. It was recovered in culture from 549 (37%) out of 1,497 trees examined, and it was isolated from roots on 96% of the 78 plots. In addition, some of the infections in the 326 trees with root rot from which no fungus was isolated could have been caused by this fungus; hence, the proportion cited above is conservative. By contrast, in a root rot survey of large trees in Ontario (Whitney et al. 1974) *A. mellea* was isolated from only 6% of the roots of 509 trees of the three species under investigation in this report, and was recovered from only 23% of the 96 locations where five-tree samples were obtained. Also, Basham and Morawski (1964) isolated *A. mellea* from only 0.25% of more than 8,000 trees of these three species in an Ontario cull survey dealing with the merchantable portion of the tree above a 30 cm stump height. When one large root was sampled from each of 80 black spruce between 80 and 145 years old, *A. mellea* was isolated from 7.5% of the trees (Basham 1973). Basham et al. (1953) found *A. mellea* to be fourth in frequency of occurrence among yellow stringy butt decays of balsam fir when they reexamined causal fungi from four previous studies in eastern North America. Again, the stems were examined above the 30 cm height. Prielipp (1957) isolated *A. mellea* from 11% of 95 balsam fir trees above stump height in Michigan; this fungus was second to *Poria subacida* in frequency of isolation from the butt log.

The comparative rarity of *A. mellea* recovery in the latter four Ontario studies and one Michigan study is probably due to the sampling technique. In the study by Whitney et al. (1974), all the large roots were examined at a point about 15 to 30 cm from the root collar, but a sample for culturing was obtained from this point on only one root; trees were not excavated. Basham and Morawski (1964), Basham et al. (1953), and Prielipp (1957) did not sample trees below a 30 cm stump, and Basham (1973) removed a 15 cm section from one root on each tree at a point about 30 cm from the root collar. In the present study the entire stump and all major roots were removed from the soil, and roots and stumps were sectioned at several locations so that a more thorough sampling of decays and stains was made in each root system. Many of the *A. mellea* decay columns were present only on the stump bottom or on the bottom of large roots in close proximity to the stump. Frequently the

column did not extend to ground level, or more than 15 to 20 cm distally in the large roots. Yet the bark of the entire stump bottom of such trees was often dead (Fig. 10). It is little wonder that, when only one large root (Whitney et al. 1974) was sampled, only about one sixth of the *A. mellea* infections found with complete stump examination were isolated. Except in the most advanced stages of *A. mellea* disease, the decay caused by this fungus remains chiefly below ground in all three of the tree species examined in this study. The proportion of *A. mellea* infections found was greatly diminished when trees were sampled only above 30 cm, viz., 0.25% (Basham and Morawski 1964), compared with 37% when root systems were removed and completely examined, as in the present study. Not only does *A. mellea* kill trees outright, as evidenced by extensive bark mortality in roots and extensive mycelial fans beneath the bark of roots and the root collar, but roots weakened from death and decay by this fungus greatly increase tree susceptibility to windthrow while the trees are still living, especially where they are growing on the thin rocky soil prevalent in northern Ontario. This study confirms the results of a recent study (Whitney and Myren 1978) in which 70% of 91 dead or dying saplings of these three species at various locations in Ontario were infected with *A. mellea*. This was found to be the most important root-rotting fungus killing saplings of these and other Ontario conifers.

Polyporus tomentosus was second in abundance, as it was isolated from an average of 10% of the trees of the three species and occurred on 52% of the plots. It was most abundant, however, in the two spruces, for it was present in 17% of the trees and occurred on 73% of plots on which spruce was sampled. This fungus was about equal in abundance in black spruce and white spruce. In the Ontario root rot survey (Whitney et al. 1974), *P. tomentosus* was isolated from 22% of 294 black spruce and white spruce. The greater occurrence of *P. tomentosus* in that survey, in which only one root per tree was sampled, is probably due partly to the older age of trees in the 1974 survey. Of more significance is the fact that sample trees in the 1974 survey were purposely selected adjacent to dead trees. Thus many trees in that survey were from pockets of root rot or "stand openings" created by dead trees. *Polyporus tomentosus* is known to be associated with such openings in white spruce (Whitney 1962), and the openings are more prevalent in older stands. Basham and Morawski (1964) isolated *P. tomentosus* from about 1.5% of their nearly 7,000-tree sample of black spruce and white spruce. The greater recovery of this fungus than of *A. mellea* in their study is probably due to the difference in growth pattern of the two fungi in the tree. While they both enter through the roots, *P. tomentosus* extends up the trunk to a much greater extent than *A. mellea*; hence, when only stems above 30 cm are sampled, a much higher proportion of infections of the former is encountered than of the latter. Lack of isolation of *P. tomentosus* from 39 black and white spruce trees in the Ontario sapling study (Whitney and Myren 1978) suggests that this fungus is much less prevalent in younger trees,

although it is known to kill trees as young as 19 years old (Whitney 1977). In the present study, *P. tomentosus* grew extensively in sapwood and apparently killed much root bark of spruce (Fig. 17) as has been observed in previous studies of this fungus (Whitney 1962, 1972). Killing of roots results in outright mortality of the tree, but as with *A. mellea*, probably the greatest damage from the fungus is caused indirectly by the increased susceptibility of trees to windfall.

Scytinostroma galactinum was third in abundance of root infections: it was isolated from 8% of the 1,497 trees, and occurred on 49% of the plots. This fungus ranks second in occurrence in balsam fir, and third in each of the two spruces. It was seldom isolated from balsam fir (1% of 215 trees) in the Ontario root rot survey (Whitney et al. 1974), and it was not isolated from the 294 black spruce and white spruce trees sampled there. Possible reasons for the apparent scarcity of *S. galactinum* in the 1974 study is the sampling technique, mentioned earlier, and the bias of the study towards "stand openings" that seem to be caused chiefly by *P. tomentosus*.

Fig. 17. White pocket decay caused by *Polyporus tomentosus* in large root of 70-year-old black spruce. The sapwood and bark have been killed by this fungus except in upper 1/3 of root (X 1/5).

Basham and Morawski (1964) isolated *S. galactinum* from 2.1% of 8,200 trees of these species. Although *S. galactinum*, like *P. tomentosus*, often extends several metres up the trunk, the sampling technique mentioned earlier probably accounts for the lower recovery of this root-rotting fungus in their study. In the sapling survey, *S. galactinum* was isolated from 2% of 91 trees of these three species (Whitney and Myren 1978), a fact which indicates that this fungus also attacks young trees. Prielipp (1957) isolated *S. galactinum* from 4% of 94 balsam fir trees in Michigan.

Three other common root-rotting fungi in balsam fir, *Odontia bicolor*, *Coniophora puteana*, and *Stereum sanguinolentum*, were isolated from 9%, 9% and 6% of the 650 trees, respectively. With the exception of the chiefly trunk-rotting fungus, *S. sanguinolentum*, which was isolated from 11% of the 1,388 balsam fir trees sampled by Basham and Morawski (1964), these three fungi were generally less frequently isolated from balsam fir in the above four Ontario studies with which comparisons have been made. Again, tree age and sampling technique are probable factors in the differences. In Michigan, Prielipp (1957) isolated *O. bicolor* and *C. puteana* from 7% and 5%, respectively, of 94 balsam fir with decay on the stump. *Polyporus balsameus* Peck and *Poria cocos* (Schw.) Wolf were each as frequently isolated as *O. bicolor* in his study.

The increase in decay with tree age (Basham and Morawski 1964) generally applies to root rot as well (Whitney 1976). However, the fungi causing the root rot do not become uniformly more prevalent in the living trees as a stand ages (Basham and Morawski 1964). Results of this study indicate that the fungi most active in killing root tissues, i.e., *A. mellea* and *P. tomentosus*, actually were present in a lower proportion of the living trees of older age classes, probably because of mortality and windthrow of many trees infected by them. This was the case with *P. tomentosus* in black spruce as well (Basham 1973). In the present study, other fungi such as *S. galactinum* and *O. bicolor*, especially in balsam fir, were more frequently isolated from older trees, probably because they are less active in killing the trees, and trees infected by them do not fall from the stand as readily as those infected with *A. mellea* or *P. tomentosus*. *Coniophora puteana* and *Xeromphalina campanella* (in balsam fir) also increased in frequency of isolation with increasing tree age. These fungi invaded little living tissue, and trees remained living for many years, even though heavily infected by them. This finding with *X. campanella* agrees with that of Basham et al. (1953), namely that *X. campanella* had a pronounced tendency to occur in older balsam fir age classes. A later study, on the other hand (Basham 1973), revealed that most *C. puteana* infections were in younger black spruce. Almost all black spruce in the present study were on upland sites, while many of Basham's older trees were on lowland sites where *C. puteana* infections are reduced because of site

conditions. The increase in frequency of isolation of Unknown F with increased age of black spruce (Basham 1973) was confirmed in the present study. The slight increases in occurrence of *Ascocoryne sarcoides* with tree age in black spruce and white spruce in this study corroborate Basham's (1973) findings in black spruce. Contrary to what he found in tree stems, however, *A. sarcoides* was commonly isolated from roots of *young* black spruce trees. An average of about 30% of 283 black spruce between 31 and 70 years of age were infected by this fungus.

Infections by the three main fungi in black spruce, *A. mellea*, *P. tomentosus* and *S. galactinum*, all tend to decrease with an increase in M.R., a situation similar to that found by Basham (1973). This probably accounts to a large extent for the decreased windfall, breakage, and mortality of stands of this species on lowland wet sites compared with stands of the same age on upland drier sites. Fresh sites, which are probably the best sites for rapid growth of black spruce, appear to be most susceptible to *P. tomentosus* and *S. galactinum* for this species. Other common root-rotting fungi in black spruce such as *C. puteana*, *Merulius himantioides*, *Poria subacida* and *X. campanella* showed no strong relationships with M.R., but infections by Unknown F and *A. sarcoides* (except in young trees) increased with increasing M.R., as was found by Basham (1973).

There was a tendency for *A. mellea*, *S. galactinum*, *M. himantioides* and *S. sanguinolentum* to be more severe in balsam fir on drier sites, but this was partly offset by the reverse relationship for *C. puteana* and *O. bicolor* in this species. However, when one considers all the fungi, balsam fir, like black spruce, appears to be less susceptible to fungal infections on wetter sites. Prielipp (1957) also found less butt rot in balsam fir on lowland than on upland sites.

Armillariella mellea, *P. tomentosus*, *O. bicolor*, *M. himantioides*, *P. subacida* and *F. pini* all caused more infections on sandy than on silty soil, while the reverse tendency prevailed for *S. galactinum*, *Stereum sanguinolentum* (in balsam fir only), Unknowns F, S2, and S3, and *A. sarcoides*. As sandy soil usually had a lower M.R. than silty soil, higher proportions of *A. mellea*, *P. tomentosus*, and *M. himantioides*, and lower proportions of Unknown F and *A. sarcoides*, could be expected on it. However, characteristics of soil texture other than moisture holding capacity apparently affect the occurrence of the other fungi. The fact that *A. sarcoides* was much more prevalent in roots of black spruce and white spruce on silty sites could also account for the reduced occurrence of the first group of six root-rotting fungi listed above, if *A. sarcoides* is active in reducing decay fungi in black spruce as suggested by Basham (1973). Prielipp (1957) found the incidence of brown butt rots in balsam fir (chiefly *Polyporus balsameus*, *Poria cocos*, *Coniophora puteana*, and *Merulius himantioides*)

was about three times higher on sandy sites than on clay sites. Here also, the sites with many infections (sand) would probably be drier than those with fewer infections (clay).

Balsam fir trees in stands with low site indexes had fewer infections by *A. mellea, S. galactinum,* and *M. himantioides* than those in stands with medium or high site indexes. Other fungi such as *P. subacida* and *A. sarcoides* infected higher proportions of trees in stands with low site indexes. Still others such as *O. bicolor, C. puteana,* and Unknown S2 infected about equal numbers of trees in stands of all site indexes. This indicates that individual fungi are related to site index in different ways. Site quality as measured by site index cannot be used as an indication of root rot potential, therefore, unless on the basis of individual fungi or groups of fungi that react similarly on all sites as rated by site index. *Scytinostroma galactinum* infections also increased with increasing site indexes of black spruce and white spruce as did *M. himantioides* infections with site indexes of black spruce. As in balsam fir, *P. subacida* was most prevalent in black spruce stands with low site indexes. Thus, some root-rotting fungi are related to site indexes of more than one tree species.

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