FUNGI ASSOCIATED WITH DECAY IN TREATED SOUTHERN PINE UTILITY POLES IN THE EASTERN UNITED STATES[1]

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ABSTRACT

Approximately 1,320 fungi were isolated and studied from 246 creosote- or pentachlorophenol-treated southern pine poles in service in the eastern United States. The fungi identified were Basidiomycete decayers. soft rotters, and microfungi. White rot fungi predominated in the 262 Basidiomycete decayers isolated from 180 poles. The major Basidiomycetes isolated by radial position from poles of varying service ages appeared to develop initially in the outer treated zones and were often associated with seasoning checks. Some decay origins, however, appeared to be cases of preinvasion and escapes of preservative treatment. Five species of soft rot fungi comprised nearly 85% of 211 isolates obtained from 131 poles. They were isolated primarily from creosote-treated poles in outer treated zones at the groundline. Dissection analysis of 92 poles indicated that six developmental decay patterns and certain fungi were associated commonly with a pattern. The pole mycoflora isolated was relatively uniform in distribution in the eastern United States. The soft rotters and white rot group of Basidiomycete decayers appear to be a more important component of the treated southern pine pole mycoflora than has been recognized previously.

Keywords: Decay, soft rot, southern pine. utility poles, creosote, pentachlorophenol, decay patterns, Basidiomycetes. microfungi.

INTRODUCTION

Information on the identities, frequencies. and roles of the major fungi associated with decay development in wood products has many values. It provides clues on when and where the fungi invade the wood products that may be useful in control programs. Laboratory tests of fungal effects on wood properties permit

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estimates of their damages to wood in various uses. Isolations and identifications of known decay fungi may be useful to detect incipient decay in some wood uses. Such information facilitates selection of test fungi for bioassays of potential wood protectants or fumigants. A long-range value is that it may lead to a better understanding of decay development as a process, the organisms involved, their relative roles, and interactions over time. This may set the stage for more useful control approaches.

For these reasons, Cowling (1957) and Duncan and Lombard (1965) assembled useful lists of the decay fungi found in wood products in the United States. Eslyn (1970) presented valuable information on the major Basidiomycete fungi associated with decay development in utility poles in North America. He stressed the need for additional studies to determine the identities of the fungi causing decay in utility poles.

Recent studies in Europe and Australia indicated that a type of decay known as soft rot is important in utility poles (Henningsson et al. 1976; Leightley 1978). Soft rots are caused by microfungi that selectively attack portions of the cell wall (Corbett 1965; Wilcox 1970; and Nilsson 1973). Their development in wood was associated with high moisture levels and some preservative treatments (Henningsson et al. 1976; Duncan 1960. 1961). Carranza (1979) reported the isolation of fungi capable of soft rot damage from creosote treated poles in New York. Morrell (1981) demonstrated that some soft rot fungi isolated from treated southern pine poles were resistant to wood preservatives and tolerated both low oxygen levels and short periods of high temperature in wood.

The increasing costs of utility poles and their replacements stimulated studies of decay control in utility poles. Graham et al. (1976) reported on decay development in Douglas-fir poles in the western United States and showed that agricultural fumigants injected in the groundline zone may extend service lives up to 10 years. This raised the important question of the applicability of such treatments to treated southern pine poles in the eastern United States. This study was initiated in the fall of 1979. as a prelude to field fumigant effectiveness tests where it was necessary to establish the decay locations and identities of associated fungi in a series of representative test poles prior to treatment. The objectives were: (a) to isolate, identify, and group into types the major fungi associated with decay development in the groundline zone of creosote- and pentachlorophenol-treated southern pine poles in service in the eastern United States. (b) to determine when and where these fungi appeared in poles, and (c) to describe the typical decay patterns in the groundline zone of the poles and their associated fungi.

MATERIALS AND METHODS

Pole samples

A total of 246 creosote- or pentachlorophenol-(penta) treated southern pine poles, located primarily in the eastern United States, were selected for the cultural and related decay pattern study. They were sampled over a three-year period to handle the many fungal isolations and identifications involved.

The first study sample was 51 poles selected and installed in two test plots in 1979 and 1980, for intensive isolation and decay position studies prior to establishing long range tests of the agricultural fumigants Vapam and chloropicrin. The

Western Electric test plots (WE) contained 33 poles chosen from their preservative test installation at Chester. New Jersey. Twenty-one poles were creosote-treated and represented service ages of recently treated and 10, 18, 25. 30, 40, and 48 years. Twelve poles were penta-treated and represented service ages of recently treated and 10, 18, and 25 years. The New York State Electric and Gas test plot (NYSEG) was established near Binghamton, New York, and contained 18 poles (9 creosote-treated and 9 penta-treated). These poles were selected from distribution lines in New York and Pennsylvania to represent sound, early decay, and intermediate decay classes based on groundline conditions.

To determine the decay patterns and their associated fungi on a regionwide basis, a second sample of 195 poles was studied at various locations in the eastern United States as cooperator interest provided. Of these. 103 were sampled by borings from poles in the Georgia Power Company and Virginia Electric Power Company distribution systems in 1980 and 1981. These poles were selected to represent service ages of 10-50 years. Also in 1982. 92 cross sections from groundline zones of large defective poles were provided for cultural and dissection studies by nine cooperating utilities.[2] Information on pole age, preservative treatment, and service conditions was provided.

A dozen additional poles that failed in service were available during the study for lengthwise dissection to determine decay locations. No isolations were made from these poles.

Core collections and isolations

Two increment cores were taken aseptically (at right angles) from the groundline zone of each of the 51 poles in the WE and NYSEG test plots. Single increment cores were taken from the 103 Georgia and Virginia pole samples and extracted adjacent to deep checks or external decay evidences from the groundline zones of decay suspect poles. The cores were placed aseptically in sterile glass tubes and isolations made within 24 hours of collection whenever feasible. Cross sections and longitudinal slabs exposing radial surfaces were sawed from the borders of decay zones in the 92 pole groundline sections. These isolations were made directly from chips cut from the exposed surfaces. Isolations were made from four radial positions in all cores or cross sections (the outer-treated, inner-treated, the treated-untreated interface. and the inner-untreated zones).

The media used for isolations were: malt extract agar (MEA) and malt benomyl agar (Zabel et al. 1982). Eighteen chips were cut aseptically from each radial position, briefly surface flamed, and partially embedded in the media. The isolation plates were incubated at 22 C. Isolates were subcultured from mycelial margins or by plate streaking to establish pure cultures.

In those cases where bacteria were associated consistently with some microfungi, the antibiotics penicillin G, streptomycin sulphate. alone and in combination. were used to purify the cultures.

When the same fungus appeared repetitively in a radial position in the replicate

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[2] The utilities providing pole samples from their distribution systems were New York State Electric and Gas, Arkansas Power and Light Co., New Orleans Public Service Inc.. Texas Electric Service Co.. Public Service of Indiana Inc., Niagara Mohawk Power Corp., Carolina Power and Light Co., Gulf States Utilities Co.. and Houston Lighting and Power Co.

plates or selective media, it was recorded once. Fungi that could be identified readily from cultural and microscopic characteristics were recorded only. Unknown fungal isolates were maintained in a culture bank for identification and study.

Decay descriptions

The cores, cross sections, and longitudinal surfaces of radial slabs were studied with a stereoscopic microscope at a magnification of 40 x . Wood colors, textural changes, and softness to probing were determined. Locations, dimensions, and the characteristics of visible defect areas were recorded. The decays were grouped into early, intermediate, and late stages.[3] The decays were recorded by visual appearances as either white or brown rot (fibrous or cubical) types. Other defects such as termite or carpenter ant damage, ring shake, and compression wood were recorded.

Grouping and identification of the isolates

Macroscopic cultural and microscopic characteristics of the isolates were determined. The general criteria used were growth rates. mat color and texture, growth patterns of marginal hyphae, hyphal features, presence or absence of clamp connections, mode of conidial formation, and conidial morphology. The fungi were then grouped into similar entities based on microscopic comparisons of each probable taxon. These taxa were then grouped tentatively into either Basidiomycete decayer or microfungal categories based on microscopic features.

The Basidiomycete cultures were studied and identified using the methods of Davidson et al. (1938, 1942). They were compared then with named isolates from the Reference Culture Collections of wood decay fungi maintained at the Center for Forest Mycology Research at the Forest Products Laboratory, Madison, Wisconsin. Monokaryon isolates were identified by mating with named monokaryons and the subsequent formation of clamp connections.

Decay tests were conducted on representatives of all taxa in the Basidiomycete decay group that were not identifiable. Decay chambers (8 oz square bottles) were prepared containing 40 ml of MEA. They were autoclaved. positioned horizonally for medium gelation, and planted with small discs cut from the margin of actively growing isolates. Southern pine sapwood blocks, 2 x 2 x 1.3 cm (longitudinal plane), were dried to constant weight (odw) at 105 C and weighed to the nearest mg. The blocks were treated to 150% moisture content, autoclaved at 100-102 C for 15 minutes and cooled. Two blocks per chamber were placed aseptically on small V-shaped glass rods laid on the fungus mats in the chambers. Replication per isolate was six blocks (three decay chambers). Chambers were incubated in the dark at 28 C for 2 months. The blocks were then removed, cleaned of surface mycelium. and the odw's reestablished. The sixth block was fixed in a killing solution and retained for anatomical study. Unknown isolates with clamp connections or causing weight losses exceeding 5% in the decay tests and cell-wall erosion were placed in the Basidiomycete group.

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[3] The decay stages were defined as follows: *early-wood* soft and/or discolored, early cell-wall erosion often in the early wood zones: *intermediate-wood* softer with severe cell-wall erosion yet annual rings remain discernable; and *late-wood* disintegrated.

Soft rot tests were conducted on representative isolates of the major microfungi. The test procedure developed by Nilsson (1973) was used with the following modifications: 60 ml of the prescribed nutrient solution was used instead of 30 ml, and after 2 months of incubation, 10 ml of sterile distilled water was added aseptically to each chamber to replace the evaporation loss. Test blocks were prepared and replicated as described in the above decay test. The test chambers were incubated in the dark at 32 C. At the end of 3 months, the blocks were removed and handled as described in the decay test above.

Microfungi that formed longitudinal bore holes and/or anatomical evidence of cell-wall damage within the S2 zone coupled with weight losses exceeding 5% were classified as soft rotters. The remaining taxa were considered to be microfungi. The microfungi and soft rotters were identified subsequently by microscopic study, comparison with known cultures, special cultural studies, or in a few cases by sending representative isolates to group specialists for confirmation or identification.

Anatomical studies

Microscope slides were prepared from the test blocks retained from decay and soft rot tests. Sections (15-20 μm) were cut from the transverse and radial surfaces with a sliding microtome, stained in picro-aniline blue (Wilcox 1964), dehydrated in an alcohol-xylene series, and mounted in a permanent medium for study under oil immersion. Because fungi capable of soft rot damage were isolated frequently, a random sample of 35 poles was studied anatomically to verify soft rot attack. Microscopic sections were prepared for these poles as described above from four radial positions in the groundline zone. Specimens of special interest were studied further using Scanning Electron Microscopy (SEM).

Sensitivities and tolerances of the isolates to creosote and penta

These data were sought for possible explanations of when and where a major isolate invaded treated poles in service. The major fungi were grown on an MEA medium containing various concentrations of the toxicant. Creosote concentrations were 0.0, 0.05, 0.1, 0.5, 1.0, and 5.0%. Penta concentrations were 0, 1, 2, 5, 10, and 50 μg/ml. A 0.5% concentration of dimethyl sulfoxide was added to all mixtures to enhance toxicant solubility. Replication per fungus for each toxicant concentration was 6. Radial growth of the various fungi was measured at 7- and 14-day periods, plotted against the toxicant concentration (semi-log scale), and 50% growth reduction and inhibition thresholds were determined by extrapolation.

Decay pattern study

To further clarify the location and association of decay patterns with fungi isolated, cross sections were sawed from 92 poles, where groundline samples were available for dissection study. Vertical sections were cut radially to expose the decay zones detected in the cross sections. Measurements of the decay zones were made. Isolations, as described previously, were made from four radial positions and the margins of the decayed zones.

Data handling and analysis

The isolates, identified as to species (or taxon) and fungus type, were grouped with the pole and decay data and sorted for fungal frequency as affected by pole radial position, age, and treatment. Decay patterns were determined and analyzed by position and age also for 92 dissected pole samples. Since the pole samples collected were often opportunistic hence non-random, no attempt was made to analyze these data for significance.

RESULTS

Identifications

From the 246 poles in the study, 1,320 fungi were isolated from the various core or cross-section positions sampled in the groundline zone. The fungi as identified or placed in definable taxa are grouped by major type and listed in order of prevalence (Tables 1, 2).

Basidiomycete decayers (262) were isolated from a total of 180 poles. *Coriolus versicolor, Bjerkandera adusta, Irpex lacteus,* the "chain-chlamydospore" taxon, *Sistotrema* sp., *Phlebia brevispora, P. rufa,* and *Poria placenta* were the major decay fungi and comprised approximately 70% of the decay isolates. The other 12 identified species appeared only in a few poles. The decayers that were not identifiable culturally represent an estimated several dozen additional species. A total of 28 monokaryons were isolated representing the following species or taxa: *B. adusta,* "chain-chlamydospore," *C. versicolor, Hirschioporus pargamenus, Phlebia radiata,* and *P. rufa.*

The "chain-chlamydospore" taxon is an unknown brown-rot fungus that is characterized in culture by chains of chlamydospore-like cells that later develop into microscopic sclerotia. Isolates of *Sistotrema* sp. fruited in culture and could be identified only to genus. *Phlebia brevispora is* a newl described species reported from southern pine utility poles in Maryland, Virginia. and Mississippi (Nakasone and Esyln 1981).

Soft rot fungi (211) were isolated from a combined total of 131 poles. *Scytalidium lignicola, Alternaria alternata, Phialocephala dimorphospora, Phialophora heteromorpha,* and a species designated as taxon 121 were the major soft rot fungi and comprised nearly 85% of the fungi isolated that were established to have soft rot capability.

Microfungi (850) were isolated consistently from most poles with the exception of a few recently treated creosote and penta poles included in the WE and NYSEG fumigant test plots as controls. *Cladosporium resinae, Paecilomyces varioti, Trichoderma* spp., *Exophiala mansonii, Penicillium* spp., and the "black yeasts" were most abundant and comprised 60% of the microfungal isolates. Forty-one additional species or taxa were isolated in lower frequency. Sixty-six fungi from thirty poles were categorized as unknown microfungi despite intensive study. Actinomycetes were isolated from only four poles. Bacteria were present in many older poles and frequently associated with the "black yeasts." No attempt was made to identify the major bacterial isolates.

Three unknown taxa isolated frequently are described briefly, both culturally and microscopically. Taxon 121 was isolated 12 times from 8 poles. In the soft rot test, it formed abundant longitudinal cavities. Cultures were slow-growing

TABLE 1. *The basidiomycete decay and soft rot fungi isolated from the groundline zone of 246 creosote- or penta-treated southern pine poles in service in the eastern United States.*

Species or taxon	Isolation frequency	
	Poles[a]	Radial positions[b]
Basidiomycete Decayers		
Coriolus versicolor (L. : Fr.) Quél.	45	57
Bjerkandera adusta (Willd. : Fr.) Karst.	27	37
lrpex lacteus (Fr. : Fr.) Fr.	20	39
"Chain-chlamydospore"	14	17
Sistotrema sp.	10	11
Phlebia brevispora Nakas. in Nakas. et Eslyn	3	7
Hyphoderma praetermissum (Karst.) J. Erikss. et Strid	2	6
Phlebia rufa (Pers. : Fr.) M. P. Chris.	4	5
Poria placenta (Fr.) Cke.	4	4
Phlebia subserialis (Bourd. et Galz.) Donk	3	4
Poria spissa (Schw.) Cke.	2	3
Phlebia radiata Fr.	2	3
Hyphodontia setulosa (Berk. et Curt. in Berk.) Maas G.	2	2
Phanerochaete sordida (Karst.) Erikss. et Ryv.	2	2
Ptychogaster rubescens Boud.	1	1
Hyphoderma puberum (Fr.) Wallr.	1	1
Trichaptum biforme (Fr. in Klotzsch) Ryv.	1	1
Phanerochaete flavido-alba (Cke.) Rattan	1	1
Rigidoporus vitreus (Pers. : Fr.) Donk		
Gloeoporus pannocinctus (Rom.) Erikss.	1	1
Unknown decayers	43	60
(Subtotal— basidiomycete decayers)	(189)[a]	(262)
Soft Rotters		
Scytalidium lignicola Pesante	65	100
Alternaria alternata (Fr.) Keissl.	17	29
Phialocephala dimorphospora Kendrick	11	21
Phialophora heteromorpha (Nannf.) Wang	8	16
Leptodontium elatius (Mang.) de Hoog	5	10
Chaetomium globosum Kunze : Fr.	2	5
Epicoccum purpurascens Ehrenb. : Schlect.	4	5
Taxon 121	8	12
Phialophora richardsiae (Nannf.) Conant	5	5
Phialophora olivacea W. Gams	2	4
Cladosporium cladosporoides (Fr.) de Vries	4	4
(Subtotal—soft rotters)	(131)[a]	(211)
Total—decay fungi	159[a]	473

[a]The number of times a fungus was isolated from a pole. The numbers do not reconcile with the number of poles with decay fungi since in some cases more than one species or fungus type was found in a pole.

[b]The number of times a fungus was isolated from a radial position. The four core or cross-section positions were outer-treated. inner-treated, interface between treated and untreated, and untreated.

colonies initially appressed with tufts of mycelia in the center. Mat colors ranged from white, yellow to pink with diffused pigments of similar colors in the media. Older colonies became powdery, and colors of the colonies as well as diffused pigments varied from dark yellow, rust, red to maroon. Microscopically, hyphal strands were common. Conidiogenous cells were phialidic, but some were annellidic. Conidia were oval to cylindrical. Taxon 194 was isolated 32 times from

TABLE 2. *The microfungi isolated from the groundline zone of 246 creosote- or penta-treated southern pine poles in service in the eastern United States.*

Species or taxon	Isolation frequency	Radial positions[b]
Cladosporium resinae (Lindau) de Vries	86	229
Paecilomyces varioti Bainier	44	79
Trichoderma spp.	27	70
Exophiala mansonii (Castell.) de Hoog	28	57
Penicillium spp.	31	47
Taxon 194	14	32
Unknown "black yeasts"	23	29
Unknown yeasts	16	28
Zygomycetes spp.	16	26
Arthrographis cuboidea (Sacc. et Ellis) Sigler	14	21
Phialophora spp.	15	19
Taxon 248	13	18
Rhinocladiella atrovirens Nannf.	11	16
Moniliella sp.	9	16
Aureobasidium pullulans (deBary) Arnaud	9	11
Mortierella sp.	6	10
Aspergillus spp.	7	8
Ascomycetes spp.	7	7
Gliocladium virens Miller, Giddens et Foster	5	5
Trichoderma harzianum Rifai	1	4
Actinomycetes	4	4
Acrodontium intermissum de Hoog et Rao	1	3
Phaeococcus sp.	1	3
Pycnidial taxon	2	3
Phialophora fastigiata (Lager. et Melin) Conant	I	3
Septonema sp.	1	3
Curvularia lunata (Wakk.) Boed.	3	3
Oidiodendron griseum Robak	2	2
Sporothrix sp.	2	2
Acremonium sp.	2	2
Rhizopus sp.	2	2
Gliocladium roseum Bainier	1	2
Asteromella sp.	2	2
Taxon 442	1	2
Mycelia sterila	1	2
Misc. microfungic	12	12
Unknown microfungi	30	66
Totals	175[a]	850

[a]The number of times a fungus was isolated from a pole. The numbers do no: reconcile with the number of poles with microfungi since in some cases more than one species or fungus type was found in a pole.

[b]The number of times a fungus was isolated from a radial position. The four core or cross-section positions were outer-treated. inner-treated, interface between treated and untreated, and untreated.

[c]Microfungi isolated once were: *Cladosporium herbarium* Link : Fr., *Sporothrix inflata* de Hoog, *Bactrodesmium* sp., *Mucor* sp., *Trichoderma wide* Pers. : S. F. Gray, *Scopulariopsis* sp., *Verticillium* sp.. *Tetraploa aristata* Berk. et *Br., Acremonium curvulum* W. Gams, *Monoascus* sp., and *Byssochlamys nivea* Westling.

14 poles. The soft rot test of this fungus was negative. Colonies were white, thin, filmy, and gradually became powdery. Microscopically, the hyphae were thin and hyaline. Conidiophores were micronematous with integrated conidiogenous cells bearing blastic conidia. After the secession of the conidia, denticles were prominent on the conidiogenous cells. This fungus is significant since it was also isolated

consistently from recently creosote-treated poles in storage yards (Polishook 1982). Taxon 248 was isolated 18 times from 13 poles. The soft rot test of this fungus was negative. It was characterized by brown, wrinkled, thick-walled chlamydospores that were smooth with hyaline walls when young. Colonies were brownish, yeasty with scanty aerial mycelia. Hyphae were light brown showing a blastic mode of conidial production. Identifications of the above three fungi are in progress and will be published elsewhere.

Geographic distribution of the major isolates

The pole isolates were grouped into northern (New York, Pennsylvania, New Jersey, and Indiana) and southern (Virginia, North Carolina, Georgia, Louisiana, Texas, and Arkansas) zones to determine possible geographic effects on distribution and frequency (Table 3). The major Basidiomycete decayers (isolated from four or more poles) were found generally in both geographic zones. *Irpex lacteus* and *C. versicolor* were isolated in higher frequency from the northern zone while *Poria placenta, Phlebia brevispora,* and *P. rufa* were commonest in the southern zone. Most soft rot fungi were found also in both geographic zones.

Isolation groupings by preservative type

Most of the fungi listed in Tables 1 and 2 were isolated from both creosote- and penta-treated poles. Important exceptions were the soft rot fungi that were isolated primarily from creosote-treated poles as follows: *Phialocephala dimorphospora, Phialophora heteromorpha, Leptodontium elatius,* taxon 121, and *Alternaria alternata* (Table 3). Several of the major microfungi were isolated also primarily from creosote-treated poles. These are listed with the ratios of creosote to penta pole isolations in parentheses as follows: *Exophila mansonii* (48/9), *Arthrographis cuboidea* (20/1), and *Paecilomyces varioti* (75/4). *Rhinocladiella atrovirens* (4/12), the single exception, was isolated primarily from penta-treated poles.

Decay isolate grouping by pole positions

The major decay isolates were grouped by type and isolation position in the pole radius and pole service age for inferences on when and where the fungi invaded the poles (Table 4). The number of Basidiomycete decayers isolated from the outer-treated position of the poles was largest and increased with age. However. some decayers were isolated commonly from the inner untreated zone of sound appearing young poles.

Some soft rot fungi such as *S. lignicola* and *Phialocephala dimorphospora* were present most frequently in outer positions of the younger poles, while *Phialophora richardsiae* was obtained only from inner positions of poles.

Decay patterns and fungal associations

One hundred twenty-three discrete decayed zones were detected and described in the groundline sections of the 92 poles dissected. Six general decay patterns based on location and decay characteristics of the zones were determined as follows:

Pattern 1. Surface decay is shallow and generally uniform. The wood is soft

TABLE 3. *The frequency of the major decay fungi isolated from creosote- or penta-treated poles in the northern and southern regions of the eastern United States.*

Isolates by fungus type[c]	Geographic region: Northern[a] Creosote	Northern[a] Penta	Southern[b] Creosote	Southern[b] Penta	Totals Creosote	Totals Penta
Basidiomycete Decayers						
Coriolus versicolor	31	8	18	0	49	8
Bjerkandera adusta	15	4	17	1	32	5
Irpex lacteus	29	4	6	0	35	4
"Chain-chlamydospore"	7	5	5	0	12	5
Sistotrema sp.	2	1	7	1	9	2
Phlebia brevispora	0	2	5	0	5	2
Phlebia rufa	0	0	4	1	4	1
Poria placenta	1	0	3	0	4	0
Soft Rot Fungi						
Scytalidium lignicola	32	17	29	22	61	39
Alternaria alternata	10	1	18	0	28	1
Phialocephala dimorphospora	18	0	2	1	20	1
Phialophora heteromorpha	14	0	1	1	15	1
Taxon 121	5	0	7	0	12	0
Leptodontium elatius	10	0	0	0	10	0
Phialophora richardsiae	0	0	3	2	3	2
Epicoccum nigrum	5	0	0	0	5	0
Cladosporium cladosporoides	2	1	1	0	3	1

[a]States included are New York. Pennsylvania. New Jersey, and Indiana.
[b]States included are Virginia. North Carolina. Georgia. Louisiana. Texas, and Arkansas.
[c]Authonties are presented in Tables 1 and 2.

and a white or gray in color. The surface may erode unevenly at the groundline and in advanced stages forms an hourglass shape.

Pattern 2. Decay pockets are present in the outer-treated zones. These range from numerous small pockets associated with shallow checks to one to several large pockets associated with deep checks. The associated decays are white or brown cubical in appearance.

Pattern 3. Extensive and irregularly shaped decayed zones are present in the inner-treated zones generally limited by firm heartwood. The decayed zones are associated with one or more deep checks opening to the pole surface. The associated decays are white or brown stringy in appearance.

Pattern 4. Earlywood portions of the annual rings are decayed in localized regions of the outer- or inner-treated zones. In advanced stages localized ring shake may develop. The decay is a tan to reddish brown color as seen on exposed vertical surfaces and is often associated with a roughened sawed surface due to extensive fiber pulling.

Pattern 5. These decay zones are similar in appearance to pattern 3 but the decay columns are not traceable to checks or outside origins such as knots or mechanical damage.

Pattern 6. Extensive decay is present in the heartwood and may extend to inner zones of the untreated sapwood. In advanced stages, the poles are hollow and/or the pith zone of the heartwood is dislodged. The associated decays are white or brown stringy in appearance.

TABLE 4. *The frequency of the major decay fungi, grouped by types, isolated from the outer-treated and inner untreated portion of poles in the groundline zone as affected by pole service age.*

Isolates by fungus type	Pole service age in years					
	0-18		19-36		37-52	
	Core position					
	Outer-treated	Inner untreated	Outer-treated	Inner untreated	Outer-treated	Inner untreated
	Basidiomycete Decayers					
Coriolus versicolor	2	5	24	3	12	11
Bjerkandera adusta	4	3	9	7	10	4
Irpex lacteus	7	4	6	4	16	2
"Chain-chlamydospore"	0	1	4	5	5	2
Sistotrema sp.	2	1	2	1	4	1
Phlebia brevispora	2	0	1	0	3	1
Phlebia rufa	0	0	3	1	0	1
Poria placenta	0	0	2	0	2	0
	Soft Rot Fungi					
Scytalidium lignicola	21	5	34	23	10	7
Alternaria alternata	1	1	8	2	13	4
Phialocephala dimorphospora	6	1	4	0	8	2
Phialophora heteromorpha	4	3	1	1	6	1
Taxon 121	1	1	1	1	7	1
Leptodontium elatitus	2	4	0	0	2	2
Phialophora richardsiae	0	1	0	4	0	0
Epicoccum nigrum	2	0	0	0	3	0
Cladosporium cladosporoides	1	0	0	1	1	1

Based on wood color and texture characteristics, the decayed zones were judged to represent decay types as follows: 73, white rots; 12, brown cubical rots; and 5, brown stringy rots. The decay type associated with decay pattern 4 was uncertain and not included.

Seventy-three decay and 64 soft rot isolates obtained from the 92 dissected poles were grouped by associated decay patterns within three age classes (0-18. 19-36, and 37-52 years) for inferences as to time and location of the initial invasion. *Coriolus versicolor, B. adusta,* and *I. lacteus* were associated both with non-check-related center and in-between patterns 5 and 6, and check-related in-between pattern 3. Eight isolates of these three species (21 obtained) came from the inner untreated portion of the poles with no discernible defect connection with outer pole zones. *Phlebia brevispora, Poria placenta,* the "chain-chlamydospore" taxon, and *Sistotrema* sp., on the other hand, were associated consistently with patterns 1.2, and 3 (defect patterns adjacent to the pole surface or check-related). Of the infrequent Basidiomycete decayers in these poles, nineteen were associated with the check-related defects and six with untreated inner pole zone defects. A majority of the decay isolates were obtained from the poles in service for 20 years or longer. Generally, the isolation frequency of decay fungi was low from poles with advanced decay or brown cubical rots.

Scytalidium lignicola and *Alternaria alternata* were associated frequently with the ring shake defect (pattern 4) in the intermediate age class. The other five soft rot fungi were isolated only from defect patterns 1 and 2 located in outer-treated

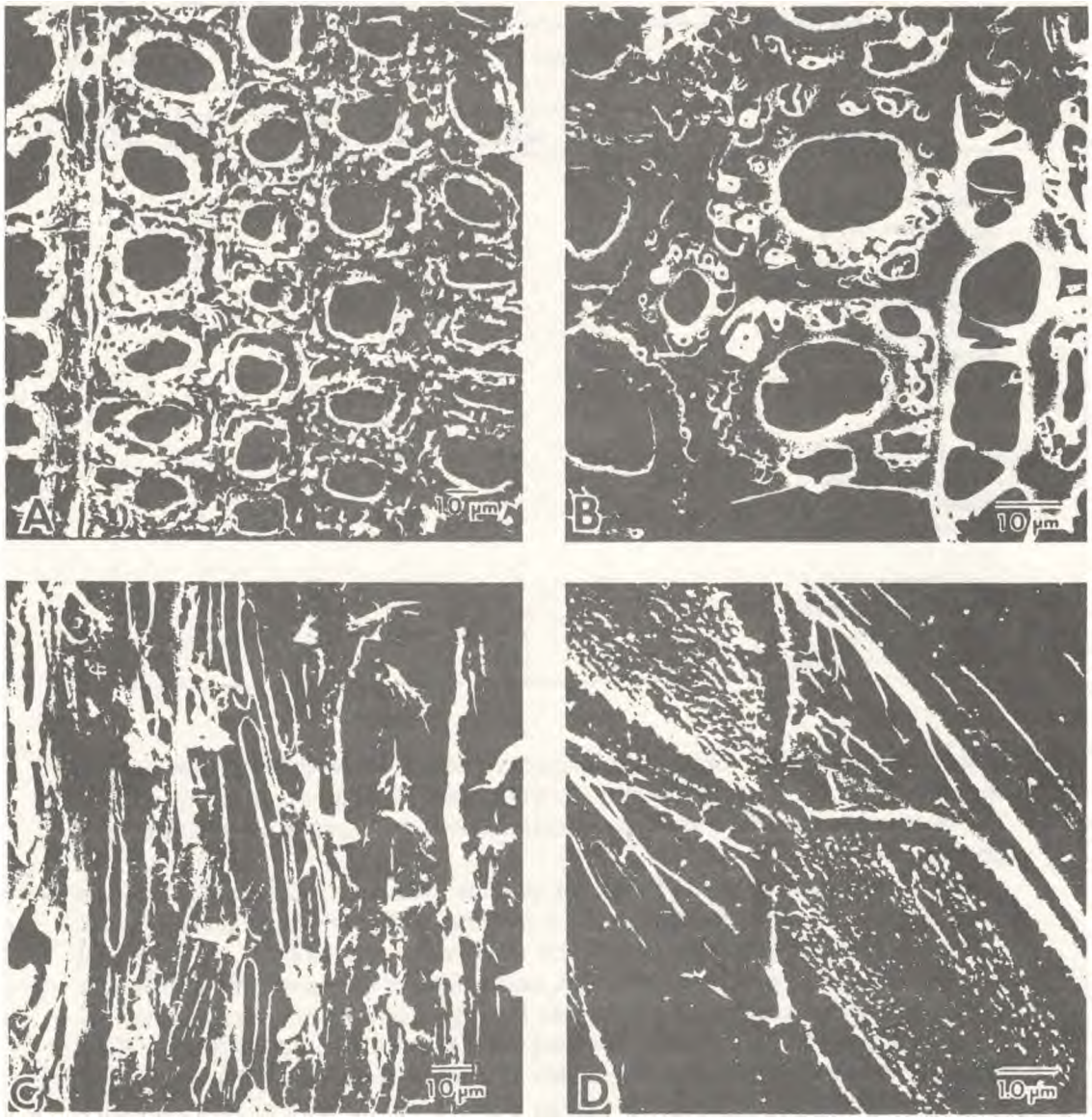

FIG. 1. Type 1 soft rot damage detected in a creosote-treated southern pine pole. The pole (Class 5-35′) was treated in 1957 and installed in western New York. The decayed zone was at the groundline about 2 cm from the outer surface. A. A cross section showing extensive cell-wall damage associated with longitudinal bore hole formation (SEM 500 x). B. An enlarged version showing early damage and the longitudinal bore holes in the inner S2 wall and associated thick walled hyphae (SEM 1.000 x). C. A radial section cut through the early-latewood boundary zone showing longitudinal cavities in chains (SEM 600 x). D. An enlarged version showing a hypha in a longitudinal bore hole and the typical conical zones (SEM 10,000 x).

TABLE 5. *The tolerances and sensitivities of pole inhabiting fungi to creosote and penta. The isolates are grouped by fungus type and listed within each group in order of increasing tolerance based on the growth inhibition concentrations.*[a]

Species or taxon	Penta (μm/ml)[b] 50% growth reduction	Penta (μm/ml)[b] Growth inhibition	Species or taxon	Creosote (mg/ml)[c] 50% growth reduction	Creosote (mg/ml)[c] Growth inhibition
Basidiomycete Decayers					
Coriolus versicolor	1.2	*2.2*	*Coriolus versicolor*	0.3	0.5
Bjerkandera adjusta	1.2	2.5	*Hyphoderma praetermissum*	0.3	0.5
Poria placenta	1.4	2.8	*Irpex lacteus*	0.3	1.1
Irpex lacteus	1.8	3.8	*Bjerkandera adusta*	0.8	1.6
Hyphoderma praetermissum	1.5	3.0	*Phlebia subserialis*	0.8	1.7
Phlebia subserialis	1.0	12.0	*Poria placenta*	0.3	5.5
Soft Rot Decayers					
Taxon 121	3.0	*5.0*	*Scytalidium lignicola*	0.5	1.6
Phialocephala dimorphospora	2.3	5.2	*Phialophora heteromorpha*[d]	0.8	5.0
Leptodontium elatius	3.1	6.4	*Alternaria alternate*	0.2	8.0
Alternaria alternate	*1.7*	12.5	*Leptodontium elatius*	0.3	9.0
Scytalidium lignicola	5.6	16.0	Taxon 121	1.8	10.0
Phialophora heteromorphad	5.7	*19.0*	*Phialocephala dimorphospora*	0.2	13.0
Microfungi					
Cladosporium resinae	0.7	5.3	*Exophiala mansonii*	0.5	1.2
Exophiala mansonii	3.5	5.6	*Rhinocladiella atrovirens*	0.3	7.0
Rhinocladiella atrovirens	2.4	12.0	*Cladosporium resinae*	1.0	50.0

[a]Values are the average growth diameters of six replicates per preservative concentration after seven days of incubation at 28 C. The values were determined by extrapolation from dosage response curves.

[b]Pentachlorophenol was technical grade (86% pentachlorophenol), Aldrich Chemical Co.

[c]The creosote was provided by U.S. Steel Corp.; specific gravity. 1.089 at 38 C; water percent volume. 0.7; and xylene insolubles. 0.28%.

[d]Comparative values included with author permission from a related study (Morrell 1981).

positions. *Alternaria alternata* and *Phialocephala dimorphospora* were obtained in highest frequency from the oldest poles (37-52 years).

Anatomical verification of soft rot damage

Type 1 damage was detected in 20 of 35 poles studied anatomically. It was found generally in outer-treated portions of poles in the groundline zone. It was associated frequently with the ring shake decay (pattern 4) and with the soft exterior surface of older poles. Anatomical evidences were generally sporadic in the sections studied. The bore holes were detected most readily in latewood tracheids in the vicinity of rays. It was found only in creosote-treated poles and throughout the eastern region. Examples of typical soft rot damage observed are presented (Fig. 1).

Sensitivities of selected major fungi to penta and creosote

The fungi exhibited a wide range in tolerance to creosote or penta (Table 5). The soft rot fungi were generally more tolerant to the preservatives than the Basidiomycete decayers. *Cladosporium resinae,* the most tolerant fungus to creosote, was isolated primarily from creosote-treated poles at all service ages. *Rhinocladiella atrovirens* was isolated primarily from penta poles, which may be related

to its high tolerance to this toxicant. Also, *Phlebia subserialis,* which was most tolerant to penta, was isolated only from penta-treated poles.

DISCUSSION AND CONCLUSIONS

The approximately 80 species or taxa identified or described from many isolates indicate that a large and diverse mycoflora is present in the groundline zone of treated southern pine poles (Tables 1, 2). The major decay fungi that appeared in 4 or more poles are listed in Table 3. There is always some uncertainty about the validity of isolation frequency as an indicator of relative importance. The isolation process may miss important fungi. Some fungi may be favored by the isolation methodology. With these limitations in mind, nonetheless, isolations are a useful first step towards determining the significant fungi potentially involved in the preservative depletion and decay process.

The Basidiomycete decayers isolated in greatest frequency from the large region-wide sample of creosote- or penta-treated poles were white rot fungi. The preponderance of the white rot type in the decay defects associated with these poles supports the isolation pattern. This suggests that white rot fungi may play a greater role in decay development in poles than has been recognized. This is in opposition to the findings in a recent survey of treated Douglas-fir poles in the Northeast in which nearly two-thirds of the decay isolates were brown rotters (Zabel et al. 1980). In this case, however, the majority of the brown rot fungi were isolated from untreated pole zones and *Coriolus versicolor.* a white rotter, was found most frequently in outer-treated zones. *Irpex lacteus* and *Bjerkandera adusta* (white rotters) were associated with decay development in western red cedar shingles and shakes (Smith and Swenn 1975). We speculate that the high frequency of white rot fungi in creosote- and penta-treated poles may be related to their lignin decomposing abilities, permitting them to adjust to higher levels of toxic phenolic moieties in wood. The isolations of *Phlebia brevispora, C. versicolor, Poria placenta, Ptychogaster rubescens,* and the *Sistotrema* sp. from this study are in accord with reports on the Basidiomycetes associated with decay in pine poles (Eslyn 1970). *Lentinus lepideus* Fr. and *Fibroporia vaillantii* (DC. : Fr.) Parm., reported as frequent in pine poles in the Northeast, were not found. An explanation may be that most of the poles sampled in this study were still in service and many at early decay stages. Regular pole maintenance practices generally rapidly replace visibly defective poles. so our sampling approach missed cases of advanced decay or failed poles. Also the pole sections studied here were restricted to the groundline zone.

The large number of infrequently appearing species or taxa of Basidiomycete decayers from region to region suggests that many opportunistic fungi may be involved with decay development in poles under varying circumstances. An interesting example was the single isolate of *Rigidoporus vitreus* obtained in this study and reports of its widespread occurrence in foundation piling in the Netherlands (Bech-Anderson and Harmesen 1980). The isolation of many Basidiomycete decayers, which were not readily identifiable from current cultural identification data, suggests that other important taxa may be involved in decay development in poles and neglected because of identification difficulties. The identification of the six species in the monokaryon phase is an example, and was

solved primarily because of the availability of a bank of monokaryon cultures maintained at the Forest Products Laboratory.

Eleven species or taxa of the 211 microfungi isolated were demonstrated to be capable of causing substantial soft rot attack in southern pine test blocks (Table 1). Four were in the genus *Phialophora.* This genus has been reported to contain many soft rot fungi (Nilsson and Henningsson 1978). We speculate that soft rot fungi may be causing more decay damage in treated pine poles in the eastern United States than is generally recognized. Anatomical study indicated Type 1 soft rot damage in 21 of 30 poles. This is a conservative number since Type 2 damage could not be reliably distinguished from possible associated decay caused by Basidiomycete fungi. Three of the fungi isolated commonly *(Alternaria alternata, Laptodontium elatius,* and *Epicoccum nigrum)* caused only Type 2 damage in the test blocks. The soft rot fungi were isolated primarily from the outer-treated zones of the creosote poles.

A large number of species or taxa of microfungi were isolated from the poles (Table 2). Many were taxa that could not be reliably resolved below class or generic levels. A taxon described as "black yeasts" was also obtained 29 times from 23 poles. These isolates, characterized by an appressed slow, slimy growth pattern could not be resolved readily to genus and were associated frequently with bacteria.

On the basis of frequency and/or preservative tolerances, several microfungi were judged to be potentially significant in modifying the wood substrate or interacting with other fungi (Tables 2, 5). *Cladosporium resinae* and *Paecilomyces varioti* were isolated frequently from the creosote-treated poles. It is reported that these fungi may play a role in creosote depletion (Marsden 1954; Kerner-Gang 1976).

The geographic distribution of the major fungi suggests that a rather limited decay mycoflora is distributed widely and consistently associated with treated southern pine poles in service in the eastern United States.

The isolation frequency of the Basidiomycete decayers by radial position, when analyzed by pole age, suggests two origins in poles (Table 4). The frequency of Basidiomycete decayers was highest in the outer-treated positions and increased with age. This probably represents an *outside-in* invasion pattern resulting from slow preservative depletion and check extension. The early appearance of some decayers in untreated zones and subsequent increase in outer-treated zones with pole age may be cases of pre-invasion and escape from preservative treatment forming *inside-out* development patterns. The analysis of decay development in the 92 dissected poles suggests that patterns 5 and 6 may have this origin. The isolation frequency and decay pattern analysis also demonstrate many cases where decay develops initially in the outer-treated zones and is often check-related as in patterns 1, 2, and 3.

In contrast, most soft rot fungi appeared early primarily in outer-treated zones. Their outside-in pattern may be related to high preservative tolerances to creosote (Table 5). *Scytalidium lignicola* appears to invade subsequently the untreated pole zones. Taxon 121 and *Leptodontium elatius* are exceptions and initially were recovered from inner-untreated zones and outer-treated zones only in the oldest poles.

The defect patterns in the 92 dissected poles were complex and often several types were present in a single pole. The patterns were similar generally to those described previously in utility poles (Shigo et al. 1977). Most were small localized defects largely restricted to the groundline zone (0.5-1 m vertically) and extended beyond only in the case of a few hollow hearts in older poles. The localized nature and erratic locations of many decay defects in pole cross sections suggest the probability of frequent "misses" when the detection of early decay relies on a single boring or increment core.

This study identifies the major fungi associated with decay development in southern pine poles. Elucidation of the relative roles and interactions of the Basidiomycete decayers, soft rot fungi, and microfungi in the decay process in treated poles is a complex and challenging problem for the future. Its further study and clarification may lead to more reliable decay detection methods and effective prevention approaches.

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REFERENCES

BECH-ANDERSEN, J., AND L. HARMESEN [HARMSEN]. 1980. Pole fungus A. Pages 78-82 *in* T. A. Oxley, G. Becker, and D. Allsopp, eds.. Biodeterioration. Proc. Fourth Int. Biodeterior. Symp.; 1978 August—September. Berlin. London: Pitman Publ. Ltd. 375 pp.

CARRANZA, JULIETA. 1979. Fungi associated with creosoted pine utility poles in New York. SUNY College of Environmental Science and Forestry. Master's thesis. 83 pp.

CORBETT, N. H. 1965. Micro-morphological studies on the degradation of lignified cell walls by Ascomycetes and Fungi Imperfecti. J. Inst. Wood Sci. 14:18-29.

COWLING, E. B. 1957. A partial list of fungi associated with decay of wood products in the United States. Plant Dis. Rep. 41(10):894-896.

DAVIDSON, R. W., W. A. CAMPBELL, AND D. J. BLAISDELL. 1938. Differentiation of wood-decaying fungi by their reactions on gallic or tannic acid medium. J. Agric. Res. 57:683-695.

_____, AND D. B. VAUGHN. 1942. Fungi causing decay of living oaks in the eastern United States and their cultural identification. U.S.D.A. Tech. Bull. No. 785.65 pp.

DUNCAN, C. G. 1960. Wood attacking capacities and physiology of soft rot fungi. U.S.D.A. For. Serv., For. Prod. Lab. Rep. No. 2173.28 pp.

_____. 1961. Relative aeration requirements by soft rot and Basidiomycete wood-destroying fungi. U.S.D.A. For. Serv., For. Prod. Lab. Rep. No. 2218.6 pp.

, AND F. F. LOMBARD. 1965. Fungi associated with principal decays in wood products in the United States. U.S.D.A. For. Serv. Res. Paper WO-4. 31 pp.

ESLYN, W. E. 1970. Utility pole decay II. Basidiomycetes associated with decay in poles. Wood Sci. Technol. 4:97-103.

GRAHAM, R. D., T. C. SCHEFFER, G. G. HELSING, AND J. D. LEW. 1976. Fumigants can stop internal decay of Douglas-fir poles for at least 5 years. For. Prod. J. 26(7):38-41.

HENNINGSSON, B., T. NILSSON, P. HOFFMEYER, H. FRIIS-HANSEN, L. SCHMIDT. AND S. JAKOBSEN. 1976. Soft rot in utility poles salt treated in the years 1940-1954. Swedish Wood Pres. Inst. No. 117 E. 135 pp.

KERNER-GANG, W. 1976. Effect of micro-organisms on creosote. Mat. und Holz Beiheft 3:319-330.

LEIGHTLEY, L. E. 1978. Soft rot fungi found in copper-chrome-arsenic treated hardwood power transmission poles in Queensland. Int. Res. Group on Wood Pres., DOC No. IRG/WP/185.

MARSDEN, D. H. 1954. Studies on the creosote fungus. *Hormodendrum resinae.* Mycologia 46:161-183.

MORRELL, J. J. 1981. Soft rot fungi: Their growth requisites and effects on wood. SUNY College of Environmental Science and Forestry. Ph.D. Thesis. 161 pp.

NAKASONE, K. K., AND W. E. ESLYN. 1981. A new species, *Phlebia brevispora.* a cause of internal decay in utility poles. Mycologia 73:803-810.

NILSSON, T. 1973. Studies on wood degradation and cellulolytic activity of microfungi. Studia Forestalia Sueica Nr. 104, Stockholm. 40 pp.

_____, AND B. HENNINGSSON. 1978. *Phialophora* species occurring in preservative treated wood in ground contact. Mat. und Org. 13(4):298-313.

POLISHOOK, J. D. 1982. The fungal flora of untreated and recently treated utility poles of southern yellow pine. SUNY College of Environmental Science and Forestry. Master's Thesis. 54 pp.

SHIGO, A. L., W. C. SHORTLE. AND J. OCHRYMOWYCH. 1977. Detection of active decay at groundline in utility poles. For. Ser. Gen. Tech. Rep. NE-35, For. Ser. U.S.D.A. 26 pp.

SMITH. R. S.. AND G. W. SWENN. 1975. Colonization and degradation of western red cedar shingles and shakes by fungi. Org. und Holz 3:253-262.

WILCOX, W. W. 1964. Preparation of decayed wood for microscopical examination. U.S.D.A. For. Serv., For. Prod. Lab. Res. Note FPL-056. 22 pp.

_____.1970. Anatomical changes in wood cell walls attacked by fungi and bacteria. Bot. Rev. 36(1): 1-28.

ZABEL, R. A., F. F. LOMBARD. AND A. M. KENDERES. 1980. Fungi associated with decay in treated Douglas-fir transmission poles in the Northeastern United States. For. Prod. *J.* 30(4):51-56.

_____.C. J. K. WANG, AND F. C. TERRACINA. 1982. The fungal associates. detection, and fumigant control of decay in treated southern pine poles. Electrical Power Research Institute. Project 1471-1. Final Report. 93 pp.