FUNGI CAUSING ABOVE-GROUND WOOD DECAY IN STRUCTURES IN CALIFORNIA

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ABSTRACT

Decay fungi were isolated and identified from decayed wood above-ground in structures in California. It was an opportunistic sample made available by a number of individuals dealing with decay problems throughout the state. An attempt was made to isolate as large a number of different decay fungi as possible from the limited sample material available. The total number of fungi involved in above-ground decay appeared to be small, and the list of fungi was almost identical with the list of fungi isolated from green lumber prior to use. This suggested the possibility that most of the fungi responsible for structure decay were present in the green lumber when the structure was built. Effects on distribution of decay by type of structure, location in structure, structure age, sub-structure construction and type of siding are reported, along with the frequency of structural defects and moisture problems promoting decay. Structures with slab-on-grade and stucco siding appeared to be the most vulnerable to decay. These data suggest an explanation for why California, with a low calculated Scheffer Climate Index, has decay problems of far greater severity than predicted by the Index.

Keywords: Wood decay, structures, above-ground, basidiomycetes.

INTRODUCTION

California imports over half of the framing lumber it uses (McWilliams and Goldman 1994). Because nearly all framing lumber is used green on the West Coast, the opportunity exists to import decay fungi not endemic to the region of the building and build them into a structure by using preinfected lumber without benefit of the sterilization that should accompany kiln-drying. Although decay fungi, presumably, would become inactive upon air-drying of the infected lumber, the fungi would be expected to become dormant, rather than dying (Cartwright and Findlay 1958; Zabel and Morrell 1992), and be available to resume growth whenever the lumber again became wet. Because historically the focus of decay studies has been primarily upon wood in ground contact, where the perceived decay hazard is greatest, little is known about the fungi that cause decay specifically in above-ground locations in the United States (Cowling 1957; Duncan and Lombard 1965).

The following questions formed the basis for the research reported here:

1. Is the number of fungi responsible for decay above-ground in California structures large or small?
2. Are they, generally, the same fungi as those causing decay in ground contact?
3. Does the distribution of fungi in above-ground decay appear related more to the geographic location of the structure or the source of the lumber?

4. What similarity exists between the fungi primarily responsible for above-ground decay and those decay fungi encountered in green lumber in transit?
5. What are the fungi primarily responsible for decay above-ground in structures in California?

LITERATURE REVIEW

Two of the most comprehensive lists of fungi associated with decay in wood in use offer little information on which fungi may cause decay out of ground contact (Cowling 1957; Duncan and Lombard 1965). The species most associated with structures by Duncan and Lombard were *Meruliporia incrassata, Gloeophyllum trabeum, Paxillus panuoides,* and *Antrodia vaillantii.* Research on Douglas-fir poles in the Pacific Northwest found decay fungi present even in freshly felled trees, with *Antrodia carbonica* and *Postia placenta* among the most frequent isolates (Graham and Corden 1982; Morrell et al. 1987, 1988; Przybylowicz et al. 1987). Gilbertson and Neuhauser (1981) isolated 10 fungi, all brown-rotters, from Douglas-fir timbers deep in a Nevada mine tunnel and suggested that the fungi may have come with the timbers in the form of resistant spores or mycelium. Their most frequent isolates were *Paxillus panuoides* and *Antrodia carbonica.* Morrell et al. (in press), in a study of decay fungi present in Douglas-fir poles during air-seasoning, reported isolating most frequently *Postia placenta, Peniophora* spp., *Stereum hirsutum, Phanerochaete sordida,* and *Sistotrema brinkmanii,* after a 3-month exposure; after 6 months, *Postia placenta* and *Stereum hirsutum* were the only identifiable decay fungi isolated in large numbers. Zabel et al. (1980) reported that the most frequently isolated decay fungi from preservative-treated Douglas-fir utility poles in the northeastern U.S., *Antrodia carbonica* and *Postia placenta,* were not common to the area of use. The presence of these fungi was attributed to successful colonization during the air-seasoning process at the pole origin in the Pacific Northwest and survival through the pressure-treatment process.

MATERIALS AND METHODS

Pest control operators, contractors, homeowners calling for help with problems, and neighborhood observation were the primary sources of decayed wood, making this more of an opportunistic, than systematic, sample. Although an attempt was made to secure samples from a variety of geographic and environmental sites, given the meager resources and the size of the problem, it was impossible to organize the sampling in either a systematic or randomized manner. Nevertheless, samples were obtained from 32 of California's 58 counties. When fresh (still moist) decayed wood was available, samples were taken and information about their location and conditions of service was recorded. In addition, retail lumber yards and construction sites where lumber had recently been delivered were visited, and samples were taken from green lumber showing obvious decay.

Sampling for decay fungi was performed either in the laboratory or in the field. A number of locations were sampled in each piece of decayed wood available. The laboratory procedure consisted of selecting areas that contained the boundary between apparently sound and obviously decayed wood, swabbing the surface with 70% ethanol, raising a surface chip with a flamed chisel, removing several small wood chips from the underneath surface with a flamed wood-carver's gouge, and plating the chips on 2% malt agar. For sampling in the field, the sampling site was swabbed with 70% ethanol, and a core was removed with a flamed increment borer and flamed extractor directly into a sterile plastic bag. Upon return to the laboratory, pieces of the core were sliced with a flamed razor blade, flamed lightly, and aseptically plated on 2% malt agar. Some plates also contained 20 ppm benomyl, to favor decay fungi over mold and stain fungi. Isolates that appeared to be possible decay fungi were transferred to malt agar tubes, or-

TABLE 1. *Basidiomycete fungi isolated from decay in wood exposed above-ground in structures in California.*

Fungal taxon[1]	Type of structure and number of isolations[2]			
	Commercial	Multi-family	Single-family	Total
Antrodia carbonica (Overh.) Ryv. & Gilbn.	6	1	16	23
Antrodia sinuosa (Fr.) Karst.	1		1	2
Antrodia vaillantii (Fr.) Ryv.	3	5	5	13
Antrodia xantha (Fr.) Ryv.		2	2	4
Coniophora puteana (Schum.:Fr.) Karst.		1		1
Fomitopsis cajanderi (Karst.) Kotl. et Pouz.		1		1
Fomitopsis rosea (Alb. & Schw.:Fr.) Karst.	1			1
Gloeophyllum sepiarium (Fr.) Karst.	1	9	6	16
Gloeophyllum trabeum (Fr.) Murr.	1	10	9	20
Phanerochaete sordida (Karst.) Burt		1		1
Pleurotus ostreatus (Jacq.:Fr.) Kummer		1		1
Postia placenta (Fr.) M. Lars. & Lomb.	2	3	10	15
Unknown basidiomycete	1	2	2	5
Total	16	36	51	103

[1] The fungi are listed alphabetically by name according to the currently proposed nomenclature. Because of recent flux in the nomenclature and taxonomy of basidiomycete fungi, the scientific names formerly in common use have not been used. Dietz (1994) (Appendix A) contains a synonymous listing of these fungi with the source literature, as well as other fungi mentioned throughout the text.

[2] Commercial structures include: churches, schools, restaurants and other public gathering buildings; multi-family structures refers to either apartment buildings or condominium complexes; single-family refers to single-family homes.

ganized into groups based upon cultural characteristics, and a representative of each group was studied following the methods of Nobles (1948, 1965) and Stalpers (1978). Decay capacity of each selected isolate was confirmed using a modified agar plate test modeled after the European Standard Method (EN-113, 1982). After tentative identification was made, isolates were compared with identified cultures from the collections of the U.S. Forest Products Laboratory and the Eastern Forest Products Laboratory of Forintek. All isolates reported here were either verified or identified by the Center for Forest Mycology Research at the U.S. Forest Products Laboratory.

RESULTS

Table 1 lists the wood-decay fungi isolated and their frequency of occurrence in various types of structures. Most isolates (65%) were obtained from Douglas-fir lumber. Twelve identified species of wood-decay fungi and 5 decay fungi of unknown identity were obtained from 103 successful isolations of basidiomycete fungi from above-ground decay in structures. Of the twelve, the 5 isolated most frequently, in decreasing order of occurrence, were: *Antrodia carbonica, Gloeophyllum trabeum, Gloeophyllum sepiarium, Postia placenta,* and *Antrodia vaillantii.* There was no evidence of association of any species with any particular geographic region.

Table 2 lists these same fungi with reference to the part of the structure from which they were obtained. Expressed as a percentage of the total isolates for each given fungus, the fungi most frequently isolated from exterior exposure were *Gloeophyllum sepiarium* (88%), *Gloeophyllum trabeum* (89%), *Antrodia carbonica* (70%), and *Postia placenta* (73%), while those most frequently isolated from interior locations were *Antrodia vaillantii* (54%), *Antrodia carbonica* (30%), and *Postia placenta* (27%).

The locations in the structure where decay fungi were isolated most frequently were decks (20%) and attics (15%) (Table 3). Based upon 5-year age groupings, the highest percentage of isolates was obtained from buildings in the 6- to 10-year age class (Table 4). Buildings with slab-on-grade construction (67%) and stucco siding (30%) yielded the greatest number of isolates (Table 5) and, therefore, appear to be at greatest risk of decay

TABLE 2. *Number of decay fungi isolated from above-ground decay in various rooms or parts of structures.*

	Interior exposures						Exterior exposures							
Fungal taxon	Attic	Bathroom	Kitchen	Living room	Garage	Total interior	Deck/patio	Glulam beam	Roof	Siding	Stairs	Trim boards	Window/door	Total exterior
Antrodia carbonica	3	2	1	1		7	5	1	2	1	2	3	2	16
Antrodia sinuosa	1					1			1					1
Antrodia vaillantii	5				2	7	2	1	1			1	1	6
Antrodia xantha				1		1	1					1	1	3
Coniophora puteana					1	1								
Fomitopsis cajanderi										1				1
Fomitopsis rosea									1					1
Gloeophyllum sepiarium					2	2	5	2		2	1	3	1	14
Gloeophyllum trabeum	1			1		2	8	2	1	1	1	2	3	18
Phanerochaete sordida								1						1
Pleurotus ostreatus				1		1								
Postia placenta	3			1		4	3		1	2	4	1		11
Unknown basidiomycete	1					1	3				1			4
Total isolations	14	2	1	5	5	27	27	7	7	7	9	11	8	76

TABLE 3. *Number of decay fungi isolated from above-ground decay in various locations in structures in California.*

	Type of structure and number of isolations			
	Commercial	Multi-family	Single-family	Total
Attic	8	2	5	15
Bathroom			3	3
Bedroom		1		1
Deck		8	13	21
Glulam beam		5		5
Garage		4	4	8
Kitchen	1		2	3
Living/family room	2	1	5	8
Patio	2	3	1	6
Roof	3	1	3	7
Siding		5	2	7
Stairs (Exterior)		1	8	9
Trim boards		5	5	10
Total	16	36	51	103

among structure types in California. Decay in the building interior also was highest (48% of isolates from the interior) in structures with both slab-on-grade foundation and stucco siding. The most common source of moisture associated with decay was direct precipitation in the form of rain, fog, dew, or landscape irrigation; the most common moisture-related problem was leakage through roofs or siding. The most frequent building defects found associated with decay were short roof overhangs allowing runoff onto exposed wood (23 cases), lack of maintenance (17 cases), leaky roofs (15 cases), inadequate ventilation (13 cases), and landscape irrigation wetting (12 cases) (Table 6).

Decay fungi also were isolated from lumber

TABLE 4. *Proportion of decay fungal isolates by the age of the structure.*

Age of structure (years)	Proportion of total decay fungi isolated (%)
0–5	14
6–10	36
11–15	26
16–20	12
21–25	8
26–30	4

TABLE 5. *Number of decay fungi isolated from above-ground decay in buildings associated with various types of siding and sub-structure construction.*

Type of siding	Type of sub-structure					Total
	Crawl space	Full basement	Pier	Slab-on-grade	Split level	
	Number of isolates					
Aluminum	1			1		2
Asbestos shingle	1			1		2
Cedar plywood				1		1
Cedar shakes	2			2		4
Douglas-fir plywood	3			12	1	16
Hardboard lap	3			11		14
Hardboard panel				6	1	7
Masonry block		1		3		4
Stucco	4	1	2	22	2	31
Wood lap	7	1		10	4	22
Total isolations	21	3	2	69	8	103

in storage or recently delivered to construction sites. Ten species of wood-decay fungi and one unidentified decay fungus were isolated from 32 specimens of green Douglas-fir lumber. Of the 10 identified species, the most frequently isolated, in decreasing order of occurrence, were *Antrodia vaillantii, Postia placenta, Gloeophyllum trabeum,* and *Antrodia carbonica* (Table 7). Although all of these fungi appear on the lists of principal fungi from both exterior and interior exposures in structures, the ranking matches most closely the interior list.

TABLE 6. *The type and frequency of structural defects and moisture-related problems in buildings from which decay fungi were isolated.*

Type of defect or problem	Number of occurrences[1]
Bathroom or clothes drier vented into enclosed spaces	2
Caulking missing or incomplete	5
Cracks in stucco siding	6
Decks or roofs improperly joined to the main structure	5
Flashing around penetrations missing or used improperly	8
Hose or sprinkler wetted wood	12
Lack of general preventive maintenance	17
Leaks in plumbing	2
Leaks in roof	15
Moisture drainage into the structure	4
Paint failure	2
Short or no roof overhang, roof runoff	23
Siding defects: exposed corners, open joints	4
Untreated, unpainted or nondurable lumber in exterior exposures	6
Vapor membranes mis-applied or lacking	5
Ventilation insufficient, restricted or lacking	13

[1] Does not add up to 103 because many buildings had more than one type of defect or moisture-related problem.

Although several white-rot fungi were isolated from above-ground decay in this study, all of the fungi identified above as being the fungi most frequently isolated are brown-rot fungi.

DISCUSSION

The results of this study suggest that the number of fungi causing economically important above-ground decay in structures in California is small and that the fungi responsible for building decay are, to a great extent, the same fungi present in the green lumber from which the buildings were built. The most frequently isolated fungi, *Antrodia carbonica, Gloeophyllum trabeum, Gloeophyllum sepiarium, Postia placenta,* and *Antrodia vaillantii,* accounted for 85% of the total isolates obtained from building decay. All of these fungi share a reputation, or potential, for being serious wood destroyers. Because of the opportunistic nature of the sampling, and the small size of the sample as compared with the enormity of the decay problem in California, this

TABLE 7. *Basidiomycete fungi isolated from new construction or lumber inventory stacks at retail sales outlets and construction sites in California.*

Fungal taxon	Number of isolations
Antrodia carbonica (Overh.) Ryv. & Gilbn.	4
Antrodia vaillantii (Fr.) Ryv.	7
Cerioporiopsis rivulosa (Berk. & Curt.) Gilbn. & Ryv.	1
Fomitopsis rosea (Alb. & Schw.:Fr.) Karst.	1
Gloeophyllum sepiarium (Fr.) Karst.	1
Gloeophyllum trabeum (Fr.) Murr.	5
Lentinus lepideus Fr.	2
Postia placenta (Fr.) M. Lars. & Lomb.	7
Sistotrema brinkmannii (Bres.) J. Erikss.	1
Trametes versicolor (L.:Fr.) Pilát	2
Unknown basidiomycete	1
Total	32

cannot be construed as an exhaustive list of the fungi responsible for all above-ground decay in California. However, the consistent nature of the results argues favorably for their significance.

All of the identified isolates have been reported previously in association with decay in structures or various wood products. Two of the five isolates found most often, *Gloeophyllum sepiarium* and *Gloeophyllum trabeum,* are well-known wood product destroyers. They are frequently associated with decay in wood exposed above-ground, frequently associated with decay in a variety of wood species, including Douglas-fir (Eslyn 1970; Graham and Corden 1980; Zabel et al. 1980) and enjoy a ubiquitous distribution (Cartwright and Findlay 1958; Duncan and Lombard 1965). These two fungi, which are able to withstand intermittent desiccation and prefer higher temperatures (>35°C) for optimum growth than most other structural wood-destroyers, are most likely to be important in the decay of exterior wood. Furthermore, they have been reported to survive up to 10 years in air-dry wood (Cartwright and Findlay 1958). In the present study, these two fungi were isolated substantially more often from decay in the externally exposed wooden members of buildings than from interior locations (Table 2), consistent with many other reports worldwide.

Antrodia carbonica and *Postia placenta* are both recognized wood destroyers, particularly in Douglas-fir, and are found especially in wood in ground contact (Eslyn 1970; Graham and Corden 1980; Zabel et al. 1980). They have not often been reported as wood destroyers in the above-ground portions of buildings. However, they have been cited as frequent colonizers of Douglas-fir poles in air-seasoning yards (Graham and Corden 1982; Morrell et al. 1987; Przybylowicz et al. 1987). Douglas-fir lumber and plywood accounted for 79% of the total decayed samples studied here, and *Antrodia carbonica* was the most frequent isolate from Douglas-fir. In addition, 82% of the *Antrodia carbonica* and *Postia placenta* isolates came from Douglas-fir lumber or plywood. The overall fungal population and distribution found in this study may have been quite different were it not for the preponderance of Douglas-fir used for framing in California.

Others have suggested the role in building decay played by preinfected lumber (DeGroot 1976; Lindgren 1955; Verrall 1952, 1956, 1957; Viitanen and Ritschkoff 1991), and careless handling of lumber prior to its being built into the structure (Wilcox 1986; Wilcox and Rosenberg 1982), but little documentation has been available.

CONCLUSIONS

This study has presented evidence that, at least in a region that depends upon green lumber for its framing, the fungi primarily responsible for above-ground decay in structures are the same species present in the wood used to build the structures. The difference between exterior and interior exposure alters the frequency of occurrence, with species able to withstand higher temperatures and periodic desiccation favored in exterior exposure and those requiring high moisture content favored indoors; but exposure appears not to introduce new species. These results call into question the role played by spores and air-borne hyphal fragments in the initiation of above-ground decay at the building site. Study of the available fungal flora in areas surrounding various building sites and remote sawmills and logging sites would have to be performed in order to completely exclude the role of spores in building decay above-ground; but the correspondence reported here in the lists of fungi in retail lumber and in structures suggests that this role may be small. In this case, if we are interested in reducing above-ground decay in structures, we should concentrate more on sources of moisture to support decay than on sources of inoculum. Common sense challenges the notion that a fragile basidiospore could make its way through doors, windows, or vents, around studs or plates, and through insulation, to encounter wet wood in the interior of a wall and there induce decay. It is much easier to accept the thesis that water can make this journey to the interior of a wall and there induce the growth of a dormant fungus already present. These data also suggest that, where green lumber and above-ground decay are concerned, building-related sources of water may have more to do with the potential for decay than the climate to which the exterior is exposed, offering an explanation for the dichotomy between the severe decay problem encountered in California and the region's low rating in the Scheffer Climate Index (Scheffer 1971).

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REFERENCES

CARTWRIGHT, K. ST. G., AND W. P. K. FINDLAY. 1958. Decay of timber and its prevention. Her Majesty's Stationery Office, London, UK. 332 pp.

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

DEGROOT, R. C. 1976. Wood decay ecosystem in residential construction. Pages 334–352 *in* Trees and Forests for Human Settlements. Proc., P1.05-00 Symposium of the XVIth IUFRO World Congress (Vancouver, B.C., 11–12 June 1976 and Oslo, Norway, 22 June 1976). Center for Urban Forestry Studies, University of Toronto, Ontario, Canada.

DIETZ, M. G. 1994. Above-ground wood decay in structures in California. Ph.D. dissertation, University of California at Berkeley, CA. 112 pp.

DUNCAN, C. G., AND F. F. LOMBARD. 1965. Fungi associated with principal decays in wood products in the United States. USDA Forest Serv., Forest Prod. Lab. Report No. WO-4. Madison, WI.

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

EUROPEAN TESTING STANDARDS. 1982. Wood preservatives. Determination of the toxic values against wood destroying basidiomycetes cultured on an agar medium. Standard EN-113 (BS6009). British Standards Institute, London, UK.

GILBERTSON, R. L., AND K. S. NEUHAUSER. 1981. Wood-rotting fungi in structural timbers at the NTS. Sandia National Laboratory. SAND 81-1538. Unlimited release, 19 pp.

GRAHAM, R. D., AND M. E. CORDEN. 1980. Conserving energy by safe and environmentally acceptable practices in maintaining and procuring transmission poles for long service. A cooperative pole research program, Oregon State University, Corvallis, OR. Annual Report.

———, AND ———. 1982. Conserving energy by safe and environmentally acceptable practices in maintaining and procuring transmission poles for long service. A cooperative pole research program, Oregon State University, Corvallis, OR. Second Annual Report. June 1982.

LINDGREN, R. M. 1955. Decay in exterior millwork. Forest Prod. J. 5(3):163–164.

MCWILLIAMS, B., AND G. GOLDMAN. 1994. The forest products industries in California: Their impact on the state economy. Division of Agriculture and Natural Resources, University of California. 30 pp.

MORRELL, J. J., M. E. CORDEN, R. D. GRAHAM, B. R. KROPP, P. PRZYBYLOWICZ, S. M. SMITH, AND C. M. SEXTANT. 1987. Basidiomycete colonization of air-seasoned, Douglas-fir poles. Pages 284–296 *in* Proc., 83rd Annual Meeting of the American Wood-Preservers' Association, Toronto, Canada.

———, M. A. NEWBILL, C. M. SEXTON, AND A. R. ZAHORA. 1988. Fungal colonization of preservative treated Douglas-fir poles during storage. Forest Prod. J. 38(1):21–22.

———, C. M. FREITAG, S. SMITH, M. E. CORDEN, AND R. D. GRAHAM. 1997. Pretreatment decay in Douglas-fir poles: Basidiomycete colonization after 3 or 6 months of air-seasoning. Forest Prod. J. (in press).

NOBLES, M. K. 1948. Studies in forest pathology. VI. Identification of cultures of wood-rotting fungi. Can. J. Res., C 26:281–431.

———. 1965. Identification of cultures of wood-inhabiting Hymenomycetes. Can. J. Bot. 43:1097–1139.

PRZYBYLOWICZ, P. R., B. R. KROPP, M. E. CORDEN, AND R. D. GRAHAM. 1987. Colonization of Douglas-fir poles by decay fungi during air-seasoning. Forest Prod. J. 37(4):17–23.

SCHEFFER, T. C. 1971. A climate index for estimating potential for decay in wood structures above ground. Forest Prod. J. 21(10):25–31.

STALPERS, J. A. 1978. Identification of wood-inhabiting Aphyllophorales in pure culture. Studies in Mycology. No. 16: Centraalbureau Voor Schimmelcultures, Baarn. 248 pp.

VERRALL, A. F. 1952. Recent investigations on the avoidance of decay in exterior woodwork of buildings. J. Forest Prod. Res. Soc. 2(1):32--33.

———. 1956. Non-pressure preservative treatments for exterior woodwork of buildings. Forest Prod. J. 6(11): 17A–18A.

———. 1957. How to prevent fungus damage to wood structures. Forest Prod. J. 7(1):15A–17A.

VIITANEN, H., AND A. C. RITSCHKOFF. 1991. Brown rot decay in wooden constructions. Effect of temperature, humidity, and moisture. Rapport—Institutionén för Virkeslära. Sveroges Lantbruksuniversitet. No. 222, 57 pp.

WILCOX, W. W. 1986. Wood: Decay during use. Pages 5412–5416 *in* M. B. Bever, ed. Encyclopedia of Materials Science and Engineering. Pergamon Press, New York, NY.

———, AND A. F. ROSENBERG. 1982. Architectural and construction deficiencies contributing to decay of wood in buildings, or how not to build with wood and why. Pages 246–255 *in* R. W. Meyer and R. M. Kellogg, eds. Structural uses of wood in adverse environments. Van Nostrand Reinhold Co.

ZABEL, R. A., AND J. J. MORRELL. 1992. Wood microbiology. Academic Press, Inc., San Diego, CA. 476 pp.

———, F. F. LOMBARD, AND A. M. KENDERES. 1980. Fungi associated with decay in treated Douglas-fir transmission poles in the northeastern United States. Forest Prod. J. 30(4):51–56.