Addressing Marketplace Durability Issues with Post-Mountain Pine Beetle Lodgepole Pine – A Compilation of Three Reports

Tony Byrne and Adnan Uzunovic

Mountain Pine Beetle Initiative
Working Paper 2005-25

Forintek Canada Corp.
2665 East Mall
Vancouver, BC V6T 1W5

Mountain Pine Beetle Initiative PO # 8.06

Natural Resources Canada
Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, British Columbia V8Z 1M5
Canada

2005

Printed in Canada

Abstract

This is a compilation of three reports addressing marketplace durability issues with products made from post mountain pine beetle (MPB) lodgepole pine. The first report covers the establishment of the field tests. The second report reviews the nature of bluestain, and differences between stain, mold and decay. A third report is a more general fact sheet suitable for customers or users of spruce-pine-fir lumber containing bluestained pine. The information in this compilation will enable producers and marketers of spruce-pine-fir to address perceptions they encounter in the marketplace.

Lodgepole pine lumber from trees that have been attacked by the MPB displays bluestained sapwood, which has been found to have much higher permeability than non-stained sapwood. Two long-term field tests were established to determine whether the higher permeability would affect the decay resistance of the wood. First, an "L-joint" test, based on the American Wood Preservers' E-9 Standard test method was established with 10 replicate mortice and tenon joints made of bluestained lodgepole pine sapwood, and 10 replicates made of non-stained lodgepole pine sapwood. The second test, a "sandwich" test, consists of 10 replicate, three-piece sandwich units prepared from bluestained lodgepole pine sapwood, non-stained lodgepole pine sapwood, lodgepole pine heartwood from bluestained lumber, lodgepole pine heartwood from non-stained lumber, and non-stained Scots pine sapwood. Six and one half months after installation, the Scots pine sandwich units were showing signs of deterioration due to white rot. Only a slight trace of wood-decaying fungus was noted on one bluestained lodgepole pine sample, the others were free of visible signs of decay.

In scientific literature, clear distinctions are made between the types of fungi that colonize wood, starting with the staining fungi and molds which do not cause structural deterioration of wood substance, and ending with various wood-decaying fungi that can cause severe structural damage to the wood. The bluestain fungi associated with the MPB are primary colonizers of fresh wood, causing dis*color*ation but not deterioration. Although they are sometimes mistaken for other wood colonizing fungi, they differ biologically and morphologically from molds and black yeasts that also discolor wood, and from soft-rotting fungi and decay fungi that destroy wood. They also differ from tropical bluestain fungi that can cause strength loss.

Key words: bluestain, lodgepole pine, durability, mold, decay-resistance

Résumé

Le présent document est une compilation de trois rapports consacrés à la viabilité commerciale des produits tirés du bois de pins tordus latifoliés tués par le dendroctone du pin ponderosa (DPP). Le premier rapport traite des essais réalisés sur le terrain. Le deuxième examine la nature du bleuissement et précise les différences qui existent entre le bleuissement, les moisissures et la carie. Le troisième est un feuillet d'information plus général conçu à l'intention des clients ou des utilisateurs de bois EPS (épinette-pin-sapin) contenant du pin bleui. Les renseignements présentés dans cette compilation aideront les producteurs et les commerçants de bois EPS à mieux comprendre les perceptions qui circulent sur le marché.

L'infestation des pins tordus latifoliés par le DPP entraîne le bleuissement de l'aubier et un accroissement de sa perméabilité. Des chercheurs ont effectué deux essais de longue durée sur le terrain afin de déterminer si cet accroissement compromet la résistance à la carie de l'aubier. Le premier essai, dit « essai d'assemblage en L », a été réalisé en dix répétitions, conformément à la norme E9 de l'American Wood Preservers' Association, avec des assemblages à tenon et mortaise d'aubier bleui et d'aubier non bleui de pin tordu latifolié. Le deuxième essai, également réalisé en dix répétitions, prévoyait l'utilisation d'assemblages trois couches de type Sandwich préparés à partir d'aubier bleui de pin tordu latifolié, d'aubier non bleui de pin tordu latifolié, de duramen de bois bleui de pin tordu latifolié, de duramen de bois non bleui de pin tordu latifolié et d'aubier non bleui de pin sylvestre. Six mois et demi après leur installation, les assemblages en aubier de pin sylvestre présentaient des signes de détérioration due à la carie blanche. Par comparaison, une seule pièce de bois bleui de pin tordu latifolié présentait une très faible trace de carie.

Dans la littérature scientifique, une distinction très nette est établie entre les divers types de champignons qui colonisent le bois, d'abord entre les champignons et les moisissures qui causent une décoloration du bois sans altérer la structure de la substance ligneuse, puis entre les divers champignons de la carie qui provoquent une importante détérioration de la substance ligneuse. Les champignons du bleuissement associés au DPP sont des colonisateurs primaires du bois frais qui causent une décoloration mais n'entraînent aucune détérioration structurale de la substance ligneuse. Bien qu'ils soient parfois confondus avec d'autres champignons colonisant le bois, ils diffèrent par leur biologie et leur morphologie des moisissures et des levures noires qui causent également une décoloration du bois et des champignons de la carie spongieuse et autres agents fongiques de la carie qui détruisent le bois. Ils diffèrent également des espèces tropicales de champignons du bleuissement qui provoquent une réduction de la résistance du bois.

Mots-clés : bleuissement, pin tordu latifolié, viabilité, moisissure, résistance à la carie

1 Introduction

Bluestained sapwood is the most immediately visible characteristic of forest products made from lodgepole pine attacked by the mountain pine beetle (MPB). Although bluestain is accepted in North American National Lumber Grades Authority lumber grading rules for most construction grade lumber, some markets require that bluestained wood be absent or kept to a minimum. One example is the Japanese market, where the premium "J-grade" lumber permits little or no bluestain to be present.

Bluestain may be regarded as visually undesirable but there is no evidence that the integrity of post-MPB bluestained wood has been compromised. In fact, post-MPB bluestained wood has been characterized as having essentially the same strength properties as non-stained wood (Lum 2003) which would not be the case if the wood contained decay. However, according to scientists at the Japan Forestry and Forest Products Research Institute, Japanese consumers equate bluestain to the first stage of decay and question whether the wood is sound. They report that Japanese customers traditionally associate bluestained wood with logs that have been stored under conditions that are conducive to decay. The different origin of MPB bluestain is discussed elsewhere (Solheim 1995). However, since the increased permeability of this wood has been reported (McFarling and Byrne 2003) the question has arisen as to whether the bluestain predisposes lodgepole pine wood to decay more readily than non-stained wood.

If bluestained wood holds moisture in-service, it may spend a longer time above the threshold of about 25% moisture content where decay can occur. This could result in slightly higher susceptibility to decay, but whether a slight increase in susceptibility to decay for this wood is of practical significance is questionable. Lodgepole pine sapwood is classified as "perishable" and will rot if used in wet locations, whether it is stained or not. However, at the moment there are no data on the subject. To examine durability, two field test methods for testing wood in non-soil contact were selected. Even though these tests are designed to trap water in the test assemblies and are accelerated over normal end-uses, significant decay of the test woods normally takes a minimum of three years to develop. The first report in this compilation covers the establishment of the field tests. Preliminary evaluation suggests that the field tests will generate data showing that any difference in susceptibility to decay would be of no practical significance.

The second attachment is a scientifically documented technical report on the nature of bluestain, and differences between it and mold and decay. The results should alleviate the Japanese perceptions that bluestained wood is decayed or moldy.

The third attachment is a summary factsheet suitable for customers. It is broader than the durability issue and is meant to address additional questions/issues around bluestained lumber identified by the Council of Forest Industries:

- Can the bluestain in beetle-killed SPF spread without the presence of the MPB?
- Is the MPB killed in lumber processing?
- Can the fungi be spread from bluestained lumber into the living space?
- Can allergies be caused by bluestained lumber?

- Can bluestain cause lumber to decay?

The summary factsheet is backed up by thoroughly researched technical documents. The three reports in this compilation will enable the producers and marketers of spruce-pine-fir to address perceptions they encounter in the marketplace.

2 Project Objectives

1. To establish accelerated durability field tests that compare bluestained and non-bluestained lodgepole pine sapwood.

2. To review scientific literature and produce a technical report on the nature of bluestain in post-MPB wood and the differences between bluestain and mold and decay.

3. To summarize scientific information on market issues with bluestained wood in the form a factsheet suitable for distribution to North American customers and for translation for Japanese customers of Canadian spruce-pine-fir lumber.

3 Research Methods and Results

Three separate reports are given in Attachments 1 to 3, covering the research methods and results obtained for the objectives listed above.

4 Conclusions

- Long-term field tests of bluestained and non-stained lodgepole pine were established. Six and a half months after installation, the Scots pine sapwood reference material is demonstrating early signs of deterioration due to white rot while the lodgepole pine, stained and non-stained sapwood, was virtually free of decay.

- In scientific literature, clear distinctions are made between the types of fungi that colonize wood, starting with the staining fungi and molds which do not cause structural deterioration of wood substance, and ending with various wood-decaying fungi that can cause severe structural damage to the wood.

- The bluestain fungi associated with the MPB are primary colonizers of fresh wood, causing discoloration but not deterioration. Although they are sometimes mistaken for other wood colonizing fungi, they differ biologically and morphologically from molds and black yeasts that also discolor wood, and from soft-rotting fungi and decay fungi that destroy wood. They also differ from tropical bluestain fungi that can cause strength loss.

5 Acknowledgements

This project was funded by the Government of Canada through the Mountain Pine Beetle Initiative, a six-year, $40 million Program administered by Natural Resources Canada –

Canadian Forest Service. Publication does not necessarily signify that the contents of this report reflect the views or policies of Natural Resources Canada – Canadian Forest Service.

6 References

Lum, C. 2003. Characterising the mechanical properties of wood containing beetle-transmitted bluestain. Forintek Canada Corp. Report to Forestry Innovation Investment Program. Vancouver, B.C.

McFarling, S.; Byrne, A. 2003. Characterizing the dimensional stability, checking, and permeability of wood containing beetle-transmitted bluestain. Forintek Canada Corp. Report to Forestry Innovation Investment Program. Vancouver, B.C.

Solheim, H. 1995. Early stages of blue-stain fungus invasion of lodgepole pine (*Pinus contorta*) sapwood following mountain pine beetle attack. Canadian Journal of Botany 73(1): 70–74.

Contacts

- Adnan Uzunovic, Mycologist, Durability and Protection Group, Forintek Canada Corp. (Project Leader). Phone: 604-222-5729, e-mail: adnan@van.forintek.ca

- Tony Byrne, Wood Protection Scientist, Durability and Protection Group, Forintek Canada Corp. Phone: 604-222-5650, e-mail: byrne@van.forintek.ca

Attachment 1

Setting Up of Accelerated Decay Tests

Tony Byrne and Paul Morris

Forintek Canada Corp.
2665 East Mall
Vancouver, BC V6T 1W5

Table of Contents

List of Tables

List of Figures

7 Introduction

With the advent of the extensive mountain pine beetle (MPB) outbreak in British Columbia, a large amount of bluestained lodgepole pine is finding its way into the spruce-pine-fir lumber and plywood markets. Bluestain may be regarded as visually undesirable but there is no evidence that the integrity of post-MPB bluestained wood has been compromised in mechanical properties (Lum 2003). However, the wetting properties of post-MPB sapwood are different, and McFarling and Byrne (2003) reported increased permeability of this wood. The question has arisen as to whether bluestain predisposes lodgepole pine to decay more than non-stained wood. If bluestained wood wets more readily or holds moisture in-service it may spend a longer time above the threshold of about 25% moisture content where decay can occur. This could result in slightly higher susceptibility to decay, but whether a slight increase in susceptibility to decay for this wood is of practical significance is questionable. Lodgepole pine sapwood is already classified as "perishable" and will rot if used in wet locations, whether it is stained or not. However, at the moment there are no data on the subject. This project initiated data generation on the decay resistance of bluestained post-MPB and non-stained lodgepole pine. To do this, two field test methods—one a standard test and one a new method—for testing wood in non-soil contact were selected. Though these tests are designed to trap water in the test assemblies and are accelerated over normal end-uses, significant decay of the test woods normally takes a minimum of three years.

8 Objective

To establish accelerated durability field tests that compare bluestained and non-bluestained lodgepole pine sapwood.

9 Materials and Methods

In July 2004, kiln-dried nominal 2 x 4 in. and 2 x 6 in. lodgepole pine lumber, heavy to sapwood, both bluestained and non-stained, was collected from 15 BC Interior sawmills. These mills were all processing mountain pine beetle-killed trees. At Forintek's Vancouver laboratory, the pieces were sorted and 30 were selected for cutting test samples for two outdoor exposure tests. The 30 pieces of wood represented 30 different trees. The wood was conditioned indoors at 25°C and about 30% relative humidity. When it had conditioned to about 8% moisture content two types of samples, "sandwich" units and L-joints, were prepared from the wood. The first type was a set of assemblies, similar to those reported by Morris et al. (2004), each consisting of three wood samples 25 mm thick x 85 mm wide x 305 mm long. The three samples were stacked together, wide face on wide face to form a "sandwich" held together with two stainless steel clips along one edge.

The sandwich units were made from five types of test material, with 10 replicates of each:

1. bluestained lodgepole pine sapwood,
2. non-stained lodgepole pine sapwood,
3. lodgepole pine heartwood from a bluestained piece of lumber,
4. lodgepole pine heartwood from a non-stained piece of lumber, and
5. non-stained Scots pine sapwood.

The wood for the Scots pine samples originated from a freshly harvested 30-year-old tree grown at the University of BC Research Forest in Maple Ridge, BC. The Scots pine wood was oven-dried rather than kiln-dried and, due to raw material limitations, cut into test samples that were slightly smaller (23 mm x 80 mm x 305 mm). The 50 sandwich units were labelled, weighed and installed on September 27, 2004. They were placed on edge, in random order, supported at either end on aluminums racks with the bottom edge 20 cm above the ground and with the metal clips on the bottom (Figure 1). Ground cover was thin grass and low-growing weeds maintained by periodic mowing. With the exception of the Scots pine, it was not possible to obtain sandwich units of 100% of each target material type. Estimates of what proportion of the total wood that was true to target type were made.

The second type consisted of mortice and tenon "L-joints" made according to the AWPA Standard E-9 (AWPA 2001). The joints were prepared from clear 38 x 38 mm stock cut from the lumber pieces. The mortice and tenon arms of the joint were both 308 mm long. After pressing them together the whole joint was painted with one coat of white water-based latex primer followed by one coat of white exterior latex topcoat. When the finish had dried, the paint film at the joints was broken apart and then the joints were reassembled. The joints were installed on pre-existing racks with the tenon member on the bottom shelf and the mortice member in contact with the backboard of the rack (Figure 2). There was a slight slope on the shelf carrying the joints so that water would run down the tenon and seep into the joint, thereby exaggerating the decay hazard.

The test units will be inspected annually. They are probed for decay and rated using the AWPA E9 scale of 0 – 5, where 0 is sound and 5 is failure due to decay (AWPA 2001). A preliminary examination of the test samples was done at the time of writing this report, 6.5 months after the field tests were set up. The results are described in Section 4.

Figure 1. General appearance of sandwich tests in field exposure at set-up.

Figure 2. General appearance of L-joint test in field exposure at set-up.

10 Results and Discussion

On September 27, 2004, the sandwich and L-joint tests were set up as described under Section 3.1 and shown in Figures 1 and 2. The tests were designed to monitor the progression of decay in the wood. Decay is caused by basidiomycete fungi which are the climax of the early stages of succession. These fungi are usually preceded by other organisms which tend to colonize in the following sequence: bacteria, molds, bluestain fungi, soft-rot fungi (AWPA 2001).

Progression of micro-organisms towards eventual rotting of the wood was first evident—starting with the appearance of molds on the Scots pine sapwood sandwich units—less than two weeks after the first rain (October 8, 2004). Similar growth on lodgepole pine sapwood and heartwood samples was slower to initiate but staining fungi and molds started to be visible on these units six weeks after the first rainfall.

The general appearance of the sandwich units four months after installation is shown in Figure 3. Evidence of white rot deterioration on the Scots pine sandwich units after six months of exposure led to the decision to complete an interim inspection of the field test material and not wait until the first anniversary of the installation before inspecting them (Figure 4). At this stage the inspection of the field test generated the results shown in Table 1. At that time the Scots pine sapwood sandwich units were showing the first stages of white rot damage, however there was no softening in the wood at that stage. The early onset of decay was unexpected because the slightly smaller size of the Scots pine samples should make them dry faster after rain and therefore deteriorate more slowly. Because of the occurrence of basidiomycete fungi on the wood surface, the Scots pine units were each rated an average of one (out of five) for a mean of 1.0 for the 10 replicates. The rating of one means "signs of slight surface decay (trace)" (AWPA 2001). One sample showed fruiting bodies of an unidentified basidiomycete fungus (Figure 5). With one exception, the lodgepole pine sandwich units were rated 0. The exception (rated 1) resulted in a mean rating of 0.1 for the set of bluestained lodgepole pine sapwood units compared to 0.0 for the non-stained sapwood and the heartwood test units (Table 1).

Figure 3. Close up of typical sandwich test units four months after installation. The Scots pine units are fourth and seventh from the left.

Figure 4. Probing a Scots pine sample for decay after 6.5 months of exposure. White-rot damage is visible on ends of component pieces.

Figure 5. Fruiting body of wood-decaying basidiomycete fungus on Scots pine sandwich unit after 6.5 months of field exposure.

Figure 6. Appearance of typical bluestained L-joint after 6.5 months of field exposure.

Table 1. Mean ratings for decay of sandwich units after 6.5 months of field exposure

10.1.1.1.1.1 Wood Type	Mean Rating for Decay (out of 5.0)
Bluestained lodgepole pine sapwood	0.1
Non-stained lodgepole pine sapwood	0.0
Heartwood from MPB-killed lodgepole pine	0.0
Healthy lodgepole pine heartwood	0.0
Scots pine sapwood	1.0

Inspections of the L-joints after approximately 6.5 months of exposure showed ratings of 0.0 for softening caused by decay on both bluestained and non-stained lodgepole pine sapwood. However, small amounts of growth of fresh staining fungi were found in the joint areas of all 10 bluestained wood test samples, but no such growth was apparent in the non-stained L-joints.

Both tests will continue to be inspected annually for decay and reports will be produced as part of Forintek's on-going field testing project.

11 Conclusion

Long-term field tests of bluestained and non-stained lodgepole pine were established. Six-and-a-half months after installation, the Scots pine sapwood reference material is demonstrating early signs of deterioration due to white rot, while the lodgepole pine, stained and non-stained sapwood, was virtually free of decay.

12 Acknowledgements

This project was funded by the Government of Canada through the Mountain Pine Beetle Initiative, a six-year, $40 million program administered by Natural Resources Canada – Canadian Forest Service. Publication does not necessarily signify that the contents of this report reflect the views or policies of Natural Resources Canada – Canadian Forest Service.

13 References

American Wood Preservers' Association (AWPA). 2001. AWPA book of standards. Standard field test for the evaluation of wood preservatives to be used in non-soil contact. Standard E9-97. p 422-425.

Lum, C. 2003. Characterising the mechanical properties of wood containing beetle-transmitted bluestain. Forintek Canada Corp. Report to Forestry Innovation Investment Program. Vancouver, B.C.

McFarling, S.; Byrne, A. 2003. Characterizing the dimensional stability, checking, and permeability of wood containing beetle-transmitted bluestain. Forintek Canada Corp. Report to Forestry Innovation Investment Program. Vancouver, B.C.

Morris, P.I., Ingram, J.K., Ruddick, J.N.R. and Choi, S.M.. 2004. Protection of untreated wood by adjacent CCA-treated wood. Forest Products Journal 54(3): 29-32.

Contacts

Tony Byrne, Wood Protection Scientist, Durability and Protection Group, Forintek Canada Corp.
Phone: 604-222-5650, e-mail: byrne@van.forintek.ca

Paul Morris, Group Leader Durability and Protection, Forintek Canada Corp.
Phone: 604-222-5651, e-mail: paul@van.forintek.ca

Attachment 2

Comparative Technical Review of Bluestain, Mould and Wood-Decaying Fungi

Adnan Uzunovic and Tony Byrne

Forintek Canada Corp.
2665 East Mall
Vancouver, BC V6T 1W5

Table of Contents

List of Tables

List of Figures

14 Summary

Wood is a biodegradable organic material and may get colonized by fungi before or during its service life. The degree and type of colonization depend on a number of factors, among which moisture content is key. Bluestain is the most common wood discoloration caused by a group of fungi that grow inside or on the surface of moist sapwood. The mountain pine beetle (MPB - *Dendroctonus ponderosae*) that in British Columbia is currently reaching historically epidemic proportions and threatening to extend further into boreal forests, carries several bluestain fungi including *Ophiostoma clavigerum* and *Ophiostoma montium* in specialized organs called mycangia. These fungi are typical bluestain fungi and this text on bluestain relates fully to them. Their hyphae (thread-like cells) and sporing structures are darkly pigmented and are responsible for the permanent blue/grey colour of affected sapwood. Bluestain fungi typically do not cause any change in wood structure. Once the fungus utilizes the simple carbon and nitrogen sources within the wood cells it loses its viability and dies. Similar, and often confused with bluestain, are mold fungi, represented by numerous species, some some of which may appear on the wood surface as spots or multi-coloured downy masses. Molds do not cause structural damage to the wood but are unsightly surface discolorations. In comparison to bluestain fungi that cause grayish to dark black-blue tones, molds may display an array of colours including light buff, green, yellowish, pinkish to darker grey, brown or black. Mold spores are dry and easily disturbed and carried by the air, while the wet and sticky bluestain spores are mostly disseminated by wood-infesting insects. Although some mold fungi are allergenic, and the presence of mold may cause health concerns, bluestain is not associated in the scientific literature with health issues. Under prolonged wetness, warm conditions and low aeration, some fungi might cause surface softening of wood (soft rot). Wood-decaying fungi typically develop and cause rot if the wood is subjected to elevated moisture for a prolonged period of time. The spores are easily disseminated by air and once established the decay fungi are able to grow and digest wood cell components. Wood-decaying fungi are important recyclers of wood and thus significantly affect wood integrity. Which fungi will grow and the extent to which they will grow and affect the wood is determined by the initial and subsequent moisture content, handling, maintenance or misuse. If wood is dried properly and maintained below 20% moisture it may remain in-service for centuries. Wood preservation, using various wood treatments and processes, is also an option in situations where wood is repeatedly exposed to water.

15 Introduction

Wood is a natural renewable material and, therefore, is environmentally beneficial. Being organic makes it prone to being used as a food source by micro-organisms. This will not occur if healthy trees are harvested and milled and the wood is dried and remains dry. However, deterioration may initiate quickly if conditions are suitable. One of the most significant factors is moisture. Under wet conditions, a range of organisms including insects, fungi, and bacteria will naturally colonize wood. Some organisms do not affect the strength of the wood, living on readily available food that is not part of the wood structure itself. Other organisms are more aggressive and use wood substance for food, thus speeding up the process of recycling.

When using wood as a building material, it is necessary to have some understanding of the effects of these different micro-organisms on wood properties. In British Columbia the mountain pine beetle (*Dendroctonus ponderosae*) is currently reaching historically epidemic proportions and threatening to extend further into the boreal forests across the Rocky Mountains. The mountain pine beetle (MPB) carries several bluestain fungi, usually including *Ophiostoma clavigerum* and *Ophiostoma montium* (Six 2003a; Kim *et al*. 2005). Due to the high volume of bluestained wood coming into the marketplace the public is asking questions about bluestain and its significance. There is a misconception that stained wood is the first sign of decay or that it helps decay to develop. Bluestain is sometimes confused with molds, which are associated with potential health issues. However, the bluestain fungi associated with the MPB are readily distinguished from all the other micro-organisms that can grow on wood.

16 Objective

To review scientific literature and produce a technical report on the nature of bluestain in post-MPB wood and the differences between bluestain, mold and decay.

17 Materials and Methods

This report is based on a review of the scientific literature in Forintek's library as well as material obtained through database searches. The literature was selected to differentiate between bluestain with emphasis, where possible, on bluestain caused by the fungi carried by the MPB or related fungi, and other fungal deterioration.

Numerous literature sources cover these extensively studied topics. There are several reviews and summaries of the original scientific work and we opted to quote significant reviews or books rather than a plethora of original papers. Some key papers are also referenced. Micrographs were produced using a Zeiss, Axioplan 2 microscope or were obtained through the Pulp and Paper Research Institute of Canada (Paprican).

18 Results

Filamentous fungi (having a body mass made out of hyphae) growing on wood are conveniently divided into five major groups based on their basic biology and the effect they have on wood. These are bluestain fungi, black yeasts, molds, soft-rot fungi and wood-decaying fungi (Table 1). However, as with other biological systems, the divisions between these groups are not rigid and there are numerous fungi that could fit into more than one group depending on the conditions under which they are growing. The effects they produce are bluestain, black stain, mold discoloration, soft-rot and decay respectively. This paper focuses on the types of damage they cause and typical characteristics of each group.

Table 1. Characteristics of the major groups of fungi that may colonize wood

	Bluestain Fungi	**Black Yeasts**	**Molds**	**Soft-rot Fungi**	**Wood-Decaying Fungi**
Substrate and environment	Trees, logs, green lumber, -re-wetted KD lumber	Mostly wood in-service, finishes	Logs, green lumber, rewetted KD lumber, wood in-service	All types of timber. Treated wood. Under prolonged wet and warm conditions, often in soil contact	Trees, logs, lumber, wood in-service, prolonged moisture above 25%
How do they get there?	Via insects, water, machinery	Air, water, insects	Mostly air	Soil, air, water	Mostly air, through roots and soil, water
Appearance on wood	Bluish black stain inside the wood. Fungus only visible when alive on wet wood, as dark surface whiskers.	Surface black stain. When wet, often slimy black streaks. When dry, appears as black dots or streaks.	Fungi appear as woolly or powdery, multicolored raised spots. Close up, they appear as intertwined filamentous masses	Fungi not visible on the surface. Wood surface is soft. When surface dries it develops numerous fine cracks.	Fungi appear as white to creamy fan-shaped, cotton-like strands, conks and mushrooms. Affected wood appears white and softened or dark brown, with cubical crack, soft when wet or crumbly to touch when dry.
Effects on wood	Deep discoloration, affects appearance. Occasionally discoloration confined to surface only. No significant strength change though permeability of sapwood increased.	Surface discoloration and/or finish deterioration	Surface discoloration only	Decomposition affects wood structure	Decomposition affects wood structure
Market concerns	Reluctance to buy discolored	Appears in exterior wood	Reluctance to buy moldy	Possible failure of	Possible premature

	Bluestain Fungi	**Black Yeasts**	**Molds**	**Soft-rot Fungi**	**Wood-Decaying Fungi**
	product	in-service.	products, health concerns	structure over long term	failure of structure
Common genera	*Ophiostoma* *Ceratocystis* *Leptographium* *Sphaeropsis*	*Aureobasidium* *Hormonema* *Exophiala*	*Penicillium* (g) *Cladosporium* (b) *Trichoderma* (g) *Mucor* *Epicoccum* (r, b) *Acremonium* (w) *Botrytis* (gr) *Aspergillus* (m) *Alternaria* (gr)	*Chaetomium* *Lecythophora* *Phialophora*	*Bjerkandera* (w.r.) *Trametes* (w.r.) *Phlebiopsis* (w.r.) *Pleurotus* (w.r.) *Stereum* (w.r.) *Schizophyllum* (w.r.) *Antrodia* (b.r.) Coniophora (b.r.) *Gloeophyllum* (b.r.) *Lentinus* (b.r.) *Serpula* (b.r.) *Oligosporus* (b.r.)

For molds: g=green; b=black, r=red; w=white; gr=grey
For decay: w.r. = white-rot fungus; b.r. = brown-rot fungus

18.1 Bluestain

Bluestain is the most prevalent cause of sapwood discoloration wherein the normal color of wood is changed as a result of fungal growth. Bluestain appears on log cross-sections as wedge-shaped blue or grey streaks penetrating the sapwood radially (Figure 1). It also may appear on the surface of stored green lumber where the discoloration is typically superficial and does not penetrate deeper than a few millimetres (Seifert 1993; Gibbs 1993). The fungi associated with the MPB are classified as bluestain fungi, microfungi that have the darkly pigmented hyphae responsible for the blue or grey stain in most or all of the sapwood. Little is known about the biology of the specific MPB fungal associates but they appear to have characteristics fairly typical of other softwood-colonizing bluestain fungi found in temperate climates. Bluestain fungi are primary colonizers of wood in the standing tree, felled logs and green lumber. Bluestain is sometimes referred to as sapstain, although some people argue that the term "sapstain" may also include discoloring molds and enzymatic or mineral stains. Thus, we recommend not using the term "sapstain" for the discoloration caused by bluestain fungi. Taxonomically, bluestain fungi are described under the genera *Ceratocystis*, *Ophiostoma* and *Leptographium* in temperate climates. In warmer, subtropical/tropical climates *Sphaeropsis* and *Botryodiplodia* are common causes of bluestain.

Figure 1. Bluestain showing wedge-shaped patterns in lodgepole pine sapwood (left) and as revealed in edge-glued lumber panel (right).

When wood is moist, bluestain fungi grow into it in the form of pigmented hyphae (threads), and can sporulate on the surface, producing darkly pigmented hair-like fruiting bodies, usually less than 2 mm tall (Figure 2). Pigment deposited on hyphal walls and in the fruiting bodies has been found to be brown colored melanin (Kitamura and Kondo 1958; Fengel and Wagener 1989). The blue color visible to the naked eye is an optical effect caused by diffraction of light through the mycelium growing in the wood (Münch 1907). Bluestain fungi utilize the easily assimilated nutrients, mostly simple sugars, starch, and triglicerides found in medullary ray and parenchyma cells. They do not possess extracellular enzymes capable of degrading the cell wall structure (Fleet et al. 2001; Mathiesen 1950; Käärik 1960). Once the fungi have utilized the food sources within the wood cells they typically lose viability and die. They grow longitudinally through vessels and tracheids, penetrating laterally from one cell to another through bordered pits (Figure 3). Occasionally, they physically penetrate cell walls by the mechanical activity of small penetrating hyphae that resume their normal width once through the cell wall (Hubert 1921; Liese and Schmid 1962, 1964). The rates of tangential and radial growth are slower than the longitudinal extension that can be close to 20 mm per day (Uzunovic and Webber 1998).

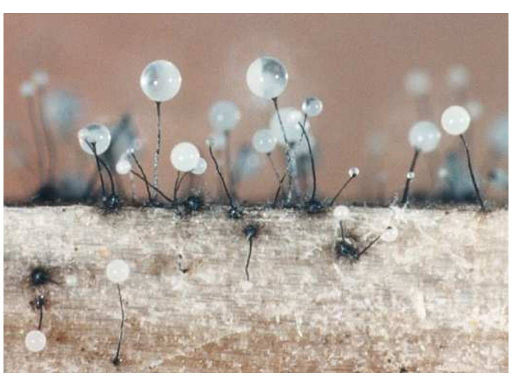

Figure 2. Fruiting bodies of surface bluestain fungi on green lumber. Note masses of slimy spores (left - 30x) and dark pigmentation (right - 200x).

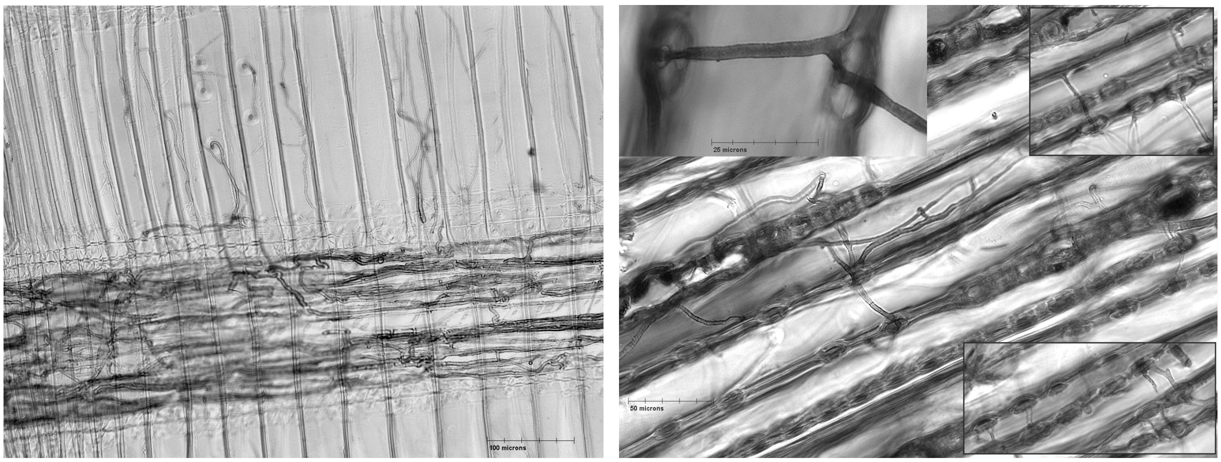

Figure 3. Hyphae of MPB-vectored bluestain fungi preferentially growing in the nutrient-rich ray cells (left - 200x) and growing through bordered pits (right - 400x). Note no wood cell wall damage is apparent.

As primary colonizers, bluestain fungi, including the MPB associates, are tolerant of the trees' defence mechanisms and the high moisture content found in standing trees and freshly felled logs. The minimum moisture content level required to support bluestain growth is reported to be slightly above the fibre saturation point (Etheridge 1957; Colley and Rumbold 1930; Lindgren 1942); however, fungi associated with MPB require much higher moisture contents to grow (Forintek Canada Corp. unpublished data). Staining fungi do not, in general, survive long in air-dried wood as compared with some of the wood-decaying species (Scheffer and Chidester 1948).

From early work it is known that bluestain fungi are seldom, if ever, carried via air currents (Lagerberg et al. 1927; Verrall 1941). This distinguishes them from molds or decay fungi that have mostly air-dispersed spores. Dowding (1969) proved experimentally that the spores of bluestain fungi are rarely dislodged by dry air currents but are readily dislodged by splash droplets, suggesting this might be important for local dissemination. Mechanical equipment, especially harvesters, may also play a significant role in stain dissemination, as during tree harvesting the stain inoculum present on the bark and other debris is pushed deeper into the sapwood. Mechanical harvesters also puncture, loosen and remove patches of bark, providing access to sound wood for a range of insects that bring stain inoculum with them (Uzunovic et al. 2004). However, spores of many bluestain fungi are most efficiently disseminated by arthropods, especially bark beetles and ambrosia beetles (Nelson and Beal 1929; Leach et al. 1934). Bluestain spores are embedded or extruded in a slimy mucilage matrix that keeps them in clusters and makes them sticky. This enables the spores to adhere easily to the exoskeleton of passing insects that then play a role in casual dissemination of the fungus. However, the association between insects and fungi can be very complex. Highly developed relationships exist between the bark and ambrosia beetles and bluestain fungi. These insects have developed special spore-carrying structures called mycangia (Batra 1963). The beetle-fungus associations are seldom limited to one fungus per beetle species; more often there are two or more fungi associated with each beetle type. Some of these associations have been studied extensively and there are several recently published reviews (Norris 1979; Jacobs and Wingfield 2001; Six 2003a; Lieutier et al. 2004). New associations are being discovered continuously. The MPB carries several bluestain fungi including *Ophiostoma clavigerum* and *Ophiostoma montium* in specialized mycangia (Six 2003b, Kim et al. 2005).

Bluestain produced by the MPB has little effect on the wood properties and this is reflected in lumber grading rules. Bluestained wood is routinely used for construction in North America and around the world. Recent Forintek Canada Corp. tests of MPB-vectored, bluestained wood vs non-stained wood confirmed there is no practical difference in strength between stained and non-stained lodgepole pine (Lum 2003; Forintek Canada Corp. 2003). This is consistent with findings from other laboratories on bluestain on other wood species (Schirp et al. 2003). Older research shows that there is a slight strength loss, improvement, or no change at all in the mechanical properties of bluestained wood (Eusebio 1962; Findlay 1939; Mejer 1946; Radvan 1951; Tsukiji 1952). Only some bluestain fungi found in tropical hardwoods have enzymes that can attack wood and these have been shown to cause significant strength loss (Encinas and Daniel 1995). There are no published data to show that bluestained wood is prone to decay more than non-stained wood. However, the presence of staining fungi increases the permeability of the wood (Lindgren and Scheffer 1939; Eaton and Hale 1993), including MPB-affected pine (McFarling and Byrne 2003). Recent data, although not related to bluestain, suggest that the higher the wood permeability the more wood will decay when conditions are suitable (Nicholas et al. 2005). Work is underway at Forintek to determine if this applies to post-MPB wood. Literature detailing the effects of MPB-associated bluestain on wood and the implications for the properties of solid wood products or pulp is limited (Byrne et al. 2005).

18.2 Black Stain

Another group of dark, melanised wood-inhabiting fungi are capable of producing black yeast forms and are sometimes referred to as "bluestain in-service". These fungi can have both hyphal growth and budding, yeast-like cells that have deposits of melanin in the cell walls (de Hoog et al. 1987) (Figure 4). They are common in both outdoor and indoor environments worldwide. Outdoors they can occur on tree leaves, stems and branches. Black yeasts do not cause bluestain and in regard to the wood, they are most commonly noted on the surface of wood in-service, especially under wood finishes, or on wet, decaying wood (Figure 5). Typical genera are *Aureobasidium* and *Hormonema* (Yurlova et al. 1999). *Aureobasidium*, in particular, can use the products of UV breakdown of wood as carbon sources.

18.3 Mold

Molds appear as spots or fuzzy/woolly masses that, under the microscope, appear as a mat (mycelium) of thread-like structures (hyphae) bearing spore-producing structures. In the dictionary of fungi (Kirk et al. 2001) mold is described as "a microfungus having well-marked mycelium and/or spore mass". In the wood products industry molds are defined as discoloring fungi that grow superficially on wood (Eaton and Hale 1993), a definition that unfortunately does not exclude surface bluestain. A more encompassing definition of mold is, "a surface-growing microfungus consisting of pigmented filamentous networks and dry spores that are typically carried by air and appear on the substrate as smudges of colored fluffy or powdery masses". As previously mentioned, spores of bluestain fungi are wet and not carried by air currents. Unlike bluestain fungi that have highly specialized niches, mold hyphae grow over the surface and inside nearly all substances of plant or animal origin (Malloch 1997; Samson et al. 2002). They are typically regarded as spoilage organisms. Unlike bluestain fungi, some molds produce toxins which help molds fight for scarce food sources against competing microorganisms (Flannigan et al. 2001). Like bluestain fungi, molds also live on non-structural nutrient components of wood and thus are more prevalent on sapwood. The color of molds can range from white to very dark in almost any hue (including light buff, green, yellowish, pinkish to darker grey, brown or black), compared to bluestain fungi which show a grey to light- or dark-bluish color (Figure 5). Taxonomically, most molds are described as anamorphic, i.e., fungi that reproduce asexually via division of cells, though some molds can produce spores sexually. Unlike bluestain fungi that have only a few types of spore-producing structures, molds can reproduce through a larger range of structures and spore types. The size and shape of spore-producing structures are key factors used to identify mold genera and species. Molds are usually characterized as a surface growth on wood because of the masses of sporulating structures on the wood surface. Some molds can penetrate wood, but the colorless hyphae are not easily seen under the microscope and the depth to which they penetrate has not been well studied. Mold discolorations in hardwoods are sometimes deeper than in softwoods and may be more problematic.

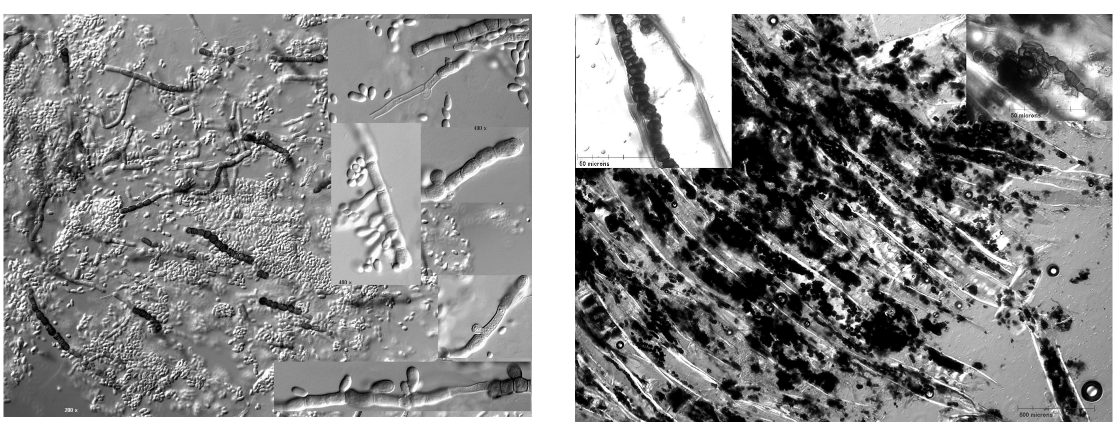

Figure 4. Dark pigmented black yeasts cells (200x and 400x).

In the past, molds have had minor importance in the wood industry. The surface discolorations of wood and wood products when they get wet or are under prolonged high humidity, are easily removed by brushing, washing or planing the surface. Over the last decade, air quality in homes and workplaces –especially in relation to mold– has become a high profile issue receiving considerable media, public and legal attention. Media have labelled molds as serious threats to human health. One scientific report in particular suggested the mold *Stachybotrys chartarum* caused lung bleeding in babies in Cleveland (Centers for Disease Control 1994). Although the findings of this report have been refuted (Centers for Disease Control 2001), the controversy has remained and the industry and the public are more sensitive to the issue of mold on building products. The real or perceived health issues with molds are reviewed in many publications (e.g., Institute of Medicine of the National Academies 2004) and are outside the scope of this paper. Bluestain has not been mentioned in the scientific literature as a health issue (Uzunovic and Byrne 2003).

18.4 Soft-Rot Decay

Soft-rot is a specific type of surface wood decay, differing from rot caused by wood-decaying fungi discussed in the next section. The fungi that cause it are typically not in the Basidiomycota but are mainly anamorphic fungi or Ascomycetes including *Chaetomium globosum*, *Lecythophora hoffmannii* or *Phialophora* sp. Soft-rot fungi break down lignocellulose and can cause significant strength loss (Eaton and Hale 1993). Soft rot of wood typically occurs in soil-contact under warm conditions, prolonged high moisture content and low aeration. A succession of several fungi rather than a distinct fungus are involved in the process and many species can be isolated from wood under conditions suited to soft rot activity (Eaton and Hale 1993). Soft-rot fungi typically attack wood from the surface inwards and the surface becomes soft. The process is slower than that of the wood-decaying fungi and microscopically is characterized by cavity formation, surface erosion and penetration of the wood cell walls (Figure 6). When dried, the surface may show shallow cracking both along and across the grain. Hardwoods and softwoods can both be attacked, with hardwoods much more susceptible.

Figure 5. Black stain on finished wood (left) and a variety of molds growing on wood (right).

18.5 Decay

Decay represents changes to the wood mass where its chemical and physical properties are altered. It is caused by wood-decaying fungi that are important in nature’s recycling process. These fungi possess complex enzyme systems that are able to break down the structural polymers including lignin, cellulose and/or hemicelluloses in wood (Figure 7). Unlike bluestain fungi, they may, therefore, cause significant damage to the wood substance and must be controlled if wood is to be used for structural or decorative purposes. The chemistry of this degradation process, which is based largely on free-radical reactions, is explained to an extent in the literature (Goodell et al. 2003; Eaton and Hale 1993; Zabel and Morrell 1992). Decay can occur in standing trees, logs, lumber, or in wood in-service (Cartwright and Findlay 1958; Rayner and Body 1988; Morris 1998). Some aggressive or pathogenic decay fungi may attack healthy trees, causing root, butt or stem rot of healthy standing trees. Decay fungi are not readily isolated from the mountain pine beetle, nor are they regularly isolated from healthy trees that have been freshly attacked. They are more frequently found developing in attacked trees that have been dead for longer than a year, when other, secondary insects attack these trees (Kim et al. 2005). Some decay fungi are associated with insects though the association is probably more casual than symbiotic. Decay fungi vary considerably in their growth rates and ability to cause decay when conditions are suitable. Macroscopically, decay fungi may not be easily visible in initial stages of attack while later they may show as a white or pale yellow cottony dense growth, often fan-shaped (Figure 7). Several decay fungi also produce mycelial cords which consist of bundles of hyphae. Decay fungi may develop observable mushrooms or conks (the spore-bearing structures). Decomposition of wood may not be obvious (at first termed “incipient decay”) until the decayed wood changes color and shrinks as it dries out.

Figure 6. Soft rot damage caused by Chaetomium globosum in pine showing characteristic orientated diamond shaped cavities in cell walls (400x).

Decay fungi taxonomically belong to a higher order of fungi in the division Basidiomycota where mushrooms and bracket fungi are placed, though not all the fungi in this division can cause wood to decay. Wood-decaying fungi are customarily grouped into two major subgroups based on the characteristics and appearance of the wood during degradation. This reflects fundamental differences in biology and chemical activity of the two subgroups: white-rot and brown-rot fungi.

White-rot fungi encompasses the largest group of known wood-rotting fungi that are able to degrade all major components of wood, leaving a bleached appearance or pale color. Decay may start in small pockets and often results in a stringy texture to the wood. Strength loss may occur slowly as lignin is degraded more rapidly than cellulose. The prevailing color of the remaining cellulose is white, hence the name of this type of rot. Sometimes white rot occurs in small pockets termed “white pocket rot” (Figure 8). White-rot fungi are more often found in hardwoods, such as aspen and maple, than in softwoods. Some white-rot fungi may also cause damage that appears similar to soft-rot. Under the microscope numerous colorless hyphae can be observed in cell lumena but they are not so obvious in the later stages of the decay (Figure 9). As the decay progresses, pit enlargements, bore holes, and gradual cell wall thinning around the fungal hyphae can be observed by light microscopy.

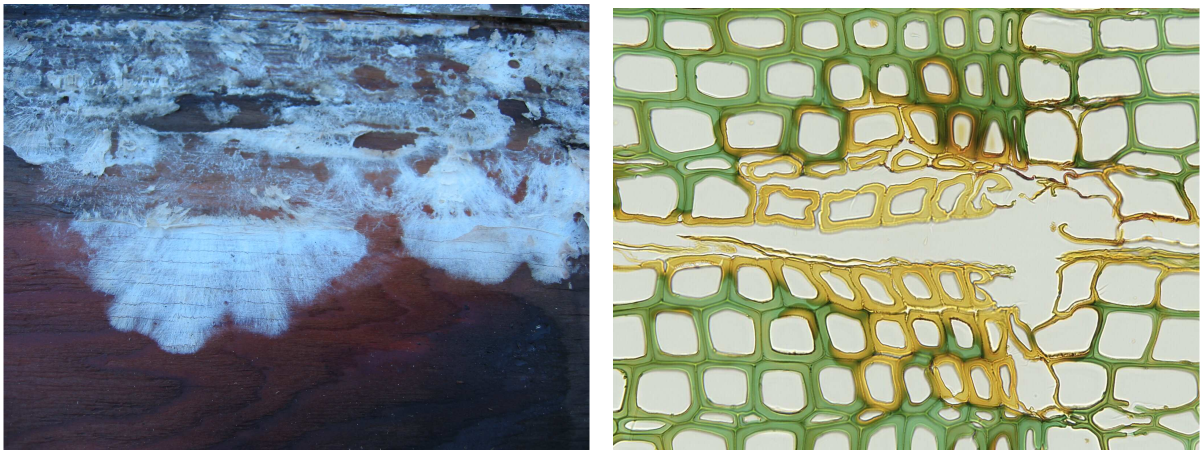

Figure 7. Fan-shaped mycelium of a wood-decaying fungus (left). Damage caused by white rot fungi (right – 400x) delignification of cell walls is indicated by yellow stain versus green in undamaged lignified tissue. (Courtesy of James Drummond, Paprican).

Brown-rot fungi preferentially degrade cellulose and hemicellulose, leaving the darker colored lignin behind. Approximately less than 10% of the known decay fungi are brown-rot fungi. They modify (oxidize) lignin to a dark brown color and thus the rotted wood has a brown appearance (Morris 1998). The wood cracks across the grain and longitudinally as it shrinks to give a characteristic cubical cracking pattern (Figure 8). Hyphae are usually not visible on the surface of decaying wood exposed to the air since the surface remains too dry, although hyphae may develop on surfaces protected from drying. Brown-rot fungi preferentially attack softwoods and are the most economically important agent of wood destruction, causing decay in buildings, and sometimes significantly affecting large structural timbers.

Figure 8. White pocket rot (left) and brown cubical rot (right).

Like the other wood-inhabiting fungi, decay fungi can grow on unprotected wood in the presence of moisture and mild temperatures. Outdoors some wood species, like western red cedar, are naturally protected by their innate preservatives while the wood of other species may need treatment with man-made preservative to keep it serviceable. Indoors, wood is protected from decay or other fungi by keeping it dry. Infection by spores of decay fungi does not occur at wood moisture contents below about 25%.

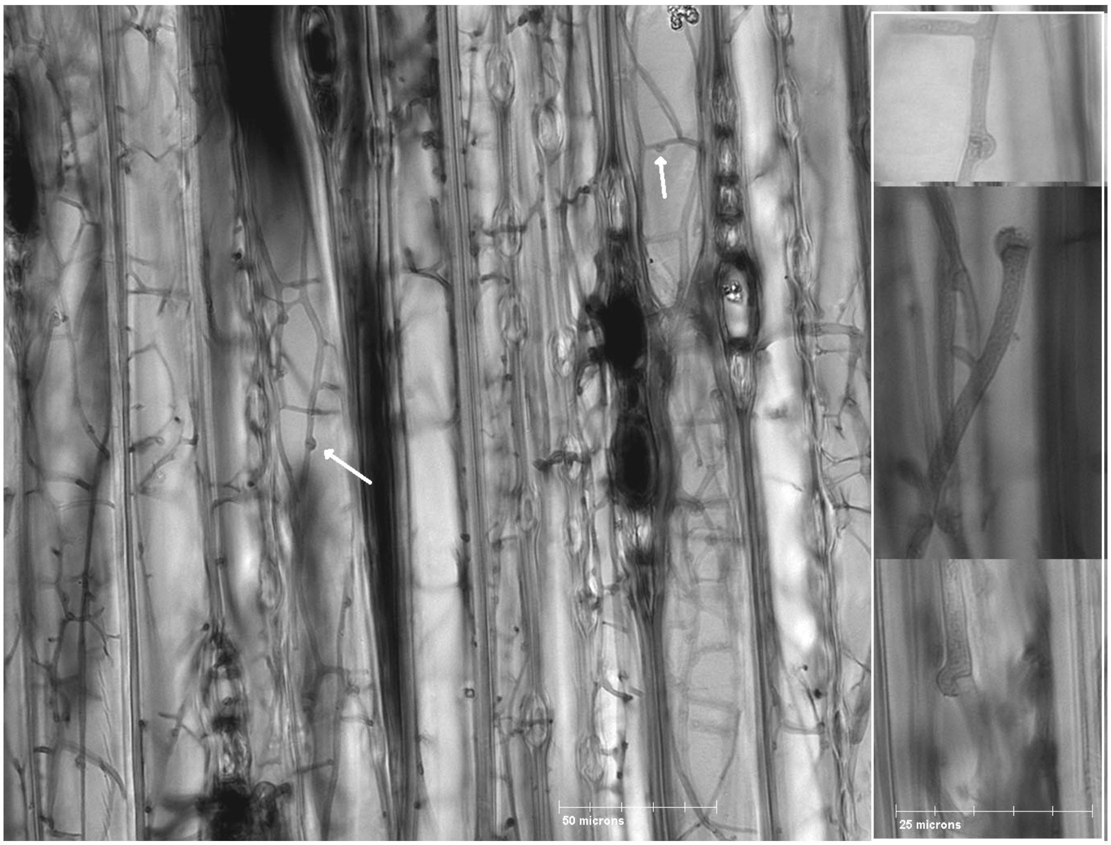

Figure 9. Numerous colorless hyphae (stained for observation) of brown rot fungus in cell lumena during the early stage of decay. Arrows indicate clamp connections, characteristic of basidiomycete fungi.

19 Conclusion

In the scientific literature clear distinctions are made between the types of fungi that colonize wood, starting with the staining fungi and molds which do not cause structural deterioration of wood substance, and ending with various wood-decaying fungi that can cause severe structural damage to the wood.

The bluestain fungi associated with the mountain pine beetle are primary colonizers of fresh wood, causing discoloration, but are unable to deteriorate wood. Although they are sometimes mistaken for other fungi, they differ biologically and morphologically from molds, black yeasts, soft-rotting fungi and decay fungi. They also differ from tropical bluestain fungi that can cause strength loss.

20 Literature Cited

Batra, L.R. 1963. Ecology of ambrosia fungi and their dissemination by beetles. Trans. Kansas Acad. Sci. 66:213-236.

Byrne, T.; Woo, K.L.; Uzunovic, A.; Watson, P.A. 2005. An Annotated Bibliography on the effect of bluestain on wood utilization with emphasis on mountain pine beetle vectored bluestain. Mountain Pine Beetle Initiative Working paper 2005-4. Prepared for Canadian Forest Service, Natural Resources Canada, Pacific Forestry Centre.

Cartwright, K.St.G.; Findlay, W.P.K. 1958. Decay of timber and its prevention, 2nd ed. Her Majesty's Stationary Office. London. 298-320.

Centers for Disease Control and Prevention (CDC). 1994. Acute pulmonary hemorrhage/hemosiderosis among infants-Cleveland, January 1993-November 1994. MMWR Morb Mortal Wkly Rep. 43:881-83.

Centers for Disease Control and Prevention (CDC). 2001. Availability of case definition for acute idiopathic pulmonary hemorrhage in infants. MMWR Morb Mortal Wkly Rep. 50:494-95.

Colley, H.R.; Rumbold, C.T. 1930. Relation between moisture content of the wood and blue stain in Loblolly pine. J. Agr. Res. 41(5):389-399.

Dowding, P. 1969. The dispersal and survival of spores of fungi causing bluestain in pine. Trans. Br. Mycol. Soc. 52(1):125-137.

Eaton, R.A.; Hale, M.D.C. 1993. Wood; Decay, pests and protection. Chapman and Hall, London, 546 p.

Encinas, O.; Daniel, G. 1995. Wood cell wall biodegradation by the blue stain fungus *Botryodiplodia theobromae* Pat. Mat. und Organismen. 29:255-272.

Etheridge, D.E. 1957. A method for the study of decay resistance in wood under controlled moisture conditions. Can. J. Bot. 35:615-618.

Eusebio, M.A. 1962. Growth of five staining fungi and stain development in pine sapwood. Philippine Journal of Forestry. Master of Science Work in Product Pathology, State University of New York College of Forestry, Syracuse. 69-91.

Fengel, D.; Wegener, G. 1989. Wood chemistry, ultrastructure and reactions. Walter de Gruyter, Berlin. 1989.

Findlay, W.P.K. 1939. Effect of sap-stain on the properties of timber. II Effect of sap-stain on the decay resistance of pine sapwood. Forestry. 13:59-67.

Flannigan, B.; Samson R.A; Miller, J.D (eds.). 2001. Microorganisms in home and indoor environments; diversity, health impacts, investigation and control. Taylor & Francis. London. 490 p.

Fleet, C.; Breuil, C.; Uzunovic, A. 2001. Nutrient consumption and pigmentation of deep and surface colonizing sapstaining fungi in *Pinus contorta.* Holzforschung. 55, 4. 340-345.

Forintek Canada Corp. 2003. Properties of lumber with beetle-transmitted bluestain. Forintek Canada Corp., Western Division, Vancouver, B.C. Wood Protection Bulletin. 4 p.

Gibbs, J.N. 1993. The biology of Ophiostomatoid fungi causing sapstain in trees and freshly-cut logs. Chapter 17, in: *Ceratocystis* and *Ophiostoma*, taxonomy, ecology and pathogenicity (ed. J.M. Wingfield, K.A. Seifert, and J.F. Webber) APS Press, 293 p.

Goodell, B.; Nicholas, D.D.; Schultz, T.P. (eds.) 2003. Wood Deterioration and Preservation; advances in our changing world. ACS symposium series 845.

Hoog, D.S. de; Ginnis, M.R. 1987. Ascomycetous black yeasts. Pages 187-199 *in:* Hoog, D.S. de, Smith, M. Th. and Weijman, A.C.M., eds.The expanding realm of yeast-like fungi. Proceedings of an international symposium on the perspectives of taxonomy, ecology and phylogeny of yeasts and yeast-like fungi. Amersfoort, The Netherlands, 3-7 August 1987.

Hubert, E.E. 1921. Notes on sap staining fungi. Phytopathology, 5 (Vol.11):214-224.

Institute of Medicine of the National Academies. 2004. Damp indoor spaces and health. The National Academies Press. Washington, DC. 355 p.

Jacobs, K.; Wingfield, M.J. 2001. Leptographium species: tree pathogens, insect associates, and agents of blue-stain. The American Phytopathological Society, St Paul, Minnesota. 207 p.

Käärik, A. 1960. Growth and sporulation of *Ophiostoma* and some other fungi on synthetic media. Symb. Bot. Upsal. 16:1-168.

Kim, J-J.; Allen, E.A.; Humble, L.M.; Breuil, C. 2005. Ophiostomatoid and basidiomycetous fungi associated with green, red, and grey lodgepole pines after mountain pine beetle (*Dendroctonus ponderosae*) infestation. Canandian Journal of Forest Research 35:274-284.

Kitamura, Y.; Kondo, T. 1958. Chemical study on blue stained Pine-wood. On the pigment obtained from mycelia of blue-stain fungi. J. Jap. Wood. Res. Soc. 4:51-55.

Kirk, P.M.; Cannon, P.F.; David, J.C.; Stalpers, J.A. (eds.) 2001. Dictionary of Fungi, 9th edition. CAB International. 655 p.

Lagerberg,T.; Lundberg, G.; Melin, E. 1927. Biological and practical researches into blueing of pine and spruce. Svenska Skogsför. Tidskr. 25:145-272, 561-691.

Leach, J.G.; Orr, L.W.; Christiansen, C. 1934. The interrelationship of bark beetles and blue staining fungi in felled Noway pine timber. Jour. Ag. Res. 49(4):315-341.

Liese, W.; Schmid, R. 1962. Submicroscopical changes of cell wall structure by wood-destroying fungi. Fifth International Congress for Electron Microscopy (Philadelphia), 2: w-5.

Liese, W.; Schmid, R. 1964. Uber das Wachstum von Bläuepilzen durch verholzte Zellwände. Phytopathologische Zeitschrift, 51:385-393.

Lieutier, F.; Day, K.R.; Battisti, A.; Grégoire, J.-C.; Evans, H.F., eds. 2004. Bark and Wood Boring Insects in Living Trees in Europe, A Synthesis. 569 p. ISBN: 1-4020-2240-9.

Lindgren, A.M. 1942. Temperature, moisture, and penetration studies of wood-staining Ceratostomellae in relation to their control. Technical Bulletin No. 807, March 1942.

Lindgren, R.M.; Scheffer, T.C. 1939. Effect of blue stain on the penetration of liquids into air-dry southern pine wood. Proc. Ann. Wood. Pres. Assoc. 35:325-336.

Lum, C. 2003. Characterising the mechanical properties of wood containing beetle-transmitted bluestain. Forintek Canada Corp. Report to Forestry Innovation Investment Program. Vancouver, B.C.

Malloch, D. 1997. Moulds, isolation, cultivation, identification. Department of Botany. University of Toronto. http://www.botany.utoronto.ca/ResearchLabs/MallochLab/Malloch/ Moulds/Moulds.html.

Mathiesen, A. 1950. Über einige mit Borkenkäfern assoziilerten Bläuepilze in Schweden. Oikos. 2(2):275-308.

McFarling, S.; Byrne, A. 2003. Characterizing the dimensional stability, checking, and permeability of wood containing beetle-transmitted bluestain. Forintek Canada Corp. Report to Forestry Innovation Investment Program. Vancouver, B.C.

Mejer, E.I. 1946. Stimulatory action of staining fungi on the development of house fungi. Bjulletin' Moskovskogo Obšestva Ispytatelej Prirody (Otdel biologi eskij). 51:3-45.

Morris, P. 1998. Understanding Biodeterioration of Wood in Structures. Forintek Canada Corp. Report.. 23 p. http://www.durable-wood.com/pdfs/biodeterioration.pdf.

Münch, E. 1907. Die Blaufäule des Nadelholzes. Naturw. Z. Forst. Landw. Stuttgart, 5:531-573, 6:32-47, 297-323.

Nelson, R.M.; Beal, I.A. 1929. Experiments with bluestain fungi in southern pines. Phytopathology. 19:1101-1106.

Nicholas, D.D.; Schultz, T.P.; Sites, L.; Buckner, D. 2005. Effect of permeability and extractives on the decay rate of southern pine sapwood in above ground exposure. International Research Group on Wood Preservation. Document No: IRG/WP 05-20310. IRG. Stockholm, Sweden.

Norris, D.M. 1979. The mutualistic fungi of xyleborine beetles. In Insect-fungus symbiosis (Batra, R.L ed.), Halsted Press, Chichester. 53-63.

Radvan, R. 1951. Effect of *Ceratostomella pilifera* on the decomposition of lignocellulosic membranes (cell walls) by wood-destroying fungi. Spisy Vydávané P irodov deckou Fakultou Masarykovy Univ. Brno, No. K3/326:79-96.

Rayner, A.D.M.; Boddy, L. 1988. Fungal decomposition of wood, its biology and ecology. John Wiley & Sons. 587 p.

Samson, R.A.; Hoekstra, E.S.; Frisvad, J.C.; Filtenborg, A. 2002. Introduction to food- and airborne fungi. 6th edition. Published by Centraalbureau voor Schimmelcultures. P.O. Box 851167, 3508 Ad Utrecht, The Nederlands. 389 p.

Scheffer, T.C.; Chidester, M.A. 1948. Survival of decay and blue-stain fungi in air-dry wood. South. Lumberm. 177:110-112.

Schirp, A.; Farrell, R.L.; Kreber, B. 2003. Effects of New Zealand sap staining fungi on structural integrity of unseasoned radiata pine. Holz als Roh und Werkstoff. 61(5): 369–376.

Seifert, K.A. 1993. Sapstain of commercial lumber by species of *Ophiostoma* and *Ceratocystis*. Chapter 16, In: *Ceratocystis* and *Ophiostoma*, taxonomy, ecology and pathogenicity (ed. J.M. Wingfield, K.A. Seifert, and J.F. Webber). APS Press. 293 p.

Six, D. 2003a. Bark Beetle-fungus Symbioses. p. 97-114. In: K. Bourtzis and T.A. Miller eds. Insect symbioses. CRC Press.

Six, D. 2003b. A comparison of mycangial and phoretic fungi of individual mountain pine beetles. Can.J. For. Res. 33:1331-1334.

Tsukiji, R. 1952. Decay durability of blue-stained timber. Wood ind., Tokyo, 7:16-18.

Uzunovic, A.; Byrne, T. 2003. Three technical questions and answers on mold and bluestain. Forintek Canada Corp to the American Forest & Paper Association. http://www.durable-wood.com/faqs/index.php.

Uzunovic A.; Webber, J.F. 1998. Comparison of bluestain fungi grown *in vitro* and in freshly cut pine billets. Eur. J. For. Path. 28: 323-334.

Uzunovic, A.; O'Callahan, D.; Kreber, B. 2004. Mechanical tree harvesters spread fungal inoculum onto freshly felled Canadian and New Zealand pine logs. Forest Products Journal. Vol 54, No. 11, 34 –40.

Verrall, A.F. 1941. Dissemination of fungi that stain logs and lumber. Jour. Ag. Res. 63(9):549-558.

Yurlova, N.A.; de Hoog, G.S.; Gerrits van den Ende, A.H.G. 1999. Taxonomy of *Aureobasidium* and allied genera. Studies in Mycology. 43:63-69.

Zabel, A.; Morrell, J.M. 1992. Wood microbiology: decay and its prevention. Academic Press, 476 p.

Contacts

- Adnan Uzunovic, Mycologist, Durability and Protection Group, Forintek Canada Corp. (Project Leader). Phone: 604-222-5729, e-mail: adnan@van.forintek.ca

- Tony Byrne, Wood Protection Scientist, Durability and Protection Group, Forintek Canada Corp. Phone: 604-222-5650, e-mail: byrne@van.forintek.ca

Attachment 3

Frequently Asked Questions about Bluestain on Canadian Wood Products

Frequently Asked Questions about Bluestain on Canadian Wood Products

Introduction

You may have noticed a larger proportion of western spruce-pine-fir lumber or plywood that contains blue streaks. This discoloration is called bluestain and is associated with the activities of the mountain pine bark beetle. In BC a lot of trees that have recently been attacked by this beetle are being processed into lumber and plywood. This beetle is associated with a discoloration called bluestain. This document has been produced to answer some of the questions that have been raised in the market about bluestained wood. The answers are based on reviews of the scientific literature written by scientists at Forintek Canada Corp.

What is bluestain?

This is a common blue-toned wood discoloration in softwoods, especially pines. The stain is caused by a type of harmless fungus. Bluestain occurs only in the sapwood, which is the outer part of the tree, closest to the bark – this is why a piece of lumber may be stained only in a very distinct section of the wood. Bluestain fungi are usually carried by forest insects, mainly bark beetles. These are common in the forest and in areas where logs are stored. When the insects land on logs that have bark partially removed, or when they attack standing trees or logs with bark still on, the fungi can germinate and grow into the sapwood. While the fungi penetrate deep into the sapwood, the bark beetles do not. In addition, the beetles are no longer present in finished products as the bark is removed during processing.

Some people mistakenly confuse bluestain with mold. Under the microscope you would see that the stain is caused by dark colored threads of fungus growing in part of the wood tissue. The threads are found mainly in the horizontal “ray” cells that the tree uses for storage of nutrients. The fungus is so intensely colored that it makes the whole of the wood which it has colonized appear blue/grey, even though only a few fungal threads may be present.

Bluestained logs, left, and wood products, right.

Threads of bluestain fungi in wood (Source: Paprican)

Will bluestain growth spread to other pieces of wood?

Bluestain can only spread to other pieces of wood if the fungus is actively growing, which is unlikely. In order to spread it must be alive in wet wood and in prolonged contact with another piece of wet sapwood. By the time a stained log reaches the sawmill the bulk of the fungus is often already dead. When the fungal threads have used up the food resource (sugars, starch and other tree nutrients) in the specific cells they have colonized, the fungus dies back. Any live fungi remaining are killed during the kiln drying process. Canadian dimension lumber that has been kiln-dried for overseas shipping bears a stamp with the initials HT (heat-treated) or has paperwork to say it has been heat-treated. The HT stamp indicates that the wood has been heated internally to the international standard of 56ºC for at least 30 minutes. This temperature kills organisms, such as fungi and insects, that can sometimes be found in wood. As for the stain itself, the pigmentation is permanent and fixed in place – it will not spread further under any circumstances, including wetting.

Is bluestain rot or mold?

No. Bluestain fungi are harmless. Decay fungi cause rot because they have the ability to digest the wood fibres and thus weaken the wood. Bluestain fungi do not attack wood itself but live on nutrients stored in a small proportion of wood cells. Mold is a multicolored wooly surface growth with spores that readily become airborne. It can easily be removed and also doesn't harm the wood.

Decayed (left) and moldy (right) wood.

Does bluestained wood affect my health?
No. Bluestain fungi have not been associated with any human health problems in medical literature. The fungi do not readily become airborne and therefore cannot affect indoor air quality.

Is bluestained wood weak?
No. Tests done at Forintek Canada Corp. and other research laboratories have demonstrated that there is no practical difference in strength between stained and non-stained pine. Bluestained wood is commonly used for construction in North America.

Can I use bluestained and non-stained wood interchangably?
Yes. For construction and other purposes where strength is required you can use either or both. Where appearance is important, bluestained wood may or may not be desirable. Tests show that bluestained wood glues and finishes just as well as non-stained wood if required. The right combination of dark finishes can be used to hide any bluestain.

21 For more information read:

Properties of lumber with beetle-transmitted bluestain. Forintek Canada Corp., 2003. Available in English, French and Japanese.

Discolorations on wood products: causes and implications. Forintek Canada Corp. and the University of British Columbia School of Occupational and Environmental Hygiene, 2002. Available in English and French.

Background research and preparation of this document was funded by the CFS Mountain Pine Beetle Initiative.