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Finishing of Mountain Pine Beetle Affected Lodgepole Wood

by

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Prepared for

Forestry Innovation Investment

Recipient Agreement No.: FII-MDP-07-0019

March 2007

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1. Executive Summary

Over 400 million m^3 of standing lodgepole pine timber in the forests of British Columbia is affected by the mountain pine beetle and associated *ophiostomatoid* fungi that stain the sapwood of infected pine trees a blue-grey colour. A literature review on the effect of MPB blue-stain on wood properties and the performance of wood finishes was prepared. The literature review indicated that blue-stain has the following effects on which are of relevance to the performance of finishes:

- MPB-affected blue-stained sapwood is more permeable, than unstained wood;
- MPB-affected blue-stained sapwood is more dimensionally stable that the non-stained sapwood during repeated wetting/drying;
- Checks are significantly smaller than on unstained wood.

There is little or no information in the literature on the effect of blue-stain on the performance of opaque finishes on lodgepole pine.

Blue-stain is undesirable in appearance grade wood products and some grades of structural timber, and a simple method of removing the stain or reducing its severity is required. A journal article on “bleaching treatments for blue-stained lodgepole pine affected by the mountain pine beetle *Dendroctonus ponderosae*”

was prepared and published in the international journal *Holz als Roh- und Werkstoff* . This paper summarizes our work on the use of bleaches to remove blue-stains from MPB-affected wood. Our results showed that bleaching treatment type and temperature had significant effects on the blueness and lightness of blue-stained lodgepole pine wood submerged in an excess of bleach. Soaking lumber in a 5% sodium hypochlorite solution at 20ºC was quite effective at removing the blue colour of blue-stained lodgepole pine wood and, to a lesser extent, lightening the wood. A concentrated solution (about 10.5%) of sodium hypochlorite sprayed on to blue-stained lodgepole pine sapwood at 25ºC was effective at removing the blue discolouration from sapwood, and no additional benefit on reduction of discolouration was obtained by increasing treatment temperature.

The utilization of blue-stained wood for painted, non-structural, products is attractive because painting masks the stain. Preliminary research by the proponent, however, showed that the ability of conventional primers to mask the blue stain was lost when the painted wood was exposed outdoors. It is not known whether this undesirable property of painted blue-stained lumber was due to the presence of the blue-stain or is simply an inherent characteristic of the sapwood of lodgepole pine. To understand and resolve this issue, an experiment using a range of finishes applied to both stained and unstained sapwood and heartwood boards was developed. Coated wood samples were exposed outdoors in Vancouver, BC. Gloss, colour, weight (MC), dimensional change etc. of the exposed boards were monitored every quarter. The results after nine months exposure showed that finishes applied to blue-stained sapwood were darker and less glossy than the same finishes applied to unstained sapwood and heartwood (both in stained or unstained wood). This effect, however, was not observed with all finishes. One finishing system (D, Primer: Behr # 436, 100% acrylic, white, water-based; Topcoat: Behr, exterior satin enamel, 100% acrylic latex, white) was effective at preventing the loss of the lightness and gloss of coated wood samples on blue-stained sapwood during weathering. The ability of this system to restrict losses in lightness and gloss of samples was associated with its high moisture excluding efficiency.

Research also commenced to determine the performance of opaque paint films on mountain pine beetle-affected wood at different stages of the decay process. Coated samples are being exposed to the weather in an exterior trial in Vancouver, and monitoring of the exposed samples will be undertaken in the coming fiscal year 2007/08. The outcome of the research will be information that can be used to optimize the finishing of blue-stained lodgepole pine with opaque finishes. This will allow manufacturers of painted wood products to continue to use mountain pine beetle-affected wood with cost savings for their production processes.

2. Literature Review on the Effect of MPB Blue-stain on Wood Properties and the Performance of Wood Finishes

2.1. Introduction

The mountain pine beetle (MPB), *Dendroctonus ponderosae* Hopkins, is a black bark beetle, native to North America, that is associated with specific blue-stain fungi, such as *Ophistoma clavigerum*, *O. monitum*, *O. ips* and *O. minus* (Kim et al. 2003; Lee et al. 2003). The beetles fly in the midsummer from the lodgepole pine trees they inhabited over-winter to colonise green trees. During excavation of bark, they produce vertical egg galleries which are inoculated with blue-stain fungal spores. Those spores germinate very quickly and infect the adjacent sapwood. The fungi move radially through the parenchyma of the xylem's rays and then spread into the tracheids (Ballard et al. 1982), where they reduce the vertical flow of sap (Ballard et al. 1984). The moisture content in infected sapwood is greatly reduced within a year of the attack and eventually water stress leads to the death of the tree (Reid, 1961). The blue-stain in the sapwood of infected trees is caused by the presence of fungal hyphae within the wood. However, blue-stain fungi don't cause decay and they never or very rarely attack heartwood. MPB-infested dead trees develop stem splits and checks during further drying, which affects their conversion into solid wood products and reduces the value of the standing timber (Fahey et al. 1986).

2.2. Properties of MPB-infested blue-stained wood:

Lum (2003) studied the strength properties of MPB-affected blue-stained wood and reported that the strength (modulus of rupture in bending) and stiffness of the blue-stained wood were comparable to those of non-stained wood. The toughness of the blue-stained wood (clear specimens) was slightly (about 5%) lower than that of normal wood. However, toughness is not a critical strength property for many end-uses.

McFarling and Byrne (2003) compared the dimensional stability of MPB-affected blue-stained sapwood with that of non-stained sapwood. They observed that MPB-affected blue-stained sapwood was more dimensionally stable (observed less twist and cupping) during repeated wetting and drying. They also observed that the checks that developed in blue-stained wood were different from those that developed on non-stained wood. Fine micro-checking on blue-stained wood (rather than fewer large checks) meant that their appearance was better than that of non-stained wood (subjected to similar wetting and drying cycles).

Woo et al. (2005) reported that MPB-affected blue-stained sapwood was more permeable than non-stained sapwood. They reported the opposite trend for heartwood. They also performed chemical analysis of the infected sapwood and observed that it had lower concentrations of extractives and lower lignin and hemicelluloses content compared to sound wood.

There are some controversial reports on the density of the MPB-affected blue-stained wood. Lum (2003) reported that there was no significant difference in density between blue-stained wood and non-stained wood. However, Woo et al. (2005) observed that MPB-affected blue-stained wood was less dense than non-infected sound wood.

2.3. Effect of MPB-infected blue-stain on wood finishing:

Williams and Mucha (2003) were the first researchers to determine what finish combinations would mask blue-stain or enhance the appearance of MPB-affected blue-stained pine wood. They used a number of commercially available solvent based stains, toners, and glazes singly or in combination to see the degree to which they would mask the blue-stain. They observed that the increased permeability of the MPB-affected blue-stained wood did not affect the evenness or adhesion of any of the finishes used. Stains, toners or glazes containing blue, red, or charcoal tints were better at masking the blue-stain than other stains. In contrast clear furniture finishes highlighted the blue-stain. They also compared the gluing properties of MPB-infected blue-stained wood and non-stained wood and did not find any significant difference between MPB-affected blue-stained wood and non-stained wood, when polyvinyl acetate (PVA) and phenol-resorcinol-formaldehyde (PRF) were used as adhesives. Evans (2006) found that a range of alkyd, acrylic-latex primers and clear coats on blue-stained lumber did not mask the blue-stain when the finished wood was exposed to the weather for a period of three months. The discolouration appeared to be due to organisms colonizing the paint film rather than the fungus growing through the film. This problem is very serious because it detracts from the appearance of the painted product, will increase maintenance costs and may reduce the longevity of the coating.

2.4. Conclusions:

In conclusion this literature review showed that blue-stain affects the following properties which are of relevance to the performance of finishes on wood:

- MPB-affected blue-stained sapwood is more permeable than unstained wood
- MPB-affected blue-stained sapwood is more dimensionally stable than non-stained sapwood during repeated wetting/drying. Checks are also significantly smaller.
- There is little or no information in the literature on the effect of blue-stain on the performance of opaque finishes on lodgepole pine.

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3. Bleaching Treatments for Blue-stained Lodgepole Pine Affected by the Mountain Pine Beetle *Dendroctonus ponderosae*

3.1. Subject

Over 400 million m^3 of standing lodgepole pine timber in the forests of British Columbia, Canada, is affected by the mountain pine beetle and associated *ophiostomatoid* fungi that stain the sapwood of infected pine trees a blue-grey color (Lee et al. 2005). Such staining is undesirable in appearance grade wood products and some grades of structural timber, and a simple method of removing the stain or reducing its severity is required. This study screened a range of bleaching agents to determine which ones were most effective at removing the blue stain and then optimized treatment parameters for the most efficient bleaching agent (sodium hypochlorite).

3.2. Methods and Materials

Kiln dried, blue-stained lodgepole pine wood (2 x 4) was purchased commercially. Initial screening of bleaches applied the following 7 aqueous treatments at room temperature (20 ^{o}C) to samples measuring 20 x 55 x 37 mm;

- **a**, Two-part commercial peroxide bleach;
- **b**, Sodium hypochlorite (10%);
- **c**, Sodium hypochlorite (10%) and sodium hydroxide (5%; 1:1) followed by 30% hydrogen peroxide;
- **d**, Sodium chlorite (10%) and urea (20%);
- **e**, Hydrogen peroxide (30%) and acetic acid (10%);
- **f**, Sodium phosphate (3%) and sodium chlorite (9%);
- **g**, Hydrogen peroxide (30%).

Water treated and untreated samples acted as controls, **h** and **i**, respectively.

Solutions were brushed onto the sapwood and heartwood of 6 replicate samples at a level of 0.012 mL/cm^2, and samples were then conditioned at 20^{o}C & 65% r.h. for 1 week. Blue-stained wood samples (38 x 89 x 76mm, 144 replicates) were also immersed in sodium hypochlorite solutions (0, 5 and 12%) at four temperatures (10, 20, 30 or 40 ^{o}C) for 10, 40 or 120 mins. Following treatment, samples were rinsed with 100 mL of distilled water, conditioned for 1 week and their colour measured. A separate experiment also examined the effect of sodium hypochlorite solution concentration (0, 5, 7, 9, 10.5%) and temperature (20, 25, 30 and 35 ^{o}C) on the colour of blue-stained samples (38 x 89 x 152 mm, 100 replicates), but in this final experiment the wood was sprayed with the solutions (0.012 mL/cm^2). These samples were then air-dried for 24h, rinsed with 400 mL of water and conditioned for 48 h (as above). The colour of bleached wood was measured with a spectrophotometer (Minolta 2600d) and is expressed using CIElab parameters, b* (blue [-60] to yellow [+60]) and L (white [100] to black [0]). All experimentation employed factorial principles, and multifactorial analyses of variance were used to determine the effects of treatment parameters and random effects on wood colour.

3.3. Results

1. Initial screening of different bleaches showed that sodium hypochlorite (treatment b) was the only bleaching agent that significantly reduced the blue colour of blue-stained wood (Fig. 1a). Three treatments (c, d & f) produced a yellow colour on heartwood, which faded over time.

2. Figure 1b. shows that immersion in 5 or 12% solutions of sodium hypochlorite at 20 ^{o}C removed the blue colour from blue-stained wood (averaged across treatment times). However, after such treatments the wood was still darker (L= 75.6 and 73.4, respectively) than unstained sapwood (L = 85.5).

3. Spraying a 10.5% solution of sodium hypochlorite also removed the blue colour from blue-stained wood (Fig. 1c). There was a positive relationship between solution concentration and the effectiveness of the treatment, but little effect of treatment temperature. Again the treatment was less effective at lightening blue stained wood.

4. We concluded that sodium hypochlorite under mild conditions is effective at removing the blue-colour from blue-stained wood, but it is less effective at restoring the lightness of the treated wood. Hence, a subsequent brightening treatment may be needed following application of sodium hypochlorite to return blue-stained pine sapwood to a more natural colour.

3.4 Reference

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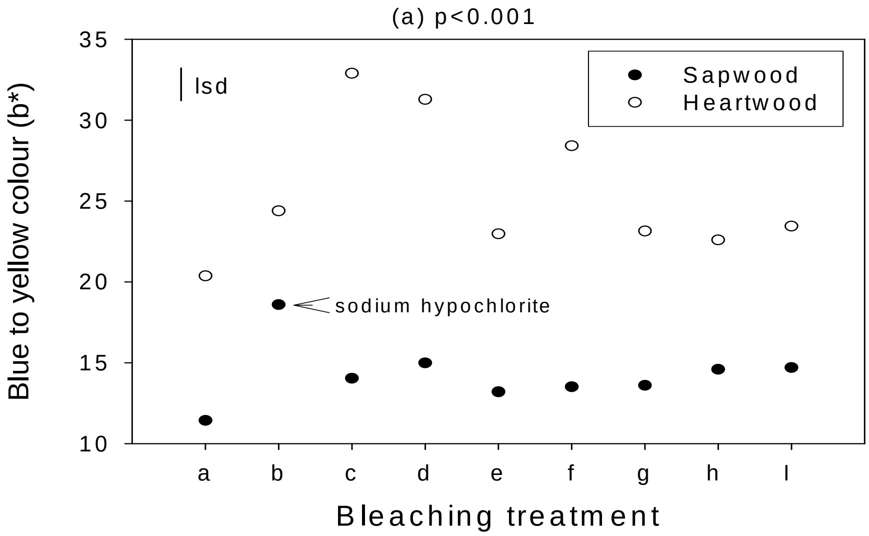
3.5. Figure Caption and figures

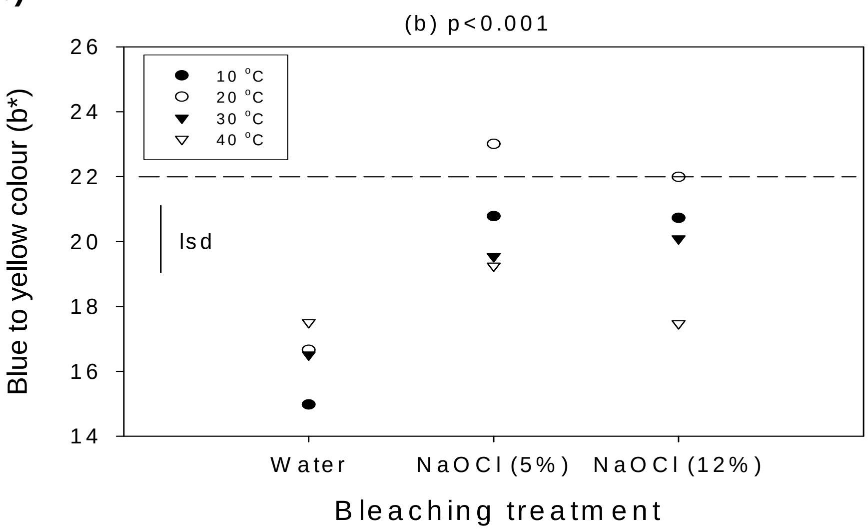
Figures 1a to 1c.
a. Effect of different bleaching agents on blue-yellow colour of blue-stained sapwood and unstained heartwood;
b Effect of solution concentration and temperature on blue-yellow colour of blue-stained sapwood samples immersed in sodium hypochlorite solutions;
c. Effect of spraying solutions of sodium hypochlorite with different concentrations on blue-yellow colour of blue-stained sapwood; Note, dotted line in Fig. 1b-c indicates colour of unstained pine

a)



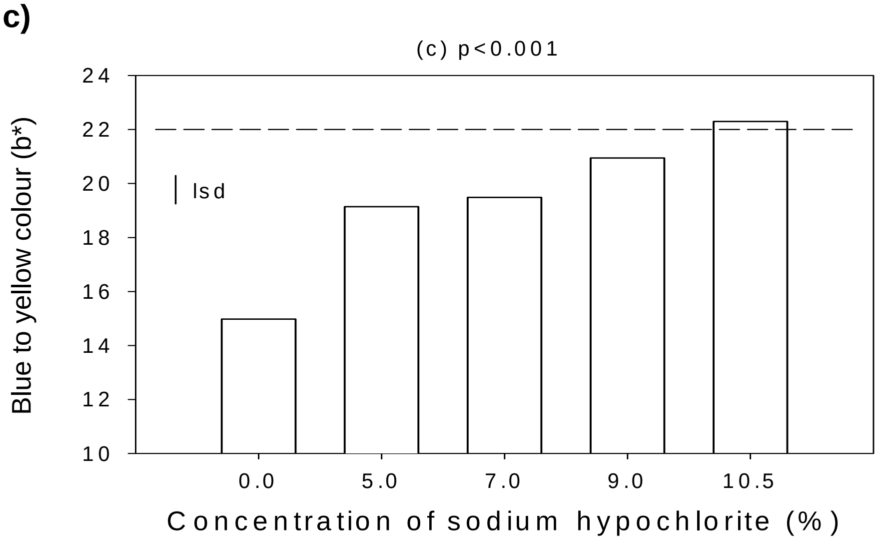
(a) p<0.001
Blue to yellow colour (b*)
35
30
25
20
15
10
lsd
Sapwood
Heartwood
sodium hypochlorite
a
b
c
d
e
f
g
h
I
Bleaching treatment

b)



(b) p<0.001
Blue to yellow colour (b*)
26
24
22
20
18
16
14
10 °C
20 °C
30 °C
40 °C
lsd
Water
NaOCl (5%)
NaOCl (12%)
Bleaching treatment

c)



(c) p<0.001
Blue to yellow colour (b*)
24
22
20
18
16
14
12
10
lsd
0.0
5.0
7.0
9.0
10.5
Concentration of sodium hypochlorite (%)

4. Utilization of Mountain Pine Beetle Affected-Wood for Painted Products

4.1. Introduction

The utilization of mountain pine beetle-affected lodgepole pine for painted, non-structural wood products (cladding and joinery) is attractive because painting masks the blue stain, and loss of mechanical properties associated with fungal attack is less serious for products that are not used in load-bearing situations. A previous project funded by CFS and undertaken in collaboration with CANFOR, however, found that a range of alkyd, acrylic-latex primers and clear coats on blue stained lumber did not mask the blue-stain when the finished wood was exposed to the weather for a period of 3 months.

The discoloration appeared to be due to organisms colonizing the paint film rather than the blue stain fungus growing through the film. This problem is very serious because it detracts from the appearance of the painted product, will increase maintenance costs and may reduce the longevity of the coating. It is not known whether this undesirable property of painted blue-stained lumber is due to the presence of the blue-stain or is simply an inherent characteristic of the sapwood of lodgepole pine. To understand and resolve this issue, an experiment using a range of finishes applied to both stained and unstained sapwood and heartwood boards was developed. Coated wood samples were exposed outdoors in Vancouver, BC. Gloss, colour, weight (MC), dimensional change etc. of the exposed boards were monitored in the 2006/07 fiscal year.

4.2. Research

Four lodgepole pine logs free of blue-stain and four lodgepole pine logs containing blue-stain were obtained from the Alex Fraser Research Forest in Williams Lake, British Columbia. The logs were debarked manually and sawn ‘through-and-through’ using a LT-15 Wood Mizer sawmill into two inch boards. Boards were kiln dried over a period of 14 days to a final moisture content of 13%. Two boards from each log were converted into cladding samples measuring 4” x 2” x 7’. All four sides of the boards were planned using a Martin T44 jointer and a Martin T54 thickness planner. All longitudinal edges were rounded to a 5 mm radius using a Martin T26 shaper. The boards were cross-cut into samples, each 6” in length using an Omga radial arm saw. Six samples from each board were randomly assigned to 6 different wood finishing systems and their end grain was sealed using an epoxy-based sealer. Samples were conditioned at 20 ± 1^{o}C and 65 ± 5% relative humidity for 1 month. Six different wood finishing systems (opaque, white, acrylic and alkyd finishes) were applied (primer plus two topcoats) to the different samples in accord with manufacturer’s instructions. The descriptions of the wood finishing systems used are given below (Table 1):

Table 1. Coating systems applied to blue-stained and unstained lodgepole pine samples

System No.	Primer	Top coat	Drying times (h)*
A	CIL smart, 100% acrylic, white, water-based	Dulux exterior latex, 100% acrylic, white, gloss, water-based	16, Primer (4) 6, Topcoat (6)
B	CIL smart, 100% acrylic, white, water-based	Dulux exterior latex, 100% acrylic, pure white 1500, satin, water-based	16, Primer (4) 6, Topcoat (4)
C	Dulux # 999 primer, alkyd, oil-based	Topcoat: Dulux, exterior, semi gloss, alkyd, oil-based	16, Primer (16) 16, Topcoat (16)
D	Behr # 436, 100% acrylic, white, water-based	Topcoat: Behr, exterior satin enamel, 100% acrylic latex, white	16, Primer (16) 6, Topcoat (4)
E	Behr # 436, 100% acrylic, white, water-based	Topcoat: Behr, exterior flat, 100% acrylic latex, pure white	16, Primer (16) 6, Topcoat (4)
F	Kilz primer	Topcoat: Dulux exterior later, satin, 100% acrylic, pure white 1500, water-based	16, Primer (1) 6, Topcoat (4)

*Recommended drying times in parentheses

Coated wood samples were conditioned for 1 month and the colour of the finishes on coated wood samples was measured using a spectrophotometer (Minolta CM-2600d). Initial gloss of the finishes on coated wood samples was measured at an angle of 85° using a HWS 5820 BYK mirror-TRI-gloss meter (model 455). Weight and dimension of the test samples were also measured. Coated wood samples were exposed outdoors in Vancouver on a vertical test fence, facing south (Fig. 2). In this quarter, after nine months of outdoor exposure the samples were brought back to the laboratory and conditioned for 1 week at 20 ± 1ºC and 65 ± 5% relative humidity, and then the colour, gloss, weight (moisture content), dimensional change etc. of samples were re-measured. The samples were then put back on the outdoor test fence for further exterior exposure.

Figure 2. One of four test fences used to expose painted blue-stained samples to the weather

4.3. Results and discussion

The measurement system used to express colour of samples is the CIELAB (CIE L*a*b* space) colour system. This system provides three coordinates for colour measurement where L* is lightness (0 = black, 100 = white), a* is greenness/redness (-60 = green, 60 = red), and b* is blueness/yellowness (-60 =

blue, 60 = yellow). Since coated wood samples darken during weathering, the L* (lightness of the colour measurement) is the main parameter of importance. Analysis of variance of the ratio of L* (after weathering/before weathering) indicated that the wood finishing system had significant ($p = 0.06$) effects on the loss of lightness of the coated wood. Fig. 3 showed that the presence of blue-stain reduced the lightness (L* ratio) of the coated wood samples. As applied finishes darken during weathering, the ratio of L* after weathering to before weathering should decrease. A good finishing system however should prevent this from occurring and the ratio of L* should be closer to 1. Fig. 4 shows the ratio of L* of the applied wood finishing systems on unstained and blue-stained sapwood after nine months of weathering. The effect of individual finishing systems on loss of L* can be compared using a least significant difference bar (0.003 at 5% level). Fig. 4 shows that the ratios of L* for wood finishing systems D, E and F were closer to 1 than any of the other finishing systems. In contrast the ratios of L* for the finishing systems A, B, and C were low.

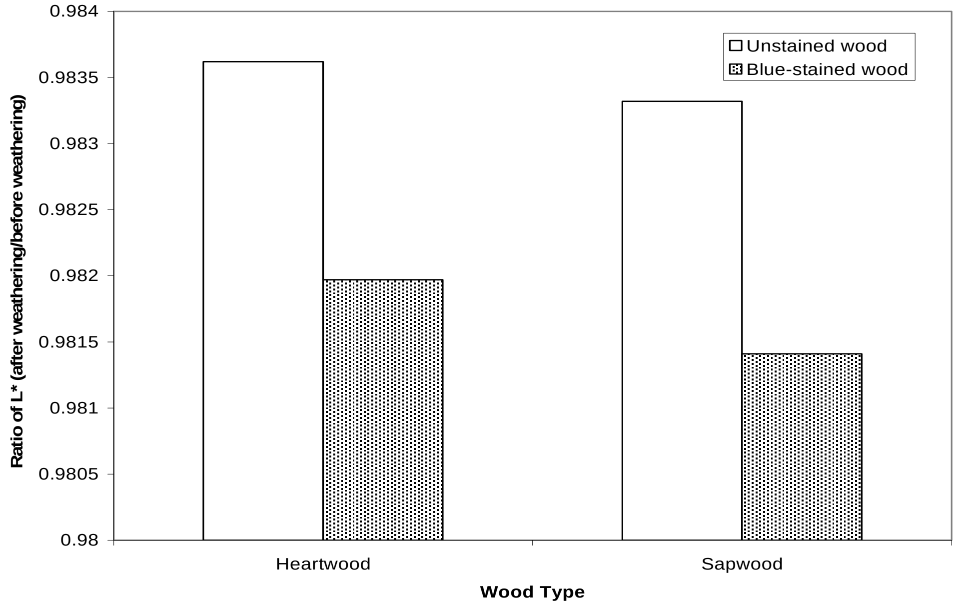


Figure 3. Effect of wood type (heartwood and sapwood) and wood condition (blue-stained and unstained) on L* (lightness) of the coated wood samples exposed to the weather for nine months (results averaged across finishing systems)

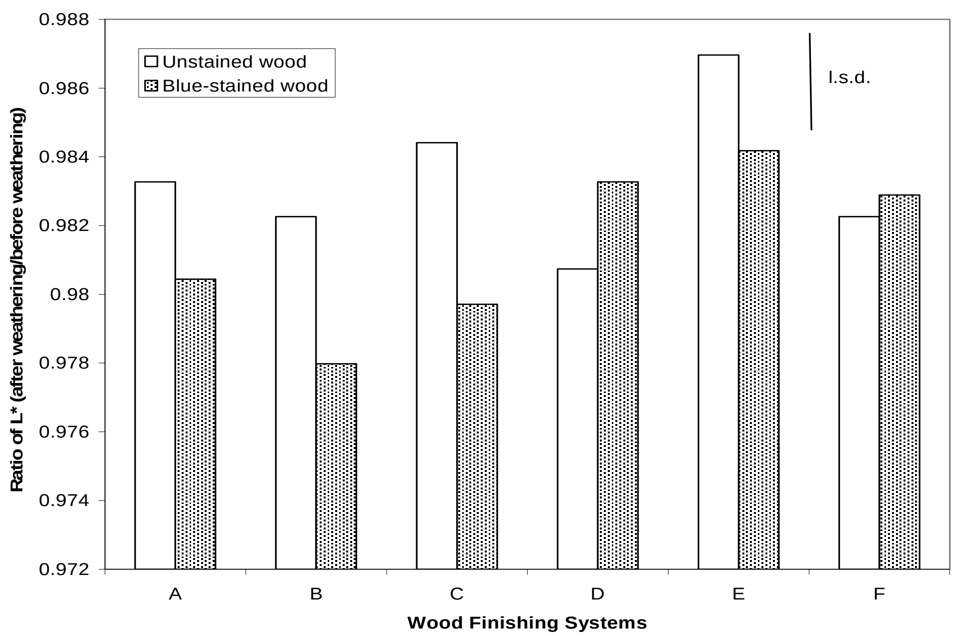


Figure 4. Effect of wood finishing system on L* (lightness) of the coated wood (sapwood) samples after nine months of weathering

In general the term “gloss” is used to express the ability of surfaces to reflect directed light. It is an important feature of wood finishes. Analysis of variance of the results for ratio of gloss (after weathering/before weathering) showed that wood finishing system had significant effects ($p < 0.001$) on the loss of gloss of the coated wood samples. Fig. 5 indicates that finishes on blue-stained sapwood showed greater losses of gloss than the same finishes on unstained sapwood. Differences in the ability of finishing system to restrict loss of gloss during natural weathering can be observed in Fig. 6. The effect of individual finishing systems on loss of gloss can be compared using a least significant difference bar (0.05 at 5% level). It can be seen that the wood finishing system A and D applied on

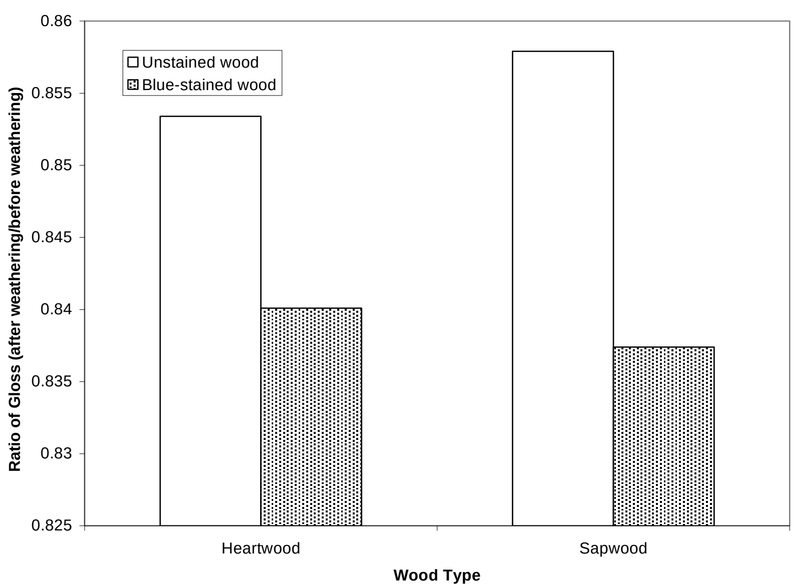


Figure 5. Effect of wood type (heartwood and sapwood) and wood condition (blue-stained and unstained) on the gloss of the coated wood samples exposed to the weather for nine months (results averaged across finishing systems)

blue-stained sapwood were the most effective at restricting loss of gloss during natural weathering.

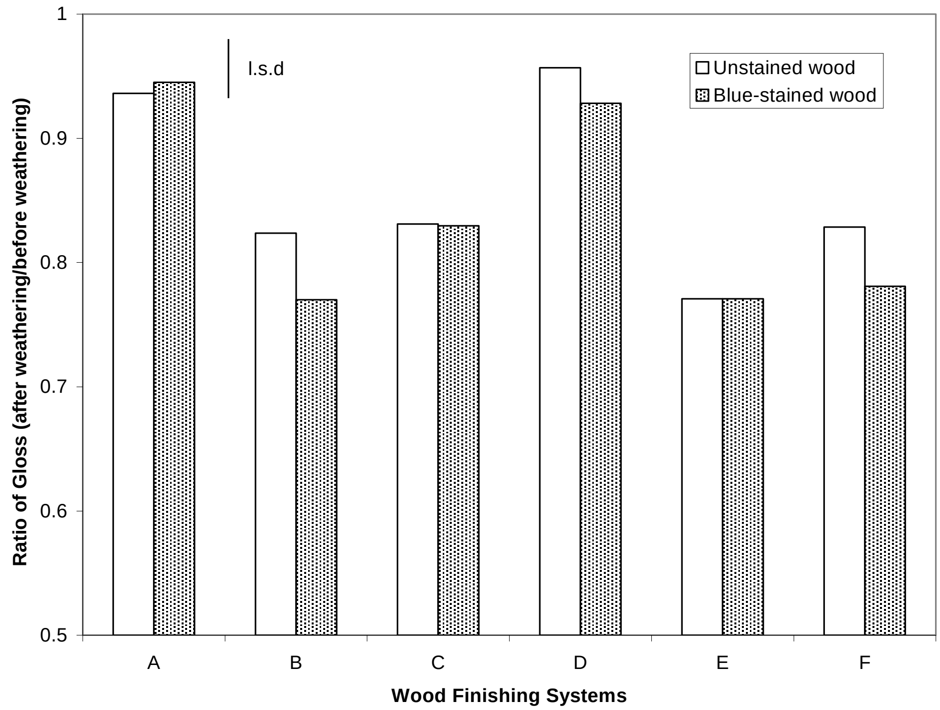


Figure 6. Effect of wood finishing system on the gloss of coated wood (sapwood) samples after nine months of weathering

Most of the samples lost their end seals after nine months outdoor exposure due to the delamination of the epoxy glue film from the ends of the samples. So the samples lost their moisture protection characteristics. However, analysis of variance of weight gain (moisture gain) of the coated wood samples after six months natural weathering showed that wood finishing system had a significant ($p = 0.004$) effect on weight gain. Fig. 7 shows the weight gain (moisture gain) of samples after six months of natural weathering. In all cases coated blue-stained wood samples gained more weight than that of coated unstained wood samples. It is obvious that a good finishing system should restrict weight gain of wood during the weathering. Fig. 7 showed that the weight ratio's for samples finished with finishes D, E and F were low compared to samples coated with the other finishing systems.

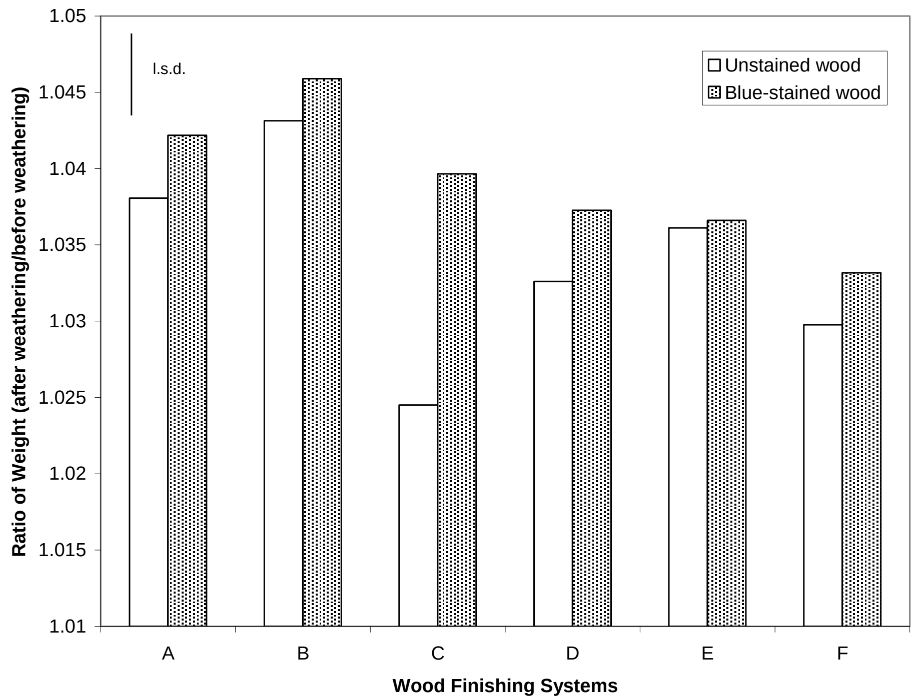


Figure 7. Effect of wood finishing system on the weight gain (moisture gain) of coated wood samples after six months of weathering

4.4. Conclusion

Results after nine months exposure showed that finishes applied to blue-stained sapwood were darker than the same finishes applied to unstained sapwood and heartwood (both in stained or unstained wood). Considering all factors it can be concluded that the wood finishing systems D (Primer: Behr # 436, 100% acrylic, white, water-based; Topcoat: Behr, exterior satin enamel, 100% acrylic latex, white) was the most effective at preventing the loss of the lightness and gloss of coated wood samples on blue-stained sapwood during weathering.

5. Performance of Opaque Finishes on Mountain Pine Beetle Affected Wood at Various Stages of Decay Process.

5.1. Introduction

The objective of this part of the work is to examine the performance of opaque finishes on mountain pine beetle-affected wood at various stages of the colonization of the wood by pathogenic fungi. Such knowledge could allow manufacturers of painted wood products to continue to use mountain pine beetle-affected wood with cost savings for their production process.

5.2. Research

Eight mountain pine beetle-affected lodgepole pine logs at various stages of the colonization process (unattacked, green (first year of attack), red (3rd year of attack) and grey (6th year of attack)) were collected from two different sites in the Alex Fraser Research Forest in Williams Lake, British Columbia. The logs were debarked manually and sawn ‘through-and-through" using a LT-15 Wood Mizer sawmill into 2.25 inch thick boards. Boards were kiln dried over a period of 14 days to a final moisture content of 13%. Two boards from each log were converted into cladding samples measuring 4” x 2” x 7’. These two boards from each log were randomly assigned to two different treatment systems (water repellent preservative and control). All four sides of the boards were planned using a Martin T44 jointer and a Martin T54 thickness planner. All longitudinal edges were rounded to a 5 mm radius using a Martin T26 shaper. The boards were cross-cut into samples, each 6” in length using an Omga radial arm saw. Four samples from each board were randomly assigned to four different wood finishing systems and their end grain was sealed using an epoxy-based sealer. Samples were conditioned at 20^{o}C and 65% relative humidity for 1 month.
The water repellent wood preservative was prepared by mixing paraffin wax (1%), wood preservative 3-iodo-2-propynyl butyl carbamate, (IPBC) manufactured by Troy Chemical Corporation, 1 Avenue L, Newark, N.J. 07105

(1%), resin (Minwax, urethane-based varnish, imported by Sherwin-Williams Canada Inc., Vaughan, Ontario, L4K 4T8) 20% (solid-based) and solvent (paint thinner) 78%. Water repellent wood preservative was brushed onto the blue-stained wood specimens at a level of 0.01 mL/cm^2.

Four different wood finishing systems (opaque, white, acrylic and alkyd finishes) were applied (primer plus two topcoats) to the different samples in accord with manufacturer's instructions. The description of the wood finishing systems is given below (Table 2):

Table 2. Coating systems applied to blue-stained samples

System No.	Primer	Top coat	Drying times (h)*
1	Behr # 436, 100% acrylic, white, water-based	Topcoat: Behr, exterior satin enamel, 100% acrylic latex, white	24, Primer (16) 24, Topcoat (4)
2	Dulux # 999 primer, alkyd, oil-based	Topcoat: Dulux, exterior, semi gloss, alkyd, oil-based	24, Primer (16) 24, Topcoat (16)
3	CIL smart, 100% acrylic, white, interior/exterior, water-based	Dulux exterior latex, 100% acrylic, pure white 1500, satin, water-based	24, Primer (4) 24, Topcoat (4)
4	Benjamin Moore # 100-00, alkyd, oil-based, exterior, white	Benjamin Moore, interior/exterior, high gloss, ultra-white, alkyd, oil-based	24, Primer (12) 24, Topcoat (24)

*Recommended drying times in parentheses

Coated wood samples were conditioned for 1 month and the colour of the finishes on coated wood samples was measured using a spectrophotometer (Minolta CM-2600d). Initial gloss of the finishes on coated wood samples was measured at an angle of 85° using a HWS 5820 BYK mirror-TRI-gloss meter (model 455). Weight and dimension of the test samples were also measured. Coated wood samples were exposed outdoors in Vancouver on a vertical test fence, facing south.

5.3 Next steps

During weathering exposure, samples will be brought back to the laboratory every quarter and will be wiped clean with a lint-free cloth, conditioned for 1 week and the colour, gloss, weight (moisture content), dimensional change etc. will be measured.