CWPA Proceedings, 2002, pp 48-60

ALTERNATIVES TO CHEMICALS

FOR CONTROL OF BLUESTAIN IN LOGS

By

Adnan Uzunovic, Tony Byrne and David Minchin
Durability and Protection Group
Forintek Canada Corp., 2665 East Mall, Vancouver, B. C. V6T 1W5

Summary

A long history of research has enabled the Canadian forest products industry to develop chemical means to combat stain in lumber. However deep bluestain often develops in logs prior to sawmilling and the industrial need for stain control is now focused more on log protection that it was formerly. Chemical products currently used for treating lumber are not feasible to use on logs in the forest and there are no products registered for this use in Canada. Although there are other options for prevention of bluestain during log storage, such as water storage (ponding or sprinkling), such practices are also not commonly used, usually because of environmental restrictions. Research is focused on management practices, biological control or integrated chemical/biological control. To successfully control stain in logs using these methods a high degree of knowledge about the biology and ecology of staining fungi and related organisms is needed. University partnerships play a major role in this more fundamental research. This paper reviews non-chemical methods of controlling bluestain in logs and gives results from two recently tested and promising methods: sour felling (delayed delimbing) and biological control using a colorless strain of bluestain fungus.

1 Introduction

Bluestain is a discoloration of sapwood caused by fungi that infect wood. Pines are especially susceptible to bluestain and, in western Canada, lodgepole pine (*Pinus contorta* Dougl.) is the most commonly harvested tree. In the last five years bluestain in lodgepole pine logs has had a big impact on the profits of affected sawmills. In summer of 1998 stain developed to epidemic proportions in logs being processed at some Alberta sawmills. Of three sawmills visited by Forintek staff bluestain caused losses for that year of $14.3 million dollars over and above the "normal" losses which the mills encounter. The losses were encountered because the sawn product cannot meet Japanese

requirements for stain free wood, nor can it be used for remanufacturing into high value products such as furniture.
Research on wood protection, sapstain control during shipping and storage, using chemicals, has been part of the Canadian Forest Products Laboratories' research program since the 1920s and 30s (Byrne, 1999). After Forintek Canada Corp. was born from these laboratories in 1979 the scope of wood protection research widened. Research on sapstain control using chemicals was concentrated in the western laboratory while in the eastern laboratory research into biological control ensued.

In the 1970s and 80s significant research effort was put into searching for chemical alternatives to the widely-used, but environmentally persistent, chlorophenates as well as improving chemical wood protection practices and results. By the early 1990s the industry had a small menu of non-chlorophenate products to choose from (Byrne 1997; Byrne 1998). The availability of products in Canada was, and still is, largely limited by the stringent pesticide regulatory framework. Potent formulations of fungicides, which are available in other countries, are often precluded from the Canadian market by these regulatory barriers. The chemical antisapstain wood treatment industry is now a mature one for in-mill applications on lumber (Byrne, 2002).

Unlike other countries there is no tradition of using chemical pesticides for the treatment of logs to prevent bluestain in Canada. Although the need for log protection is increasingly recognized it is unlikely that chemical treatments will be adapted because of negative public perceptions of the impact of pesticides on the environment. The insecticide lindane was the only pesticide registered for forestry use on logs but that registration has been recently revoked. The opportunity to treat the logs chemically in a closed non-polluting treatment system is limited given that, to be effective such chemicals would have to be applied shortly after felling and to be able to arrest any pre-infection. Its Technical Advisory Committee has given Forintek the goal "to develop and implement methods that will reduce the value loss in logs that occurs between harvesting and breakdown".

Trees felled using mechanised harvesting equipment are usually damaged in the process, either from the stem-grabbing rollers, or from the delimbing knives mounted on the machines. The aggressive spiked steel rollers cause physical damage to the logs, from tearing and holes, and loss in quality from compression marks (which penetrate up to 20 mm). Fungal deterioration, particularly bluestain, is often also associated with spiked roller damage or with other types of bark damage occurring during handling. Modern harvesting procedures and subsequent log storage may therefore result in a significant loss in value of the product derived from the logs.

In Canada water storage is the traditional method of log protection, currently used extensively by mills on the Pacific coast and formerly, by mills situated on inland rivers or lakes. Although it is a good method of stain control, due to environmental or recreational concerns storage on inland waterways has been restricted. Water spraying or

sprinkling of decked logs also provides excellent protection of logs from degradation; however the lack of availability of water at the mill or the need to recycle the water has limited use of such techniques for softwoods. Sprinkling is however often used for eastern hardwood logs that are used to produce appearance grade products, during the most critical period of stain development from May to September.

Log stain control measures, whether in the forest or in the sawmill yard, need to be environmentally benign. Thus log management practices and/or biological control methods appear to have the greatest practical potential. Forintek's research efforts described in this paper reports on two methods that were field tested over the last three years: sour felling (delayed delimbing) and biocontrol using an albino (colorless) bluestain isolate.

1.1 Sour Felling

Staining fungi efficiently and rapidly exploit wet, fresh, nutrient-rich sapwood utilizing both stored and mobile simple foods (Fleet *et al*. 2001). We postulated that modifying the substrate by reducing moisture content (MC) and/or nutrient levels may result in reduced bluestain. Because bluestain fungi initiate growth in wood with high MC, drying caused by delaying delimbing might prevent development of stain. By leaving the foliage on after felling and allowing respiration and passive transpiration to continue, some nutrients might also become depleted while the leaves remain green. The nutrition of bluestain fungi has only recently been studied in depth. These fungi use the sugars and starch present in the ray cells they colonize, as well as triglycerides, fatty acids and other lipophilic nutrients as carbon and energy sources (Eaton and Hale 1993, Chen *et al*. 1994, Fleet *et al*. 2001). They also require a nitrogen source and may use protease enzymes to break down protein (Abraham 1995).

Delayed delimbing is an old method of reducing MC in both hardwood and softwood logs and has been referred to in the literature as transpirational drying (e.g. McMinn 1986a and McMinn 1986b), biological drying (e.g. Visser 1985, Ratajczak 1973), crown drying (e.g. Hartwig and Visser 1981), leaf drying or leaf seasoning (Hakkila *et al*. 1970) [translation of the Japanese hagarashi], delayed bucking (e.g. Patterson and Post 1980), delayed processing (Garrett 1985), physiological drying (e.g. Sachsse and Oliver-Villanueva 1991), summer felling (it being customary to leave the top on summer felled logs until September [Beltram 1952]) and sour felling (a direct translation of Nordic term e.g. Faeste and Johansson 1982).

Several workers have reported on the drying effects of delaying delimbing after felling. (McIntosh, 1949; Garrett 1985; Patyakin and Belenov 1979; McMinn and Stubbs, 1985; Wells and Brooker, 1981). Despite many reports of the effects of delayed delimbing this practice does not appear to be widely used. We found few references to stain reduction associated with delayed delimbing and only one literature reference to nutrient depletion.

(Hayashi *et al*. 1988). Visser and Vermaas (1986) observed "considerably reduced" bluestain development in *Pinus radiata* in South Africa in the summer months. Visser (1990) reported that trees felled and left with crowns intact had lower incidence of warp and bluestain and there were energy savings during kiln-drying. Makas *et al.* (1998) speculated that drying stems to 25-30% moisture content should prevent damage by bluestain and red-rot fungi.

In our trials reported here we examined whether delaying delimbing could reduce bluestain in lodgepole pine roundwood.

1.2 Biological control of bluestain in logs

The concept of biological control of one organism by another has a long track record in the agricultural sector but is a more recent notion in forestry and especially in the forest products industry. In the field of wood products several workers have published information on the subject of biological control of wood staining fungi by bacteria or other fungi (among others: Benko1988, Benko and Henningsson 1986; Benko and Highley 1990; Bernier *et al*. 1986;. Chakravarty and Hiratsuka 1994; Dawson-Andoh and Morrell 1990; Highley *et al*. 1997; Kreber and Morrell 1993; McAfee and Gignac 1997; Morrell and Dawson –Andoh 1998; Schoeman *et al*. 1993; Seifert *et al*. 1987; Seifert, 1988). Results have varied in their degree of success in the laboratory but even systems, which showed success in the laboratory, have often failed under field conditions.

About 1985 Forintek's eastern laboratory began work on the biological protection of wood from sapstain and has taken a leading role in this area. The white mould *Gliocladium roseum* was eventually chosen for further development as a biocontrol agent (Yang 1999). The major challenges of biologically controlling fungi on Canadian sawn softwoods can be summarized as: 1) A large number of fungi cause stain, mould or decay and control by a single biocontrol organism (or narrow spectrum fungicide for that matter) is difficult; 2) Wood is highly variable in nutrient, moisture and extractive content which all affect the establishment and performance of biological control agents; and 3) It is very likely that the substrate is pre-infected with competing micro-organisms which could infest wood since the time of felling and during the sawing process. In lumber the problem of competing organisms can be solved, for example by clearing the niche of competing microorganisms by heat treatment prior to inoculation with *G. roseum* (McAfee and Gignac 1997). More recently a method of favoring the biocontrol fungus by using an alkali has been demonstrated (Yang 1999).

In logs staining, fungi are primary colonizers and are generally tolerant to the residual sapwood defense mechanisms and high moisture contents that prevail in freshly felled logs. Once they deplete readily available food sources, (they do not possess the enzymes necessary to utilize cell wall constituents), they die or are replaced by other fungi. Albino (non-pigmented) isolates of staining fungi occur naturally or can be obtained through

selective breeding. They have similar biological attributes to wild staining fungi and are thus able to colonize freshly felled wood and deplete the food resource but, because they are not colored, they do not cause aesthetic damage (Behrendt *et al*, 1995). Pigmented wild type fungi might therefore not be expected to grow and cause stain in the areas which albino fungi colonized first. This paper reports on tests done in Canada using an albino (colorless) strain of a common bluestain fungus *Ophiostoma piliferum* to protect lodgepole pine logs from being stained by wild type bluestain fungi. This strain is commercially available for pitch control as Cartapip 97® (AgraSol). The same organism, under the new name Sylvanex® is currently being reviewed for pesticide use (controlling bluestain) by Health Canada's Pest Management Regulatory Agency. Forintek's work using Sylvanex included laboratory and field tests. The lab tests have been already described in an earlier CWPA paper (Uzunovic *et al*, 1999a).

2 Materials and Methods

2.1 Sour Felling

Trials of sour felling were done in 2000 in the Brazeau River Valley 100-120 Km south of Edson, Alberta at an elevation of approximately 1230m (ASL). Lodgepole pine trees 85 to 100 years old were mechanically harvested with a log processor. Trees were mechanically delimbed to act as controls and trimmed to a top diameter of 11.5 cm, following the usual harvesting procedures. Others, the sour felled trees, were left with the limbs intact and not further processed. All test trees were then forwarded a short distance to a road and piled together. The pile was covered with other (non-test) trees which had been freshly-felled and the limbs left intact so that the center of a large pile was being simulated. Additionally, 9 sour-felled trees were piled where they were felled ("non-forwarded" trees), minimizing bark damage from handling during forwarding.

At the start of the 2000 trial a 5-cm thick disc for was removed from each of the test trees. The wet weight of the sample and the dry weight following oven-drying to constant weight at 105°C were used to calculate MC on a dry weight basis. In August 2000 (7 weeks after the set up), 5-cm sample discs were taken 30 cm from the butt ends of all test trees and the trees were re-piled with the covering of non-test trees. Ten of the sour felled trees were delimbed before re-piling (sour-felled/delimbed at week 7), leaving 20 delimbed control trees and 20 sour felled trees. In September 2000, 13 weeks after the trial was set up, 10 of each group, as well as the 9 sour-felled/non-forwarded trees were destructively sampled along the stem at 80 cm intervals along and brought back to laboratory for stain analysis.

Heartwood and total underbark diameters were measured twice, at right angles, on each disc. This enabled the area of sapwood to be calculated. Stained sapwood areas were measured by counting $1/16^{th}$ cm^2 squares marked on a transparent sheet grid placed over the disc face. Results were statistically analysed by ANOVA.

2.2 Biological control of stain in logs

We did two field trials in the summer of 2000 (one in the Skookumchuck River Valley, Cranbrook, British Columbia and one in Alberta in the Brazeau River Valley, south of Edson.). Lodgepole pine trees 85-100 year old, were freshly felled, delimbed and cut to 3m test logs using mechanized logging equipment.

The logs were placed in one layer on log bearers. A replication of 10 randomly selected logs (in 3 replicate piles) was used as a set for each treatment. Each log was manually rolled and its entire surface area sprayed with the assigned treatment including all sides and ends, and intact and damaged bark. Logs were treated to refusal.

The following treatments were spray-applied to the Alberta test logs:
1) Control (tap water)
2) Sylvanex – applied at a targeted 5 x 10^7 colony forming units (cfu)/mL (recommended concentration)
3) Sylvanex – applied at a targeted 1.5 x 10^7 cfu/mL (one-third of the recommended concentration)
4) Insecticide/fungicide (Tim-Bor – 10% disodium octaborate tetrahydrate)

At the BC site we applied only tap water or Sylvanex at 5 x 10^7 cfu/mL. Following treatment the logs were piled and non-test logs used to cover them.

On the sampling dates (6 and 13 weeks after set up) the cover logs were removed and 5 test logs from each pile were sampled destructively. The remaining five logs were covered again with protective logs and sampled after an additional 6 weeks of storage. At each sampling time five 50 mm discs were taken along the length of each log. The discs were cultured in the laboratory and fungi, including the recovered biological agent, were cultured and identified. The sapwood areas and amounts of stain were determined as described in the sour-felling research. Data were analyzed using analysis of variance (ANOVA).

3 Results and Discussion

3.1 Sour Felling

In Table 1 we summarized the percentage of the sapwood that was bluestained in the 2000 test.

Table 1: Amount of sapwood stained in test logs after 13 weeks.

Mean percentage of sapwood bluestained (SD) after 13 weeks			
Control logs – delimbed at time of felling	**Sourfelled/ delimbed at 7 weeks**	**Sourfelled-forwarded**	**Sourfelled-non- forwarded**
12.7 (12.1)	5.2 (7.0)	2.3 (4.9)	3.5 (6.5)

At 7 weeks there was little stain development but at 13 weeks there was enough stain development to allow for statistical analysis. Overall, sourfelled, forwarded logs had significantly less stain at 13 weeks (2% of sapwood area stained) than logs delimbed at weeks 0 or 6 (13% or 5% of sapwood area stained respectively). Analysis of covariance showed there was no difference in mean percent stain between the sour-felled, forwarded and non-forwarded logs. Analysis of co-variance also showed there was an interaction between treatment and heartwood diameter for trees delimbed at week 0 and week 7, i.e. the smaller the diameter of the disc sampled the smaller the mean percent stain.

Moisture Content

In the 2000 trial, the average MC at the set up was determined to be 126% (SD 22.3). Analysis of variance showed no significant difference between treatments. Mean moisture contents were:

- Controls delimbed at week 0 85.9% (44.7)
- Sour-felled delimbed at week 7 68.8% (39.7)
- Sour-felled –forwarded 61.3% (31.9)
- Sour-felled-not forwarded 84.4% (34.6)

There was a significant effect of disc location, with average moisture contents ranging from 64.2% in the butt portion of trees to 118.2% in the upper portions of the trees.

We conclude that in summer where bluestain develops in freshly felled logs there can be significantly less stain in lodgepole pine trees when delimbing is delayed. The mode of action is however not clear. Perhaps, simply, in a sour-felled log there is less access to the sapwood for the fungi at the critical stage, shortly after felling. Bluestain fungi get into sapwood where the bark has been damaged (Lee and Gibbs 1996). Mechanical delimbing causes considerable bark damage, and this amount of bark damage may result in more fungal colonization when it is done immediately after felling. Additionally, mechanical delimbing results in inoculation of staining fungi directly into the sapwood (Lee and Gibbs 1996; Uzunovic *et al*. 1999b).

Moisture reduction of the logs could also be a factor in reduced bluestain as the causal fungi can rapidly colonize wet wood, giving them a competitive advantage. As with the

literature reviewed, our work was inconclusive as to whether delaying delimbing results in a drier pine log and we could not relate stain reduction to moisture loss. In the 2000 test the amount of stain was significantly higher in the discs with larger diameter (i.e. discs from the butts) where the drying was higher, showing that drying did not prevent stain. The MC data did not reflect the machine operator's observations that the sour-felled logs were lighter. We hypothesize that sampling small areas for MC does not represent the whole log and that log weight is a much better indicator of MC reduction. Weight loss of an individual log probably depends on the weather and the position of a particular log in the pile.

We were unable to determine whether delaying delimbing resulted in nutrient reduction and cannot comment on whether nutrient reduction plays a role in delayed delimbing as a strategy for bluestain control.

Overall our research shows that delayed delimbing is a strategy for bluestain reduction which can be followed by companies using separate felling and delimbing equipment at the harvest site. Sour-felling is feasible when a feller/buncher is used for the initial cutting and delimbers are used to remove the branches. These mechanical harvesting techniques are widely used in the British Columbia interior and Alberta**.**

3.2 Biological control of stain in logs

Alberta and British Columbia - 2000 field tests

Mean underbark diameters ±SD (and their range) for logs used in the experiments were 19.1 ± 3.9 cm (12.4–31.3 cm). On the first sampling date (6 weeks) in Alberta we saw negligible stain and no data resulted. The lack of stain was probably due to the dry cold summer. Under such conditions the experimental logs could have dried out quickly thus preventing fungal growth. At the second sampling there was significantly less stain in Sylvanex (recommended concentration) treated logs than in the control logs ($p < 0.05$). Multiple comparison tests showed that the stain level in the control treatment was significantly higher ($p < 0.05$) than the means of all other treatments except for the Sylvanex low concentration (Table 2).

Table 2: Means and standard deviations of percentage stain

Treatment	Mean affected area (%) ± SD
Control	11.4 (±15.5)
Sylvanex (recommended)	1.5 (±3.3)
Sylvanex (low)	10.6 (±12.3)
Tim-Bor	5.6 (±6.6)

At the B.C. site, insufficient cover logs and hot weather caused considerable log drying. At the first sampling only a few logs from the bottom of the piles, were stained. Mean diameters for logs used in the experiments were 18.3 (SD 3.2 cm) (range 11.7–30.0 cm). We sampled six randomly chosen logs from each pile and did not sample the remaining logs. Our general impression was that controls had fewer but deeper patches of stain and the Sylvanex -treated logs had more frequent but shallower stain. The average percentage of the available area stained for control was 3.12 (SD 6.29) (range 0-36.4) and for Sylvanex 0.71 (SD 1.19) (range 0-6.5). However, statistical analysis showed that the effect of treatment was not significant ($F(1, 2) = 1.49$, $p = 0.346$).

During field samplings we saw abundant Sylvanex outgrowth on the surface of the Sylvanex sprayed logs. This fungus colonized the sapwood of the logs thoroughly and survived for at least three months in the field. No Sylvanex was found on the untreated logs, showing that the fungus does not easily spread onto nearby non-target woody tissue.

We assume that bluestain normally develops within this 12-week window if it is going to develop. After 12 weeks of growth, we assume that the combination of respiration of the dying tree and growth of the fungal biocontrol agent would deplete the nutrients such that the substrate is unfavorable for wild-type staining fungi.

4 Concluding Remarks

Sour felling and biocontrol are promising alternatives to chemicals for control of bluestain in logs. There can be significantly less stain in lodgepole pine trees when delimbing is delayed but the mode of action remains unclear. Further, in depth, work will help to understand the mechanisms behind the sour felling effect on bluestain reduction

In the biocontrol experiments the data clearly indicated that Sylvanex can control bluestain in freshly felled lodgepole pine logs if applied immediately after felling to the total log exterior. After six or 12 weeks of summer storage, when logs are most vulnerable, Sylvanex applied at the recommended concentration significantly reduced the amount of stain in the Alberta trials. At 1/3 of the recommended Sylvanex concentration stain resulted and the treatment was not significantly different from the control logs.

The product, and the concept of using albino isolates to control stain therefore has potential for industrial use. However, before Sylvanex is used industrially on a large scale it is recommended that additional studies should investigate whether adjuvants, such as spreaders and stickers, or using higher concentrations of the biocontrol agent, can improve its performance and consistency. The efficacy of the product should also be

tested on other wood species. Additionally there is a need to develop a field applicator so that the biocontrol agent can be sprayed on the logs during harvesting.

Acknowledgements

We gratefully acknowledge the help of: Sundance Forest Industries and Tembec Inc in the harvesting logistics; and Alan Donald of Donald Associates for statistical services. Forintek Canada Corp. would like to thank Natural Resources Canada (Canadian Forest Service), and the province of Alberta for their financial support of this research.

References

Abraham, L. 1995. Functions of a proteinase secreted by the sap-staining fungus *Ophiostoma piceae*. PhD Thesis. University of British Columbia, Vancouver, B.C.

Behrendt, C.J., Blanchette, R.A., and Farrell, R.L. 1995. Biological control of blue-stain fungi in wood. Phytopathology 85(1): 92–97.

Beltram, V. 1952. Summer felling of spruce. Schweiz. Z. Forstw. 1952 103 (8) (293-297).

Benko, R. and Henningsson, B. 1986. Mycoparasitism by some white rot fungi on blue stain in culture. . Int. Res. Group on Wood Pres. Document IRG/WP/1304. Stockholm, Sweden.

Benko, R. 1988. Bacteria as possible organisms for biological control of blue-stain. Int. Res. Group on Wood Pres. Document IRG/WP/1339. Stockholm, Sweden.

Benko, R. and Highley, T.L. 1990. Selection of media on screening of wood attacking fungi and antagonistic bacteria. 2. Interaction on Wood. Mat. U. Org. 25(3): 173-180.

Bernier, R., Desrochers, J.M. and Jursek, L. 1986. Antagonistic effect between *Bacillus subtilis* and wood staining fungi. J. Inst. Wood Sci. 10(5): 214-216.

Byrne, A. 1997. Sapstain control in Canada – Can New Zealand learn anything from the frozen north? Pp.7-15. *in* Kreber, B. (Ed.). "Strategies for Improving Protection of Logs and Lumber". Proceedings of Symposium, Rotorua, New Zealand, 21-22 November. *FRI Bulletin No. 204*.

Byrne, A.,1998 Chemical control of biological stain: past, present and future. Pp. 63-70. *in* Morrell, J.J. (Ed). "Biology and Prevention of Sapstain". Proceedings of Symposium, Delta Whistler Resort, B.C. Canada, May 25, 1997. Forest Products

Society, Madison WI, Publication No.7273.

Byrne, A. 1999. Canadian research in sapstain control-brief history and current focus. Pp 81-85 in Kreber, B. (Ed.) 1999: "The 2nd New Zealand Sapstain Symposium". Proceedings of Symposium, Rotorua, New Zealand, 18-19 November. Forest Research Bulletin No. 215.

Byrne, A. 2002. Status of anti-stain treating in Canada. *in* Proc. Canadian Wood Preservation Association 23rd Annual Meeting. Oct. 22-23. Vancouver, B.C. In press

Chakravarty, P. and Hiratsuka, Y. 1994. Evaluation of *Lecythophora hoffmannii* as a potential biological control agent against a blue stain fungus on *Populus tremuloides*. Journal of Plant Diseases and Protection, 101 (1):74-79

Chen, T., Wang, Z., Gao, Y., Breuil, C. and Hatton, J.V. 1994. Wood extractives and pitch problems: analysis and partial removal by biological treatment. Appita 47 (6).

Dawson-Andoh, B. and Morrell, J.J. 1990. Effects of chemical pre-treatment of Douglas fir heartwood on efficacy of potential bioprotection agents. Int. Res. Group on Wood Pres. Document IRG/WP/1440. Stockholm, Sweden.

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

Faeste, I., and Johansson, K.J. 1982. The course of drying in sour felled trees under various storage conditions. Rapport, Norsk Institutt for Skogforskning No. 2-82, 40 p.

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

Garrett, L.D. 1985. Delayed processing of felled trees to reduce wood moisture content. For. Prod. J. 35 (3): 55 59.

Hakkila, P., Heikkila, P., and Michelsen, P. 1970. 'Leaf seasoning' in harvesting veneer Birch. Commun. Inst. For. Fenn. 1970 70 (2). p. 42.

Hartwig, G.L.F., and Visser, J.J. 1981. Crown drying of *Pinus radiata* stems. South African Forestry Journal. No. 116, 51-59.

Hayashi, Y., Ohara, S., Furuta, M., Kurosu, H., and Kitamura, Y. 1988. Changes of chemical components and color of wood of sugi, *Cryptomeria japonica*, during

drying without lopping after felling in the forest. Mokuzai Gakkaishi Journal of the Japan Wood Research Society. 34: 11, 934- 941

Highley, T.L.; Padmanabha, H.S.A. and Howell, C.R. 1997. Control of wood decay by *Trichoderma (Gliocladium) virens* II. Antibiosis. Mat. U Org. 31:157-166.

Kreber, B. and Morrell, J.J. 1993. Ability of selected bacterial and fungal protectants to limit fungal stain in ponderosa pine sapwood. Wood and Fibre Sci. 25(1):23-24.

Lee, K. and Gibbs, J.N. 1996. An investigation of the influence of harvesting practices on the development of bluestain in Corsican pine logs. Forestry. 69. 129-133.

Makas, M. Schumacher, P. and Wegener, G. 1998. The target: semi-dry high-quality structural lumber. Holz-Zentralblatt. 124: 16, 246.

McAfee, B.J. and Gignac M. 1997. Antisapstain protection of steam pasteurized hemlock and fir lumber treated with a biocide and the potential bioprotectant, *Gliocladium roseum*. Mat. U. Org. 31(1): 45–61.

McIntosh, D.C. 1949. Project 129. Treatment of trees with chemicals (Stevens, Ontario). Transpiration experiment. Observations of trees felled and left with foliage intact (changes in weight, ease of peeling and condition of wood). Mimeo. For. Prod. Lab., Can. 1949. No. 0 141 16p.

McMinn, J.W. 1986a. Transpirational drying of Piedmont hardwoods. Georgia Forest Research Paper. No. 63, 7p.

McMinn, J.W. 1986b. Transpirational drying of red oaks, sweetgum, and yellow poplar in the Upper Piedmont of Georgia. For. Prod. J. 36 (3): 25-27.

McMinn, J.W., and Stubbs, J. 1985. In woods drying of eucalypts in southern Florida. For. Prod. J. 35(11,12): 65-67.

Morrell, J.J. and Dawson–Andoh, B.E. 1998; Biological Control: Panacea or Boondoggle. In proceedings of the meeting "Biology and Prevention of Sapstain" held at Delta Whistler Resort, B.C. Canada, May 25, 1997. Forest Products Society, Madison WI, Publication No.7273. 39-44.

Patterson, W.A. III, and Post, I.L. 1980. Delayed bucking and bolewood moisture content. Journal of Forestry. 78: 7, 407-408.

Patyakin, V.I., and Belenov, I.A. 1979. Improving the buoyancy of wood. Lesnaya Promyshlennost'. No. 7, 12-13.

Ratajczak, Z. 1973. Effect of drying Beech wood with the aid of crown suction force, and the method of stacking, on the occurrence of incipient decay and rot. Prace

Instytutu Technologii Drewna. 20: 1, 43-58; NLL.

Sachsse, H. and Oliver-Villanueva, J.V. 1991. Physiological drying and keeping windthrown beech alive. Forstarchiv. 62: 2, 51-56.

Schoeman, W.M., Webber, J.F. and Dickinson, J.D. 1993. Chain-saw application of *Trichoderma harzianum* (Rifai.) to reduce fungal deterioration on freshly felled pine logs. Mat. U. Org. 28(4): 243-250.

Seifert, K.A. 1988. Biological control and wood protection. In Proceedings of the Ninth Annual Meeting of the Canadian Wood Preservation Association. Toronto, Ontario, November 1-2, 1988. p:124-137.

Seifert, K.A.; Hamilton, W.E.; Breuil, C. and Best, M. 1987. Evaluation of *Bacillus subtilis* C 186 as a potential biological control of sapstain or mould on unseasoned lumber. Can. Jour. Microbiol. 33:1102-1107.

Uzunovic, A. Webber, J., Peace, A. and Dickinson, D. 1999b. The role of mechanized harvesting in the development of bluestain in pine. Can. J. For. Res. 29. 242-251.

Uzunovic, A., Byrne, A. and Yang, D.-Q. 1999a. Biocontrol in wood protection - can it work? Proc Cdn. Wood Preservation Assoc. 20: 69-78

Visser, J.J., 1985. Biological drying of *Pinus radiata* and *Eucalyptus cladocalyx* trees. Proceedings Volume 3. Symposium on forest products research international achievements and the future, 22-26 April 1985, Pretoria, South Africa. Paper no. 89, 15 p.

Visser, J.J. 1990. Evaporation as a parameter to measure mass loss in biological drying *Pinus radiata* trees. J. Inst. Wood Sci. 11: 6, 231-235.

Visser, J.J. and Vermaas, H.F. 1986. Biological-drying of *Pinus radiata* and *Eucalyptus cladocalyx* trees. J. Inst. Wood Sci. 10:5:197-201

Wells, G.C., and Brooker, R.E. 1981. Drying logs in the forest. Report, New Zealand Logging Industry Research Association. 6: 2, 4p.

Yang, D-Q. 1999. Pp 87-92. Biological and integrated control of sapstain on Canadian softwoods by using *Gliocladium roseum.* In Kreber, B. (Ed.). Proceedings of 2nd Forest Research Symposium, Rotorua, New Zealand, 18-19 November.