THE POTENTIAL FOR BIOLOGICAL CONTROL OF STAINING FUNGI DURING LOG STORAGE

JOELY SNOW

1996 GOTTSTEIN FELLOWSHIP REPORT

JOSEPH WILLIAM GOTTSTEIN MEMORIAL TRUST FUND

The Joseph William Gottstein Memorial Trust Fund was established in 1971 as a national educational Trust for the benefit of Australia's forest products industries. The purpose of the fund is *"to create opportunities for selected persons to acquire knowledge which will promote the interests of Australian industries which use forest products for the production of sawn timber, plywood, composite wood, pulp and paper and similar derived products."*

Bill Gottstein was an outstanding forest products research scientist working with the Division of Forest Products of the Commonwealth Scientific Industrial Research Organization (CSIRO) when tragically he was killed in 1971 photographing a tree-felling operation in New Guinea. He was held in such high esteem by the industry that he had assisted for many years that substantial financial support to establish an Educational Trust Fund to perpetuate his name was promptly forthcoming.

The Trust's major forms of activity are,

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2. Seminars - the information gained by Fellows is often best disseminated by seminars as well as through the written reports.

3. Wood Science Courses - at approximately two yearly intervals the Trust organises a week-long intensive course in wood science for executives and consultants in the Australian forest industries.

4. Study Tours - industry group study tours are arranged periodically and have been well supported.

Further information may be obtained by writing to,

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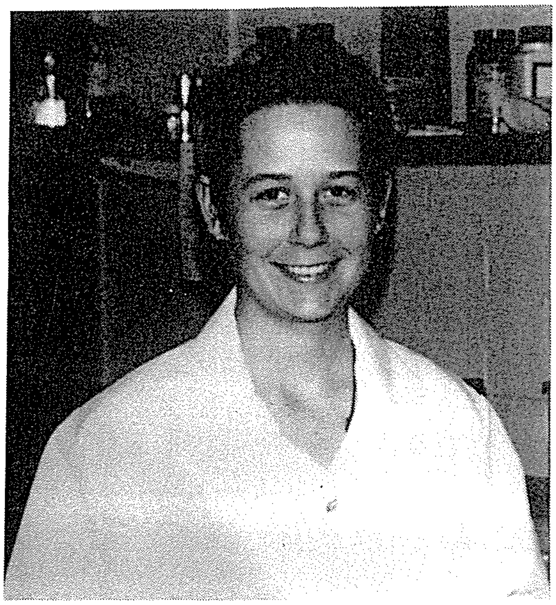

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The Potential for Biological Control of Staining Fungi During Log Storage

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"Nature abhors a vacuum"

• Spinoza
17th century

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Acknowledgments

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Summary

Fungal stain in wood is caused by the presence of fungi growing on the surface or within the wood. The presence of stain in timber can severely reduce the appearance value of timber and can result in loss of revenue for sawmills processing timber with the stain problem. One sawmill in Victoria lost $5 million in the downgrade of timber due to the stain problem during a one year period. Methods of control of fungal stain in timber include management under water sprinklers, use of chemical preservatives, and biological control.

A study tour to New Zealand was conducted to examine the possibility of biological control of staining fungi in Australia. The tour included visits to scientists at the Forest Research Institute in New Zealand, tours of Kaingaroa Forestry Corporation Sawmill and Waipa Sawmill, and a visit to HortResearch in Hamilton.

Interest in biological control has increased in New Zealand over the past few years, with chemical companies and sawmills participating in the testing of potential biological control agents. HortResearch has done a significant amount of work with biological control agents which show promising results.

Use of biological control is suggested for logs stored under water sprays, where chemical preservatives cannot be used because of leaching. Biological control is only one element in successful management of fungal stain. Other factors, such as timing of log transport from the forest to the sawmill, water sprinkling, and control of stain in sawn timber must also be addressed.

Fungal Stain in Wood

Fungal stain in wood is caused by the presence of fungi growing on the surface and/or within wood. It most commonly occurs in sapwood of conifers and in tropical hardwood species. The stain, ranging in colour from yellow to pink to blue-black, can be caused by secretion of enzymes by the fungi, which results in a change in wood colour, or the appearance of melanin-rich fungal hyphae in the wood structure (Zink & Fengel, 1988). The presence of stain reduces the appearance value of timber and may result in significant loss of revenue for sawmills processing timber suffering from the stain problem.

Several sawmills in Victoria have complained of stain problems over the past few years. Recent figures from a hardwood sawmill suggest a loss of up to $5 million in one year due to the downgrade of timber affected by the stain.

Fungi capable of causing stain range from surface moulds such as *Trichoderma* and *Penicillium* species, to fungi which penetrate deeply into the wood (*Ceratocystis* and *Ophiostoma* species). In Victoria, the most common staining fungi isolated from hardwood logs stored under water sprays were *Graphium putredenis* (Corda) Hughes, *Aureobasidium pullulans* (de Bary) Arnaud, and an *Ophiostoma* sp., all of which are able to penetrate into the heartwood (Snow, 1996). The hardwood species used for isolations were *Eucalyptus nitens* (shining gum), *Eucalyptus obliqua* (messmate), *Eucalyptus delegatensis* (alpine ash), and *Eucalyptus regnans* (mountain ash).

E. obliqua is commonly stained a bright yellow colour by *Penicillium glabrum* (pers. observation). *Ophiostoma* species are also frequently isolated from *E. obliqua*, *E. regnans*, and *E. delegatensis* (pers. observation). Fungal stains can be differentiated as stains which affect only the sapwood (sapstain), stains which affect the heartwood as well, and moulds which discolour only the surface of the wood.

Most hyphae of stain fungi utilise sugars and carbohydrates available within the ray parenchyma cells, and are unable to digest cellulose, hemicellulose, and lignin, and cause little loss in wood strength (Eaton & Hale, 1993). In conifer wood, hyphae may pass from one cell to another via pit apertures. Many staining fungi are able to produce fine penetration hyphae capable of boring through cell walls using transpressorium structures and the secretion of enzymes. Although bore holes are produced by this process, there is again very little loss in wood strength (Liese, 1970).

The major problem with stain fungi is the resulting discolouration and further conditions which may be suitable for decay. Methods for control of stain include management of timber under water sprinklers, use of chemical preservatives, and biological control.

Management and Chemical Control Measures for Fungal Stain

In Australia, most of the fungal stain problem has centred around softwood and hardwood logs during long periods of storage. Most softwood species in Australia are immediately sawn and kiln-dried, providing little opportunity for stain to develop. However, logs from large salvage operations which must be stored for months, and even years, are at risk of fungal stain. Changes in softwood shipping practices have also contributed to increased instances of fungal stain. A hazardous staining situation is created by shipping whole logs and unseasoned timber overseas in ship holds. The long storage periods and damp environment provide excellent conditions for the development of stain. Hardwood log piles, even those maintained under water sprinklers, are also at risk of fungal stain.

Many conditions within log yards and air drying yards can contribute to the spread of fungal stain. Stain-causing fungi have been isolated from logs lying in mud at both forest landings and in log piles at sawmills (Snow, 1996). Soil and organic debris, such as sawdust, may harbour stain-causing fungi. Logs from the forest can also bring staining fungi into the log pile, particularly logs with incipient decay (Snow, 1996).

Most hardwood sawmills maintain log storage piles under water sprinklers. Historically, this is done to prevent drying defects, such as splitting and checking. Generally, logs stored under water may resist attack by sapstain fungi. The presence of water severely restricts the amount of free oxygen available for use by fungi and they are subsequently unable to grow in the oxygen-deficient environment. However, the water from the sprinklers may provide a moist environment for staining fungi to grow. On the other hand, logs which are allowed to sit without water sprays are quite susceptible to attack by staining fungi, particularly by insect transmission.

Ponding and intensive sprinkler regimes are control methods which are currently being pursued in Australia. Log storage can be implemented in a pond, where logs are completely submerged in water, or as a water sprinkler regime. Both methods have been used with relative success both in Australia and overseas (Elowsson & Liukko, 1995; Kennedy, pers. comm.).

However, in order for water sprinklers to successfully control the spread of sapstain fungi in a log pile, proper maintenance is essential. Sprays must evenly distribute an adequate amount of water over the log pile. Logs from the forest must be placed under the water sprays as soon as possible after harvesting, to reduce the potential for stain fungi to become established within the wood.

In addition, water sprinklers can only control stain for a limited period of time. After logs leave the pile, they are again susceptible to attack by staining fungi. Sprinkling of logs affords no protection to sawn timber subsequently produced from these logs, which may still harbour active stain fungi until dried to below about 20% moisture content.

Ventilation is particularly important in areas where wet wood is being air-dried. Stacks of air-drying timber can be spaced to allow for maximum benefit of air currents. Periodic rotation of timber in drying sheds with particular attention paid to spacing between stacks can minimise stain development. The ground beneath timber stacks must be dry gravel, free from grass and weeds.

Logs stored in log piles should be removed in a timely manner, with the first logs into the stacks being the first to be removed for sawing. Long-term storage of green wood in Australia is difficult at best, due to temperature and humidity favourable to staining fungi. Geographic areas receiving continuous winter rainfall seem to have the most severe stain problems (pers. observation). Logs do not remain in fungal-free condition in the log piles for long periods of time, without additional chemical treatment.

Wood preservative chemicals have been used in Australia and overseas with both softwood roundwood, and softwood and hardwood sawn timber. Most roundwood is treated before shipment overseas. This is relatively successful where logs are protected from rain during shipment and the time expectancy for preservative effectiveness is less than 6 months. Preservative treatment of hardwood logs in Victoria is not feasible because of the practice of water sprinkling, which would leach the preservative from the logs.

Preservative application to sawn timber is one control method which is currently being reviewed for hardwood sawmills. However, in cases of extreme infection during log storage, fungal hyphae may penetrate to a depth in the wood where it cannot be treated by conventional preservative dip treatments. This has already occurred at one sawmill in Victoria, where preservative application was ineffective because the existing depth of infection was inaccessible to preservatives (Snow, 1996).

The most common preservative chemicals used in New Zealand to control fungal stain are Cutrol 375, NP-1, and Hylite Extra. Cutrol 375 and Hylite Extra are both made and distributed by Fernz Timber Protection. NP-1 is produced and distributed by Koppers-Hickson. Formulations can be applied to sawn timber and logs (for shipment overseas). However, none of the commercial formulations give effective protection for over 6 months, which is the minimum period of time requested by industry (Kreber, pers. comm.).

The use of biological control in the log pile to prevent the spread of stain fungi has been an area of intense research by several organisations (Behrendt *et al.*, 1995a; Croan, 1996). As well as being an environmentally friendly alternative to preservative treatments, there may be fewer occupational health and safety concerns related to application of the biological control agents used for wood preservation. Biological control could also be applicable in situations where preservative chemicals are not able to be used, such as on logs which are maintained under water sprinklers, during long term storage, and by preventing deeply penetrating stain in logs.

Biological Control of Fungi

Biological control can be defined as the "reduction of the amount of inoculum or disease-producing activity of a pathogen accomplished by or through one or more organisms other than man" (Cook & Baker, 1983). There are several ways that biological control can be effective against plant pathogenic fungi which also apply to staining fungi:

i) if the biological control agent can destroy the inoculum (the initial amount of staining fungus present), or
ii) if it can exclude the staining fungi from the host, or
iii) if it can suppress or displace the staining fungus after an initial infection.

The fungus *Trichoderma harzianum* Rifai, for example, acts as a biological control agent of other fungi by antibiotic production, lytic enzyme production and mycoparasitism (Murmanis *et al.*, 1988).

The fungi which exist on logs within a log pile are part of a biologically dynamic community. Each organism has a direct effect upon its physical environment and is capable of modifying this environment by secreting enzymes or other products of metabolism, which then allows other organisms to enter the community (Cook & Baker, 1983). Biological control cannot hope to create an empty space within the complexities of a community: it can only hope to rearrange and replace organisms within the balance in a way that excludes the unwanted organism, in this case, the staining fungus.

There are several elements which, combined, result in a successful biological control agent for preventing wood degradation (Behrendt *et al.* , 1995b):

i) it must be able to successfully live in and colonise the nonsterile wood substrate in the field,
ii) it must be able to successfully compete against other microorganisms,
iii) it must be able to live in varying environmental conditions, and
iv) it must be able to live for extended periods of time in a nonsterile wood substrate in the field.

The biological control agent must also be able to be successfully transferred from laboratory conditions to field conditions. This transfer is not always successful because of the relative lack of nutrients in the field as compared to the laboratory and results of laboratory trials may also be closely related to the media used for culture growth (Hadar *et al.*, 1979; Rattray *et al.*, 1996). In the field there is also competition for nutrients between different fungi, whereas laboratory inoculation trials are most commonly performed with monocultures.

Hadar *et al.* (1979) demonstrated the effect of different media on the effectiveness of *Trichoderma harzianum* as a parasite of other fungi. *T. harzianum* parasitised the mycelium of wood degrading fungi when the degrading fungus was the only carbon source available to *T. harzianum*, and when glucose was added to the medium, parasitism was much more rapid. However, Rattray *et al.* (1996) also found an increase in antagonistic activity of a fungus, but under low nutrient conditions: species of *Trichoderma*, *Gliocladium*, *Penicillium*, and *Hypomyces* exhibited stronger antagonism toward *Serpula lacrymans* (Wulfen: Fr) when the malt extract concentrations were reduced in the medium. The addition of laminarin and chitin to culture medium resulted in extracellular production of ß-(1-3) glucanase or chitinase by *T. harzianum.*, enzymes which were capable of degrading *Rhizoctonia solani* Kühn cell walls when the *Trichoderma* and *Rhizoctonia* were co-cultivated (Murmanis *et al.*, 1988; Elad *et al.*, 1983).

Popular potential biological control agents against wood-inhabiting fungi are species from the genera *Trichoderma*, *Aspergillus*, *Gliocladium*, and colourless strains of *Ophiostoma*. Applications of *Trichoderma* include inoculation onto freshly felled trees using a chainsaw. Chainsaw application of *Trichoderma* in chain-oil resulted in reduced appearance of stain and decay fungi on small billets of Scots pine (*Pinus sylvestris* L.) left in the field for 12 weeks (Schoeman *et al.*, 1994).

Gliocladium virens Miller (Giddens & Foster) is commonly known to secrete antifungal gliovirin and gliotoxin (Highley *et al.*, 1996). Laboratory studies using *G.virens* and its metabolites were unsuccessful against several brown-rot, white-rot and stain fungi on wood blocks and agar media laboratory trials (Highley *et al.*, 1996). Agar plate interaction studies of *Aspergillus*, *Trichoderma*, and *Penicillium* isolates against the decay fungi *Trametes versicolor* L. ex Fr. and *Neolentinus lepideus* Fr.: Fr. had mixed results (Bruce & Highley, 1991). The cell free filtrate from an *Aspergillus* culture consistently exhibited greater inhibition against decay fungi. Bruce & Highley (1991) concluded, from the complexity of the modes of antagonism exhibited by cultures during the study, that the effectiveness of biological control agents is likely to change with differing environmental conditions.

Stachybotrys cylindrospora C.N. Jensen isolated from *Populus tremuloides* Michx. was tested against a common stain fungus, *Ophiostoma crassivaginatum* H.D. Griffin (Hiratsuka *et al.*, 1994). Dual cultures of the fungi resulted in decreased growth of the stain fungus in liquid and agar cultures (Hiratsuka *et al.*, 1994). *S.cylindrospora* inoculated onto wood chips effectively prevented the growth of *O. crassivaginatum.* Both trichodermin and trichodermol were isolated from cultural filtrates of *S.cylindrospora.* Both compounds were able to limit the growth of *O.crassivaginatum* in vitro.

Other work involving fungal agents has concentrated not only on the antagonistic properties previously mentioned, but also on exclusion of fungi from the wood substrate. A colourless isolate of *Ophiostoma piliferum* (Fr.) H.&P. Sydow, marketed by Sandoz Chemicals Corporation as CARTAPIP™58, was tested on chips of loblolly pine (*Pinus taeda* L.) (Blanchette *et al.*, 1992). Although most studies involving CARTAPIP™58 aim at reducing the amount of pitch in wood chip piles prior to pulping because the fungus utilises pitch as a food source, the isolate has shown promise as an antisapstain control measure, particularly when used in combination with an insecticide to reduce the transmission of sapstain fungi by insects (Behrendt *et al.*, 1995b).

Bacteria have also been tested as potential biological control agents against staining fungi in wood. Early laboratory studies with *Bacillus subtilis* showed a fungicidal effect against staining fungi in culture (Bernier *et al.*, 1986). Later trials, particularly those involving the common stain fungus *O. piliferum,* were unsuccessful in preventing growth of fungal hyphae on wood substrates (Seifert *et al.*, 1987). The suggested reason for failure was the inability of *B. subtilis* to colonise the wood substrate.

In conclusion, there has been variable success using bacteria and fungi as biological control agents against stain fungi. The area still has many aspects of biological control which are not completely understood, and there is considerable potential for research to be done.

Study Tour

The purpose of the study tour was to gain a better understanding of non-chemical preservation of wood against stain fungi. Within Australia, recent experience has been limited to water storage of softwoods in Queensland by the Department of Primary Industries. The one week visit to the New Zealand Forest Research Institute and HortResearch revealed the increasing interest by the softwood industry into biological control.

Department of Primary Industries

The following information was supplied by Michael Kennedy (DPI Queensland) during a telephone conversation on 18 June 1996.

About two years ago, wildfires destroyed a large portion of the softwood resource managed by the Department of Primary Industries in Queensland. Following the wildfire, salvage operations removed a 385,000 cubic meters of mainly slash pine (*Pinus elliottii* var. *elliottii* Engelm.) logs to a large-scale log dump surrounding a water reservoir. For the first 9 months, logs were sprayed with seawater pumped in from a nearby tidal creek. There were no significant difficulties during the first 9 months, and water spray amounts were reduced as seasonal rain increased and to save on energy costs. Subsequently, higher sprinkling schedules were reinstated. Very little stain was discovered on logs during this time. Most sapstain was observed on logs which were brought into the stacks a few weeks after the fire.

About twelve months after the fires, borers were found on the underside of the logs. This was attributed to algal growth on top of the logs, which was absorbing water, allowing the bottoms of the logs to remain dry and susceptible to borer attack. It was also due to inappropriate placement of water sprinklers. Later, fruiting bodies from *Rigidoporus lineatus* (Berk.) Ryvarden were discovered within the stacked logs. *R. lineatus* is the basidiomycetes that has resulted in the downgrade of a large portion of the stored timber resource.

Apart from restoration of the water sprays to the log piles, no measures were taken to prevent any fungal attack. It was suggested that replacement of the salt-water spray with fresh water coincided with the onset of the degradation problems. Presently, logs are being extracted and utilised as quickly as possible from the log storage piles to maximise use of the diminishing resource.

This is an example where management techniques have failed. The failure is probably because of the inadequate spraying. No biological control was used in this example, but future trials would provide a potential situation to experiment with use of biological control.

Forest Research Institute

While visiting the Forest Research Institute (FRI) in Rotorua, a number of methodologies were obtained for testing wood preservatives (both chemical and biological formulations). This material is presented in the section "Sapstain Preservative Trials". No research is currently being conducted into the use of biological control agents to control fungal degradation of wood at the FRI.

After speaking with several people from FRI, an inspection of field trials was conducted. Post trials and stake trials were examined, and examples of brown-rot, white-rot, soft-rot, and stain were found. Methodology for field trials was discussed, particularly the spacing requirements for post and stake trials.

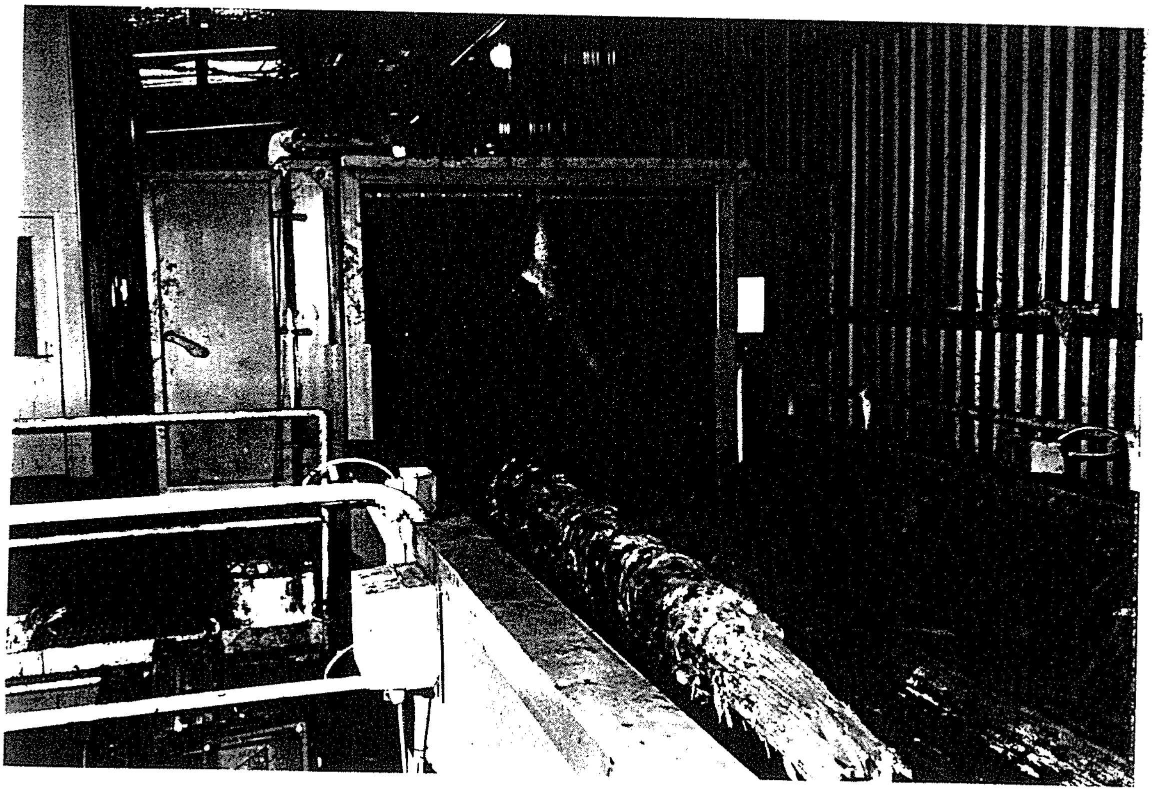
The tour of Kaingaroa Forestry Corporation Sawmill provided great insight into online spray application of anti-sapstain preservatives to roundwood. The Lektraspray, developed by the New Zealand FRI, is used to apply anti-sapstain preservatives onto pine roundwood prior to shipment overseas. The online treatment reduces waste of the chemical and, because of the electric charge applied to the spray droplets, drift is reduced.

The Lektraspray system results in even coverage of debarked logs with anti-sapstain preservatives. The logs are then loaded onto trucks and transported to docks, where they are then loaded onto ships for transport overseas. The shipment of radiata pine (*Pinus radiata*) sawlogs overseas would not be possible without effective anti-sapstain treatment because of the imminent and severe staining which occurs otherwise.

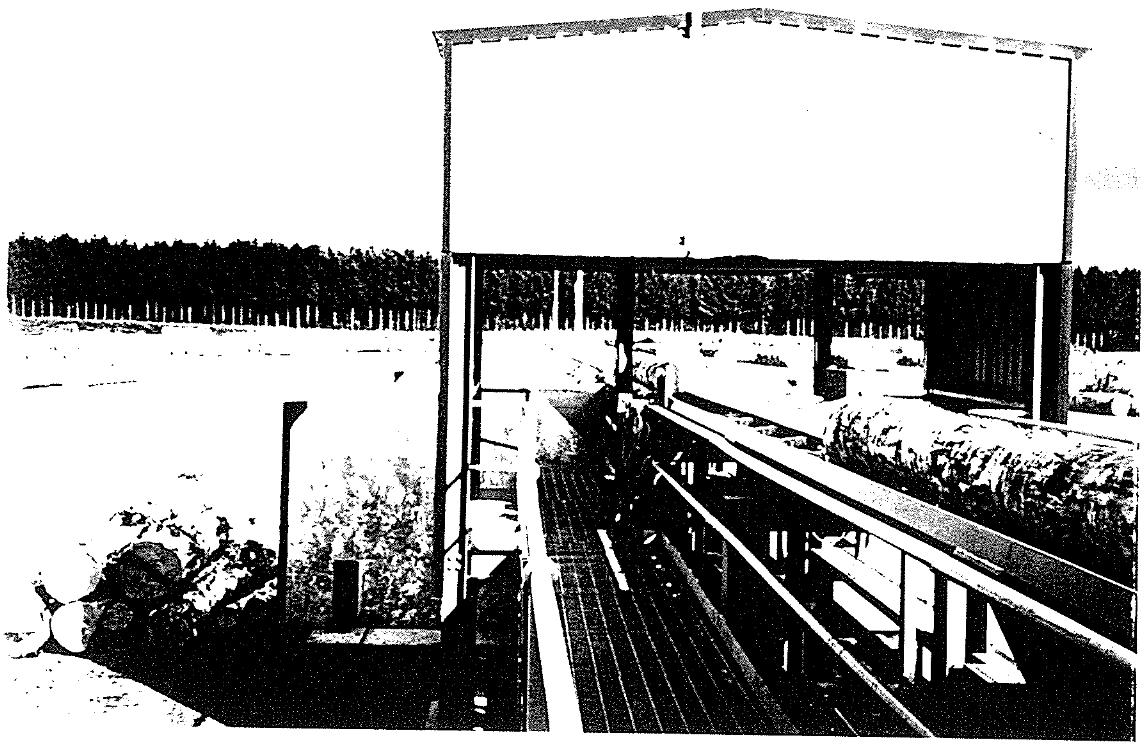
During the tour of the Prolog Sawmill (Forestry Corporation), now a part of the Fletcher Challenge group, discussion of the merits of biological control of stain fungi revealed that the sawmill is currently involved in field trials using a biological control agent. This field trial is being undertaken in conjunction with HortResearch. Prolog was also using an online anti-sapstain dip treatment for green timber at the sawmill.

Timber from the mill is dipped into a tank of solution before being stacked for export. The preservative being used at the time of my visit was Hylite Extra. The sawmill had a few problems with the treatment system at the time of the visit, with Hylite Extra dropping out of solution and clogging the dosing pump. The dipping system did not conform with the new environmental standards and a new system was being built to conform to standards.

Although Prolog had never used a biological control agent for timber protection in the past, the sawmill manager seemed quite excited about the prospect of new, safer anti-sapstain preservatives. The field trials currently underway could not be discussed, however, because of confidentiality agreements with HortResearch.



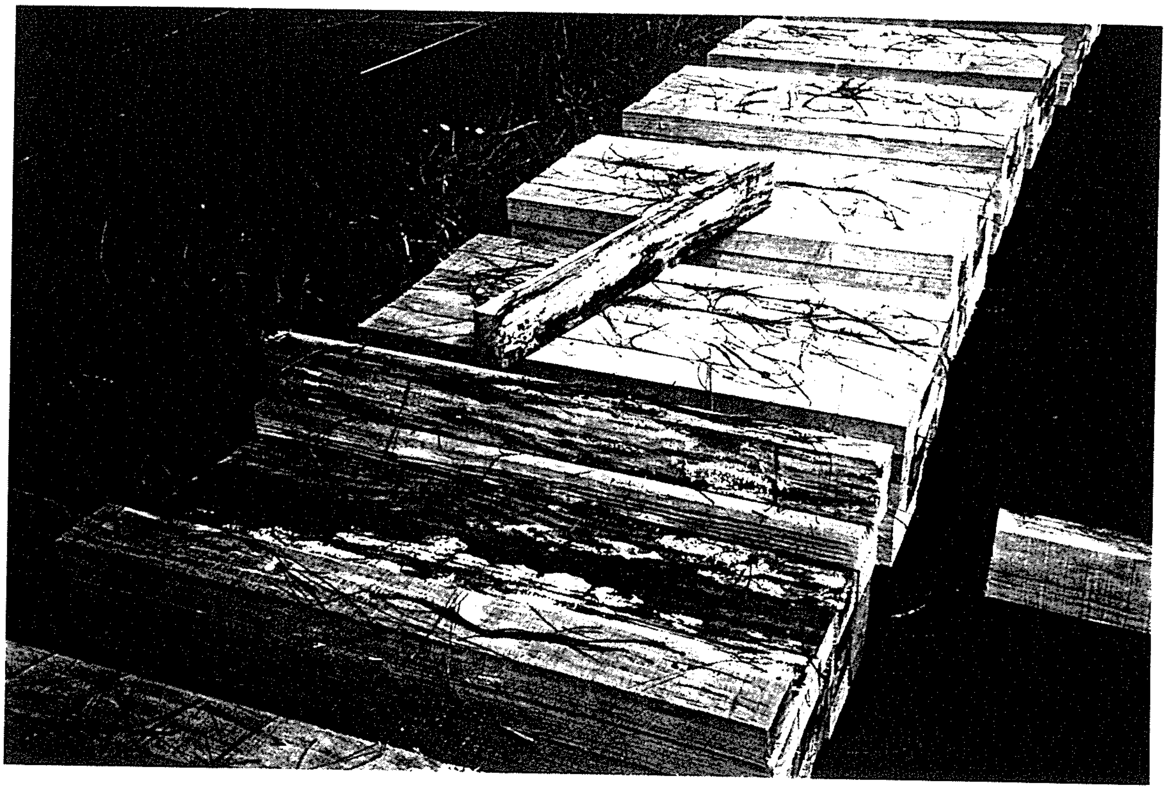
An example of a Lektraspray in use at the Kaingaroa Forestry Corporation Sawmill. The lektraspray is part of an online process. Logs enter the spray cabinet and emerge from the other side sprayed with paint as an indicator that antisapstain treatment has been used.



Sapstain Preservative Trials

Block stack tests for sapstain preservative trials are most commonly used for small-scale field trials. Packs are built of 25 boards (per repetition). Boards are 1 metre long and are block stacked with no stickers separating the boards. Treated packs are stacked on top of two untreated boards to avoid contact with the ground.

Boards are rated by surface area assessment of stain every 6 weeks.



Examples of block stacking used for sapstain preservative trials. Blocks are stacked on top of two untreated boards to avoid contact with the ground.

HortResearch

HortResearch is predominantly involved with horticulture, but has been commissioned by private companies to work with the biological control of staining and decay fungi in wood. Stuart Kay, the scientist interviewed at HortResearch, stated that "Biocontrol has potential in the New Zealand industry and the government has begun to put a lot of money in that direction." Both Fletcher Challenge and Carter Holt Harvey have approached HortResearch for testing of biological control agents.

Past research at HortResearch has been with natural products, such as plant extracts, essential oils, and enzymes as well as work with colourless strains of fungi (Kay, pers. comm.). In addition, chemical preservatives are being used, but with declining success. HortResearch has received less control from conventional anti-sapstain preservatives with small block tests conducted over the past few years, compared to previously, observed as increasing failure rates, probably due to development of fungal tolerance to the preservatives being tested (Kay, pers. comm.).

Some trials were conducted with CARTAPIP and *Ophiostoma picea* as biological control agents. Previously, scientists have concentrated on only one isolate of the biological control agent and one isolate of the stain fungus, but there are many strains of sapstain fungi. One isolate may be excellent in control of one stain fungus, but not against the entire range of potential stain fungi which may occur in a given situation. HortResearch now realises that a selection of fungi, or control methods, affords the best possible protection against a range of potential stain fungi. Currently, a yellow strain of *Trichoderma* has proven quite effective in small block tests for up to four months. It has rated better than CARTAPIP in several trials.

An effective biological control agent must grow rapidly in order to be an economically feasible option as a preservative substitute. HortResearch is currently investigating the ecology, distribution and species of staining fungi as well as penetration rates of sapstain fungi. A controlled environment room is used for accelerated trials and initial screening trials. Field trials are then conducted to test formulations and application methods.

Kay stated that biological control should be seen as one element in a complete control program that begins with timing of the handling of logs from the bush all the way through the sawmill. Biological control can possibly be used on freshly felled logs which remain in the forest for a limited period of time after felling. Commercial trials have been implemented for testing the effectiveness of this application method. However, biological control will not work well for long-term storage of logs in the forest.

There is also potential for biological control used in conjunction with water-spray log storage conditions. Such conditions have and will be further considered as elements of an integrated biological control program by HortResearch. Further research concentrating on successful isolates of *Ophiostoma picea* and *Trichoderma* sp. is being conducted. Small scale field trials with companies such as Prolog Sawmill (as previously mentioned) and Carter Holt Harvey will be used to determine the effectiveness of biological control agents outside of laboratory conditions.

An example of a small scale field trial to test effectiveness and weathering of potential biological control preparations. Both block stacked timber and roundwood are used for visual assessment.

Conclusions and Recommendations

The example of water spray for control of fungal staining and decay in roundwood by DPI has shown the problems associated with long term storage in a high risk situation. The water spray was effective in preventing stain developing for a period of time but ultimately failed to prevent attack by *R. lineatus*. That time could perhaps have been extended by the use of a biological control agent.

The effectiveness of antisapstain preservatives is likely to decline with time for many reasons, including the development of tolerant fungi as found by HortResearch and the push to stop using toxic fungicides. The application of a biological control component within a complete control program, including management and chemical techniques, is suggested for many reasons:

i) replacement of preservative chemicals which may be ecologically sensitive ,
ii) flexibility of use on both roundwood and sawn timber, and
iii) possibility for uses extending beyond that of conventional anti-sapstain preservatives, for example, protection of logs which cannot be preservative treated.

For roundwood, particularly logs stored under water sprays, biological control offers a unique option to extend the period of time logs can safely be stored. Chemical control methods are not an option under water sprays because of leaching. Use of a biological control agent may also improve the effectiveness of the water spray regime.

For sawn timber, use of chemical preservatives may still be appropriate. The development of biological control agents for sawn timber is also an option which should be considered as an ecologically friendly alternative to conventional anti-stain preservatives.

Given the discrepancies between field and laboratory trials of potential biological control agents, it is suggested that any laboratory trials involving biological control be conducted on media closely approximating the nutrient status of the wood in question. Results from laboratory studies should be used to initiate field trials as soon as possible.

Reliability of small scale field trials may also vary from year to year, in accordance with environmental changes. Field trials provide a much more rigorous test of the effectiveness of biological control agents, subjecting them to numerous naturally occurring microorganisms within the environment. Finally, use of complimentary organisms to create a broader-spectrum biological control agent is recommended. A combination of control measures may provide a more complete program towards preventing stain development within the wood substrate.

Both laboratory and field trials could be initiated in collaboration with research organisations and industry. The purpose of laboratory trials is to screen potential biological control agents prior to field testing. Not all biological control agents would be appropriate for use in the Australian situation. A differentiation needs to be made between the storage of logs and storage of sawn timber in air-drying stacks. The different environments and fungi affecting each situation may call for different biological control regimes.

Field trials could be conducted at sawmills suffering from the stain problem. The cost of field trials is relatively low, as material for testing is already on site. Application of biological control agents is primarily by spray or brushing onto the ends of the logs or boards. Both long term and short term field trials could be initiated, to determine the reasonable amount of time a particular biological control agent can be expected to remain effective. Trials should be initiated at different seasons of the year, to study the effect of different weather conditions on the effectiveness of the biological control agent.

Funding for field trials should be at the expense of the timber industry. Given the previous experiences with lost revenue due to the downgrade of appearance grade timber because of stain, biological control of stain fungi offers the potential to save millions of dollars. Furthermore, effective biological control agents are being sought after worldwide because of the potential to replace conventional preservatives with ecologically safer alternatives. The demand for cost-effective replacements for conventional preservatives would ensure a return on investment for a successful biological control program.

There is also potential to use biological control agents to expand the market for overseas export of unseasoned timber. In particular, the introduction of a biological control agent which can protect whole logs against staining fungi for up to 6 months would be received by the timber industry with much enthusiasm, because conventional preservative systems are rarely effective for that length of time. The application of biological control agents to sawn timber would allow shipment of untreated timber to the expanding market for green timber overseas.

Stuart Kay of HortResearch perhaps best summed up the possibility of biological control against wood-inhabiting fungi as "one element in a complete control program that begins with timing of the handling of logs from the bush all the way through the sawmill." Biological control will not completely resolve the stain problem in timber. However, in conjunction with best practice and other management techniques, it may provide a reasonable alternative to conventional preservative chemicals in many situations unique to Australia.

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Appendix 1
Travel Itinerary

15/4/96	Arrival at Forest Research Institute Appointments with John Foster and Robin Wakeling Inspection of Post Trials Inspection of Stake Trials Inspection of Soil Jar Tests Inspection of Fungal Cellar
16/4/96	Appointment with Robin Wakeling Inspection of Sapstain Preservative Trials Inspection of Stake Tests Appointment with Mick Hedley Appointment with Bernhard Kreber
17/4/96	Tour of Kaingaroa Forestry Corporation Forest and Sawmill
18/4/96	Travel to HortResearch Appointment with Stuart Kay Inspection of Laboratory and Field Trials
19/4/96	Tour of Waipa Sawmill Return

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